A grower guide

Bulbs & Outdoor Flowers

Narcissus Manual

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Contents

Preface

The National Agricultural Advisory Service (NAAS), with both advisory and research roles, was formed in 1946. From then until 1986, when the commercialisation of its successor, the Agricultural Development and Advisory Service (ADAS), begun, comprehensive, up-to-date, expert and free experiment-based advice was made available for farmers and growers. Much of this information was delivered in the form of the respected MAFF/ADAS reference books, booklets and leaflets, and was supplemented by detailed annual reports of MAFF-funded R&D at the research institutes, Experimental Horticulture Stations and Experimental Husbandry Farms. This was a major factor in the post-war renaissance of UK agriculture and production horticulture. The funding by MAFF of strategic – but not applied - horticultural research continued for some years, though now determined by policy rather than the needs of the industry. The Horticultural Development Council (HDC, now the Horticultural Development Company and part of the Agriculture and Horticulture Development Board) was set up in 1986 to fund applied research through a compulsory levy on growers.

As ‘rationalisation’ of strategic and applied horticultural research continued into the 21st Century, it seemed a good time to update and re-focus knowledge from those still-consulted ADAS publications. This HDC-sponsored manual is an attempt to do that for narcissus (daffodil) growing - perhaps the most successful UK horticultural sector in terms of world lead and exports. The aims were:

- To summarise information from the MAFF/ADAS books, booklets and leaflets.
- To update this information from Defra- and HDC-funded R&D and from worldwide resources.
- To summarise historic information where this might explain current practices or suggest improvements.
- To present new or alternative techniques for consideration.
- To provide a manual for newcomers to the industry.

UK narcissus growers have made great strides since the 1970s in developing an industry that is now more sustainable from both the financial and environmental viewpoints. The UK is fortunate to have seen, through the hard work and vision of key producers, a transformation of its narcissus industry into a successful international trade. In addition the industry formerly benefited from a MAFF/Defra-funded programme of strategic and applied research commensurate with the size of the sector. But this is not a time to stand still - there is potential for developing cultivars with novel attributes (such as scent, autumn-flowering, enhanced pharmaceuticals content and resistance to basal rot and virus diseases), for designing novel methods of plant protection, and for advancing production techniques (for example through the development of automated bulb handling and inspection to reduce labour inputs).

The term ‘narcissus’ is used throughout to cover all types of narcissus, including the larger-flowered ‘daffodils’, the smaller-flowered ‘narcissi’ and sundry other types such as tazettas and species. The term ‘contemporary bulb growing’ is used to refer to practices used from the 1980s, in contrast to the more ‘traditional’ practices used previously. This manual has been a long time in the writing and publication, and the author would be grateful to receive, through the HDC, any corrections, omissions, updates, additions or suggestions.

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Spalding, August 2013

1.0 Introduction

1.1 History and usage

Narcissus as native British plants

The wild daffodil, *Narcissus pseudonarcissus*, is a native of the British Isles found, usually rather locally, in woods and grasslands throughout England, Wales and Jersey and naturalised in Scotland and Ireland. The 'Tenby Daffodil', *N. obvallaris*, is questionably endemic to Pembrokeshire (and possibly other locations), though it may be of early garden origin, while a few other species and wild hybrids, notably *N. hispanicus* and *N. x biflorus* ('Primrose Peerless') are naturalised in many places.[1] As gardening and commercial horticulture spread, others, including many garden hybrids, began to occur as relics of cultivation and as escapes.

Development of a bulb industry

UK enthusiasts and gardeners have cultivated narcissus for over 300 years, the most important species probably being *N. hispanicus*, known as *N. maximus* or *N. maximus superbus*.[2,3] Serious hybridisation began in the 19th Century; notably, Peter Barr (1825-1909) re-discovered many 'lost' species and hybrids, built on earlier successful breeding, and raised the profile of the genus through his role in the RHS Daffodil Conferences of 1884 and 1890.[4] Commercial bulb production began around Spalding, Lincolnshire, in the late-19th Century. In 1885 Mrs Elizabeth Quincey was listed as a "wholesale fruiter and bulb grower", and, in its 1896 edition, Kelly's *Directory of Lincolnshire* listed three bulb-growers in Spalding. Reportedly, one of them, J.T. White, sent a trial lot of cut-flowers to Covent Garden, and "a new flower industry was started".[5] The Dutch bulb industry grew even faster, and soon narcissus became a significant floricultural crop in Western Europe. Large areas of field-grown narcissus provided both 'dry-bulbs' (i.e. bulbs for sale) and flowers, while bulb 'forcing' in glasshouses provided flowers over an extended season. Except for a hiatus during World War II, bulb-growing in the UK and elsewhere continued to increase, though, in the UK it became virtually limited to narcissus from the 1970s onwards. Early in the 21st Century, narcissus remains one of the major ornamental crops of the temperate regions, and hybridisation continues apace in the UK and elsewhere, particularly in the USA, Australia and New Zealand.

In the Flower and Plants Association's recent surveys of cut-flower tastes amongst UK consumers, narcissus (daffodils and narcissi) were rated fourth in popularity and fifth in value of sales (based on consumer purchase figures), despite being relatively inexpensive and available for only part of the year.[6,7] From the same survey, 'spring bulbs' were rated fifth in popularity and in sales for pot-grown houseplants. The area of narcissus now growing in gardens, parks, cemeteries, etc., worldwide has been estimated as five-times that of the area grown commercially, further illustrating their popularity.[8]

Both use and ornament

The opening section was concerned only with the narcissus's role as an ornamental plant, though a recent textbook has drawn attention to many other important properties of the genus.[9] Narcissus has been used in medicines and remedies since antiquity, both Hippocrates of Cos (460-377 BC) and Pliny the Elder (AD 23-77) recommending the oil in the treatment of uterine tumours, an effect now thought to be due to the compound narciclasine.[10] In 20th Century Eastern Europe, however, it was particularly the snowdrop that was used in herbal remedies.[11] In 1947 a novel alkaloid, named galanthamine (sometimes called galantamine), was isolated from the Caucasian snowdrop *Galanthus woronowii* by Russian researchers.[12] Galanthamine was soon reported to be successful in the treatment of poliomyelitis, and became part of the Soviet stock of medicines. In 1960 galanthamine was discovered to be a selective, reversible inhibitor of acetylcholinesterase,[13] an important enzyme in neurotransmission, and therefore with implications in many aspects of human health.[14] Over the next 30 years this information came to the attention of Western Europe: many potential new properties were discovered, including, in 1991, its effects in slowing the onset of Alzheimer's-type dementia[15,16,17] – a drug with a potentially huge market. The sources of galanthamine initially used were Eastern European snowdrop species, summer snowflake (*Leucojum aestivum*) and Ungernia species, all potentially vanishing natural resources. Galanthamine was also found in many other plants of the Amaryllidaceae family,[11,18] and, in the 1990s it was realised that commercial narcissus cultivars, by virtue of their bulk and easy availability, were the obvious choice as source material for large-scale extraction.[19] It is clear much more can be done: in 2002, a study of 26 *Narcissus* species revealed a 1,000-fold variation in acetylcholinesterase activity,[20] and phylogenetic selection of *Narcissus* species is being used as an aid to drug discovery.[21]

Although separate figures are not available in UK agricultural statistics for the area of narcissus grown other than as an ornamental, it appears that, from the late 1990s, a few hundred hectares have been grown annually for galanthamine extraction.[9] This interest is continuing. A 2004 review gave a historical perspective on the development of galanthamine from folk medicine to proprietary formulation,[22] and in 2006 a project to grow narcissus in mid-Wales "on a sizeable acreage" was announced.[23]

There are other uses too:

- Many potential uses of galanthamine have been the subject of patents for treating conditions as diverse as mania, fatigue disorders, erectile dysfunction, arthritis and ADHD.[24] Narcissus and related plants are now known to contain a large number of alkaloids, as well as galanthamine, with potentially many more uses.[25]

- Narcissus (mainly *N. poeticus*) is important in the French perfume industry,[26] enjoying a revival since the 1970s in perfumes such as Chanel's 'No. 19' and Givenchy's 'Silences de Jacomo'.[27] Various essential oils are used in aromatherapy and may have a role as therapeutic agents in the control of behavioural problems, and a possible role here for narcissus absolute has been suggested.[28]

- For research purposes, narcissus has been a particular source of lectins, important compounds in the study of plant-pathogen interactions.[29]

- Researchers have also used narcissus as a source of genes, for example those coding for phytoene synthase. These have been used to transform rice plants, so they produce β–carotene, not otherwise present, a procedure that could potentially reduce blindness in populations dependent on rice as their staple diet.[30] The carotenoid production of the rice ('Golden Rice') has been increased by further manipulation.[31]

1.2 The UK narcissus industry

UK field-grown crops

Field crops can be grown for both bulb and flower production. Traditionally, growers in the South-West grew narcissus primarily for early outdoor flower cropping, as well as for bulb production, while in Eastern England the bulb was once considered paramount and the flower subsidiary. This balance changes as the relative profitability of flowers and bulbs changes: in the 2000s flower sales have been considered the main driver of the UK industry, so flower picking is important in all regions where narcissus are grown. The bulbs are sold wholesale for commercial planting stocks, forcing and amenity or landscape use, and for retail sales either loose or in a variety of pre-packs. There had long been a small export trade in narcissus, but exports of bulbs and flowers were expanded in the late-1960s. UK exports now account for perhaps 50% of the UK's output of bulbs and around 60% of the output of flowers.[32] Retail sales have increasingly involved multiple retailers, rather than traditional outlets such as regional wholesale markets. Both export and multiple-retail customers set higher specifications for products than the traditional markets. There is still a place for niche marketing: one example is the Isles of Scilly scented narcissus.[33]

Some area and production estimates and values from Defra statistics are given in Figures 1 to 6.[34] Some care is needed in interpreting these statistics, however: for example, data for bulbs and other flowers are sub-divided (to show narcissus, pinks, chrysanthemums, etc.) only in respect of area and production estimates for bulbs grown in the field in England and Wales; in addition, there have also been significant changes in the way these statistics are collected, especially in the 2000's. With these provisos, the area has been stable at around 4,000 ha for some 20 years (Figure 1), while the value of production has varied greatly over the same time (Figure 2). As well, significant areas of narcissus are grown in Scotland (about 390 ha)[35] and in Jersey (about 150 ha)[1] and (though not included in the Defra statistics) for galanthamine production (perhaps a few hundred hectares from the late-1990s onwards[4]). There are several specialist bulb producers in Northern Ireland, but the overall area of production is small (less than five hectares).[4]

Forced narcissus in the UK

Defra statistics do not allow forced narcissus flower production and value to be separated from that of other forced bulbs or of other flowers growing outdoors. There was a sharp decline in production estimates from the mid-1990s for these crops (Figure 3), a result of many fewer narcissus bulbs being forced as it has become customary to pick flowers from most field-grown crops, augmented recently by new cultivars bred for earlier outdoor flower production. This leaves the bulk of this production, and certainly of its value (Figure 4), deriving from forced tulips and lilies. At its peak, narcissus forcing accounted for over 4,000 t, about 80 million bulbs, annually, a figure probably now reduced to not more than 1,000 t annually.[1]

UK exports and imports

The value of UK exports and imports are given in Figures 5 and 6. The data for narcissus bulb exports and imports are separately collected, whereas the flower data are not. In general terms, the values of narcissus bulb exports and imports have been roughly steady for 20 years, with imports running at around half the value of exports. It is likely, however, that much of the UK exports comprise bulk quantities of standard cultivars being sold by weight, whereas the imports are of a wider cultivar range, largely destined for retail sales, and often sold by numbers (as is the case for more specialist cultivars). The values for exports of narcissus flowers shown have been calculated assuming that narcissus make up the bulk of the UK's flower exports, once the numbers for separately-collected types (largely carnations, roses, etc.) have been subtracted from the total; no values are given for imports of narcissus flowers, since it is assumed that these are negligible, if any, against the huge amounts of other imported cut-flowers.

Annual outputs

The annual output of UK bulbs can be estimated from the area lifted annually, somewhat less than half of the total (say 2,000 ha), the average planting density (say, 17 t/ha) and the percentage weight increase from planting to lifting (say, lifting twice the weight planted). Disposable yield is the yield remaining after taking out the weight required for re-planting stock (say, the same weight as was planted previously). This estimate gives an annual UK disposable bulb output of about 34,000 t. A tonne of narcissus bulbs typically contains 25,000 to 30,000 medium-sized bulbs.

While the narcissus trade is significant to the UK in its own right, it also forms an important component in the much larger industry involved in trading flower bulbs, taking in the import and marketing of large quantities of tulips, lilies and many other bulbous ornamentals.

Bulb growing regions

In the UK narcissus growing is highly regionalised. In Scotland, most or all commercial narcissus production takes place in the Grampian region, while in England it is strongly concentrated in the East and the South-West. Defra regional and sub-regional cropping data do not distinguish between field-grown bulbs and other outdoor flower crops, though other data (see above) indicate narcissus production makes up the bulk of this combined area, with some large narcissus enterprises and many small non-narcissus bulb and other flower growers. Figure 7 shows these data for 2000, 2004 and 2008.[36] Over this period, the area of these crops has:

- Decreased slightly overall.
- Increased slightly in the South-West, with a complementary fall in the Eastern Region.
- Remained steady in the East Midlands Region.

In 2008, the South-West accounted for 44% of the outdoor bulb and flower area (of which 97% was grown in Cornwall and the Isles of Scilly) and the East Midlands for 39% (of which 99% was in Lincolnshire); in Norfolk and Cambridgeshire (in the Eastern Region) there have certainly been reductions in narcissus growing over this period, though more holdings here are likely to be relatively small enterprises growing flowers other than narcissus.

Figure 1 Area estimate for narcissus grown in the open in England and Wales (England from 2003)

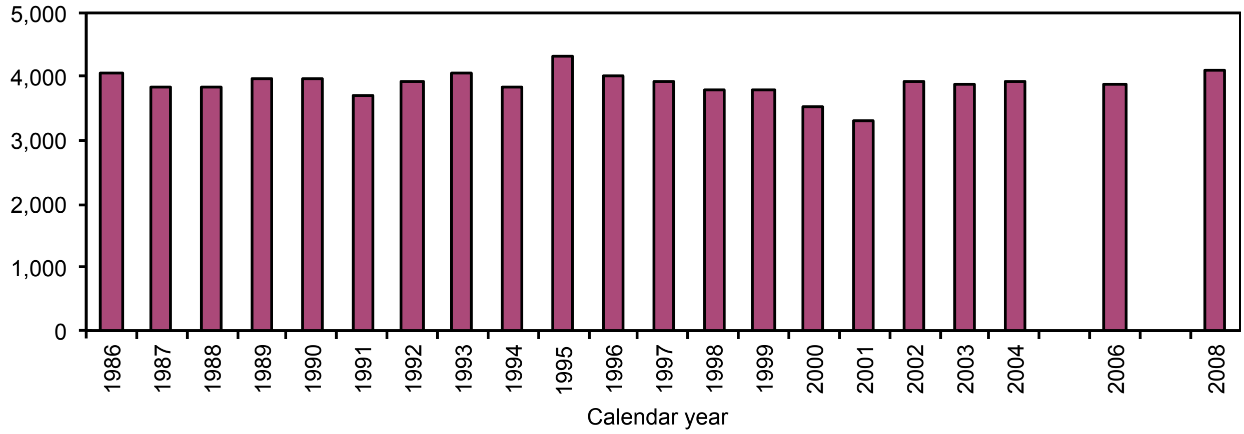


Figure 2 Farm-gate value of narcissus flowers and bulbs grown in the open in England and Wales

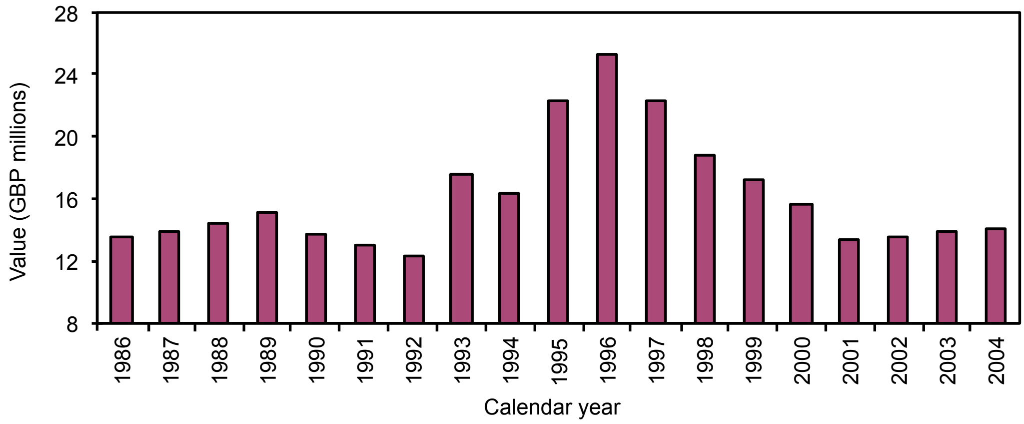


Figure 3 Production estimate for all bulb flowers, including forced bulbs, grown in England and Wales

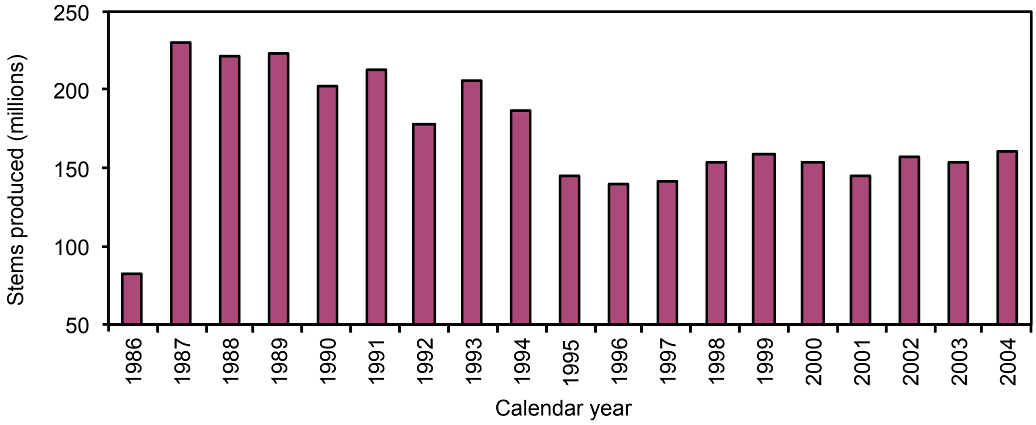


Figure 4 Value of all forced bulb flowers grown in England and Wales

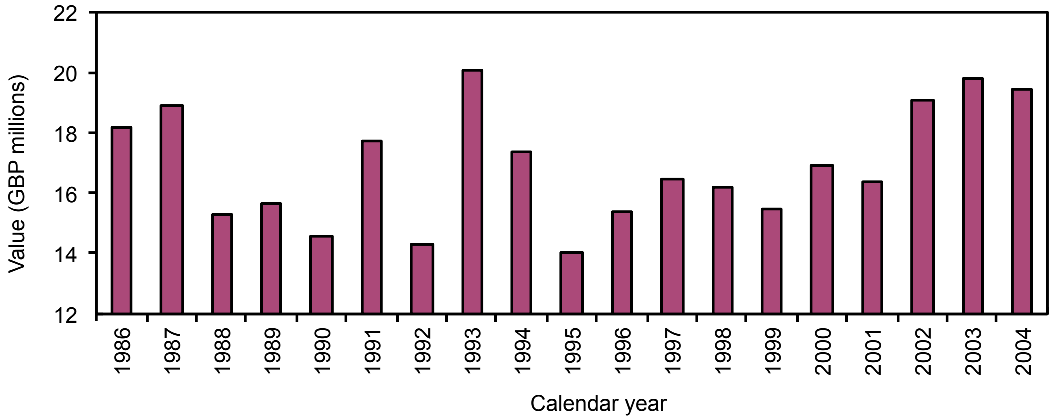


Figure 5 Value of UK exports and re-exports of narcissus bulbs and flowers (estimates, see text for assumptions)

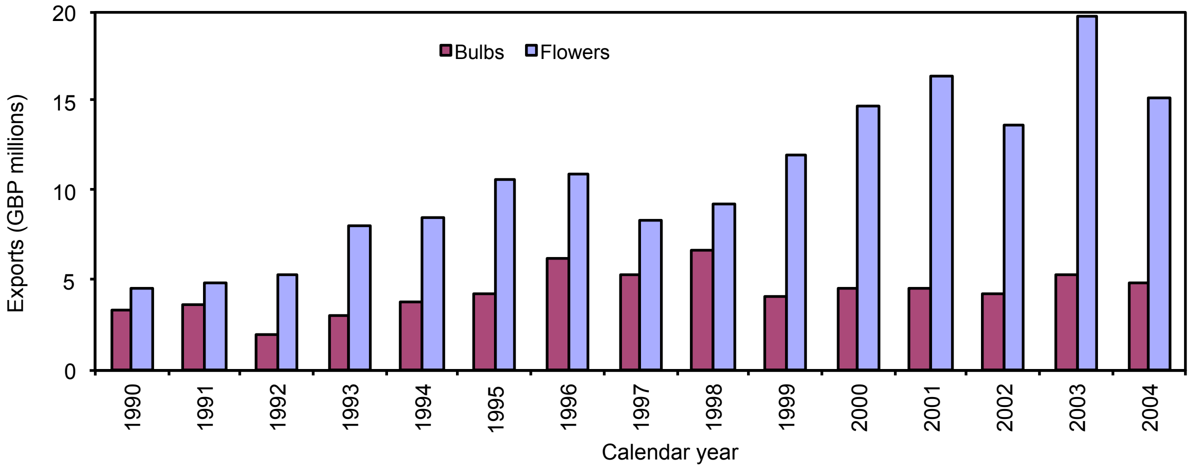


Figure 6 Value of UK imports of narcissus bulbs (deliberately drawn on same scale as Figure 5)

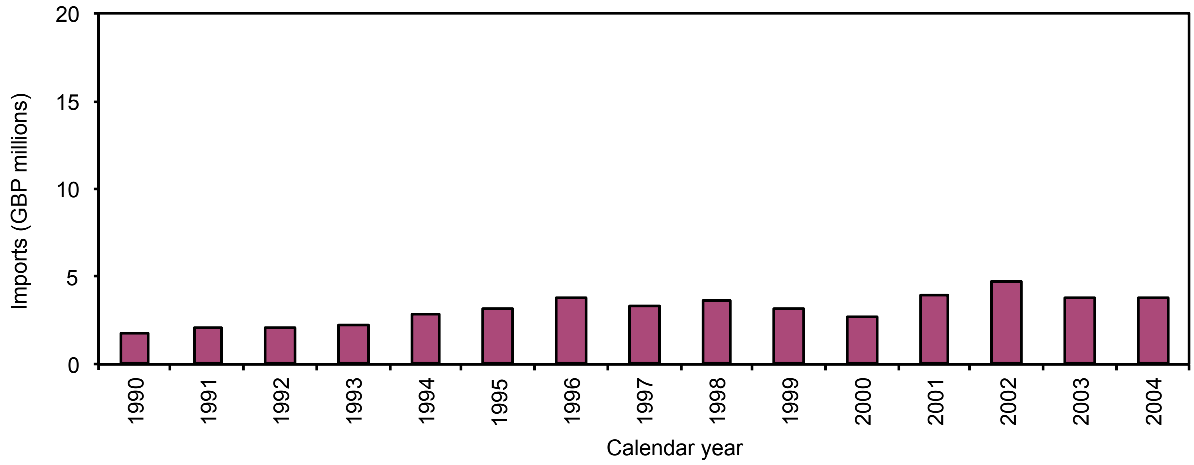
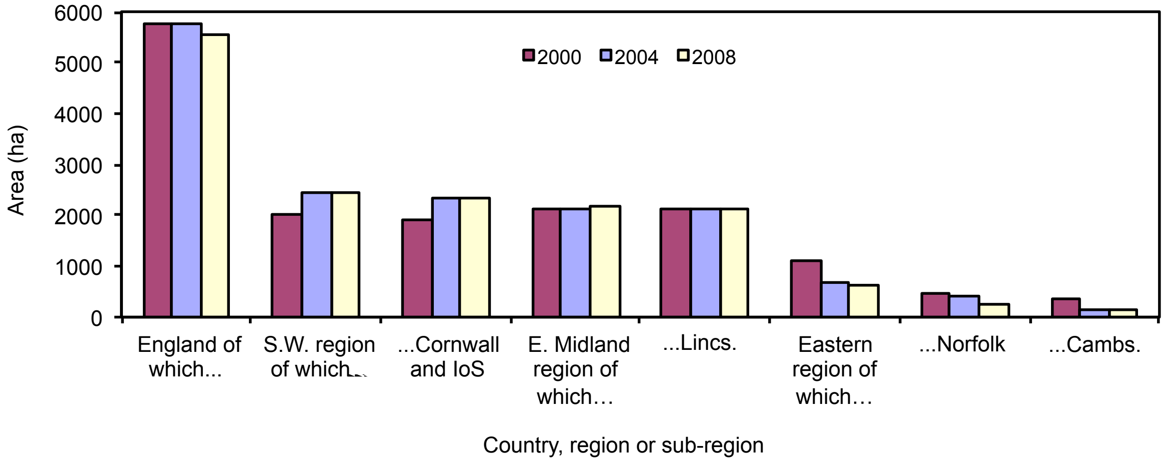


Figure 7 Regional breakdown of outdoor bulb and flower crops in England, 2000 to 2008



1.3 World trade

Overall production

The areas of field-grown narcissus in the producing countries are given in Table 1.[37] Production is dominated by the UK (4,200 ha), the Netherlands (1,800 ha) and the USA (400 ha, mostly in the Pacific Northwest, Washington State). Since the UK crop is grown on a two-year-down basis (or longer), somewhat less than half its area is lifted each year.

Other significant areas of narcissus bulb production include Australia and Canada (British Columbia), while a notable area is also grown in Jersey (Channel Islands). Bulbs of tazetta cultivars (including Paper Whites) are produced in Israel and are traditional crops in China, Japan and Korea. Country statistics for the area of field-grown narcissus crops were generally stable through the 1990s, though in this period there was an increase in the Republic of Ireland and a decrease in Poland.[37]

World trade

There is a vigorous trade in narcissus bulbs between the Netherlands and the UK, consisting largely of bulbs of standard cultivars from the UK and a greater range of cultivars from the Netherlands. The UK also exports bulbs to Germany, North America, Scandinavia and France. UK exports of narcissus bulbs were valued at £9.45 m in 1998[38] but only £4.88 m in 2004[39], while imports amounted to £3.46 m and £3.83 m for the same years, respectively. The other chief Dutch export destinations are Germany, North America and France. Dutch imports of narcissus bulbs are dominated by supplies from the UK, along with tazetta bulbs from Israel.[40,41] USA production is largely for the home market, and the USA imports some 120 million narcissus bulbs annually, including about 90 million from the Netherlands.[42]

The Netherlands and the UK also export large volumes of narcissus cut-flowers. On the assumption that narcissus make up the bulk of the cut-flower exports from the UK, these were valued at over £10 m in 1998.[39] Pot-grown narcissus (predominately the dwarf cultivar 'Tête-à-Tête') are an important export from the Netherlands, with sales to Germany approaching two million pots in 1998.[43]

Table 1 World production areas for narcissus (areas grown in the late-1990s, from various sources)

Country or territory	Area (ha)	Notes
Australia	200	
Canada	149	
China	na	Not available; includes tazetta cultivars
Denmark	na	Not available
England and Wales	3,808	Excluding growing for galanthamine extraction
France	22	
Germany	14	Mainly for flower production
Republic of Ireland	73	
Israel	150	Mainly tazetta cultivars
Italy	27	Mainly for flower production
Japan	44	Includes tazetta cultivars
Jersey, Channel Islands	175	
Netherlands	1,756	
New Zealand	70	
Northern Ireland	4	
Poland	50	
Scotland	390	
South Africa	12	
USA	410	

1.4 Classification and taxonomy

Characteristics of *Narcissus*

Narcissus is one of some 60 genera in the monocotyledonous family Amaryllidaceae.[44] Unlike other Amaryllids, *Narcissus* has a mainly Mediterranean distribution, with a centre of diversity in the Iberian Peninsula. *N. tazetta* cultivars extends in a narrow band to China and Japan, possibly as a consequence of ancient trade routes, indicative of man's long interest in the genus as an ornamental and possibly as a medicinal plant. The distinguishing feature of *Narcissus* amongst the Amaryllidaceae is the corona (or paracorolla), commonly called the cup or trumpet.[45] Typical of many monocots, the sepals and petals are both petaloid (petal-like) and are usually referred to as perianth segments (together making up the perianth).

Narcissus species

The genus *Narcissus* presents great challenges to taxonomists, partly due to the extensive natural hybridisation, escape and naturalisation, cultivation and crossing that has taken place. Specialist textbooks are available dealing with the wild *Narcissus* species and hybrids.[46,47] However, the taxonomy of the genus was last comprehensively reviewed by Pugsley in his monograph of 1933,[48] while the RHS lists *Narcissus* species following the scheme of Fernandes.[49] The number of species is variously considered as between 26[50] and about 85,[51] depending on the authority; various hierarchies of sub- and supra-specific taxa having been described, and there have been recent reviews that discuss these issues.[52,53] Using a new approach, genome size was recently shown to have strong systemic value, with some changes proposed to the conventional Sections of the genus and the total number of species determined as 36.[54] In another approach, phylogenetic analyses based on DNA sequence information are impacting plant systematics; so far, only one phylogenetic study of *Narcissus* has been published, again challenging some established relationships.[55]

Conservation

Several *Narcissus* species and taxa are, or have been, threatened by over-collecting or habitat loss, and the industry has largely addressed the ethical issues of sourcing bulbs. Four Spanish species are currently listed as 'endangered' on the IUCN Red List, due to collecting, grazing pressure or drainage.[56]

Ornamentals are generally not well served by germplasm collections at the present time, though in the USA the Ornamental Plant Germplasm Center has been set up in conjunction with the USDA National Plant Germplasm System at Ohio State University.[57] Some collections of narcissus genetic resources have been established, for example:

- Floricultural resources maintained in Lithuania include narcissus and many Lithuanian-bred varieties.[58]
- In Sweden nearly 600 accessions of old narcissus have been collected.[59]
- At Skierniewice, Poland, the gene-bank includes 140 accessions of narcissus.[60]

Hybridisation

Hybridisation has resulted in a wide range of flower forms and sizes, and a wider colour range than may be generally appreciated. Trumpet varieties with a coloured perianth and corona originated from *N. pseudonarcissus* and its varieties, and those with a white perianth and a coloured corona from *N. pseudonarcissus* ssp. *bicolor*. Large-cupped cultivars resulted from crosses between *N. pseudonarcissus* and *N. poeticus*; back-crossing with *N. poeticus* gave the small-cupped cultivars. Multi-headed ('Poetaz') cultivars are largely hybrids between *N. poeticus* and *N. tazetta cultivars*.[61]

Horticultural classification

Horticulturally, narcissus cultivars are classified according to an evolving scheme sponsored by the RHS.[51] The last main change was introduced in 1998, resulting in a scheme with 13 Divisions (Table 2). The majority of large-flowered narcissus cultivars are classified artificially into trumpet, large-cup (or long-cup), small-cup (or short-cup), double and split-corona Divisions, augmented with Divisions representing characteristic natural types - triandrus, cyclamineus, jonquilla and apodanthus, tazetta, poeticus and bulbocodium. Finally, there are Divisions for 'other narcissus' and for wild types (i.e. those described solely by a botanical name). Some examples from each Division are shown in Image 1.

Since 1975, the RHS scheme has suffixed the Division name by a colour code describing, first, the colour of the perianth segments, followed by that of the corona, using the initial letters of the colours white, green, yellow, pink, orange and red. Thus, for example, a 2 W-P cultivar is a large-cup narcissus with a white perianth and pink corona. If the perianth and (or) corona are not substantially of one colour, then a three-letter code is used to describe the colour of the distal, mid and proximal zones of the perianth segments and the proximal, mid and distal zones of the corona, respectively (i.e. starting at the petal tips, working down the petal, then up the trumpet or cup to its rim). In our example, were the proximal zones of the perianth and corona green and the corona red-rimmed, the coding would become 2 WWG-GPR. The colour codes may need to be interpreted cautiously, for example some oranges and reds can be difficult to define, while white may be used for a cream tending towards the yellowish; many flowers also show colour changes during development. Further intricacies of the scheme, with much useful background information, are described in *The International Daffodil Register and Classified List*.[51]

Table 2 The RHS Classification of narcissus into Divisions

Division	Name	Description
1	Trumpet daffodil	Corona ('trumpet') as long or longer than perianth segments
2	Large-cupped daffodil	Corona ('cup') more than one-third the length of the perianth segments, but not as long
3	Small-cupped daffodil	Corona ('cup') not more than one-third the length of the perianth segments
4	Double daffodil	Corona and (or) perianth segments with doubling
5	Triandrus daffodil	Characteristics of *Narcissus triandrus* clearly evident (usually two or more pendant flowers per stem, perianth segments reflexed)
6	Cyclamineus daffodil	Characteristics of *N. cyclamineus* clearly evident (usually one flower per stem, perianth segments well reflexed, flower held at an acute angle and with very short neck)
7	Jonquilla and Apodanthus daffodil	Characteristics of Sections Jonquillae or Apodanthi clearly evident (usually one to five flowers per stem, perianth segments spreading or reflexed, corona wide, flower fragrant)
8	Tazetta daffodil	Characteristics of Section Tazetta clearly evident (usually three to 20 flowers per stem, strong stem, perianth segments spreading, flower fragrant)
9	Poeticus daffodil	Characteristics of *N. poeticus* group (usually one flower per stem, perianth segments pure white, corona short or disc-like, usually fragrant)
10	Bulbocodium daffodil	Characteristics of Section Bulbocodium clearly evident (usually one flower per stem, perianth segments insignificant, anthers centrally attached to filament)
11	Split-corona daffodil Collar daffodil Papillon daffodil	Corona split: With corona segments opposite the perianth segments With corona segments alternate to the perianth segments
12	Other daffodil	Those that do not fit the description of any other Divisions
13	Daffodil distinguished solely by botanical name	Species, naturally occurring hybrids, etc.

1. Examples of each Division of *Narcissus*

1 (Trumpet): ‘Bleasby Gorse’ and ‘Standard Value’

2 (Large-cup): ‘Scarlett O’Hara’ and ‘Toorak Gold’

3 (Small-cup): ‘Barrett Browning’ and ‘Verger’

4 (Double): ‘Cheerfulness’ and ‘Flower Drift’

5 (Triandrus): ‘Niveth’ and ‘Tresamble’

6 (Cyclamineus): ‘Charity May’ and ‘Cornet’

7 (Jonquilla): ‘Shepherd’s Hey’ and ‘Sweetness’

8 (Tazetta): ‘Cragford’ and ‘Hugh Town’

9 (Poeticus): 'Actaea' and 'Milan'

10 (Bulbocodium): *N. bulbocodium* var. *tenuifolius* and *N. romieuxii* var. *romieuxii*

11a (Split-corona collar daffodil): 'Mistral'

11b (Split-corona papillon daffodil): 'Lemon Beauty'

12 (Other): 'Jumblie' and 'Quince'

13 ('Botanical'): *N. x medioluteus* and *N. obvallaris*

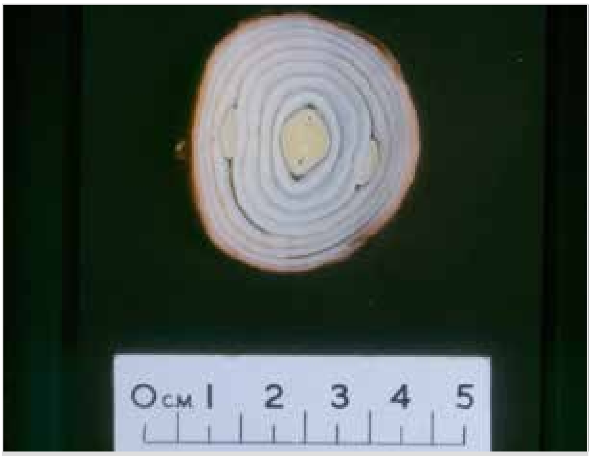
Photos: Warwick HRI and predecessors

1.5 Structure and life-cycle

The structure of bulbs was described in early Dutch research[62] and has been summarised in key ADAS references books.[63] More detailed research by Alun Rees led to a fuller understanding of the subject.[64,65] Taken from these sources, a brief outline of narcissus structure and life-cycle is given below; for more information the standard textbooks should be consulted,[66, 67] along with the excellent paper by Tsin-Tze Chan.[68]

The bulb

Bulbs are perennating storage organs often described as ‘underground buds’. The narcissus bulb in autumn consists of a disc-shaped stem plate (called the base plate or basal plate) bearing roots below and bulb scales above. The base plate can be considered a much compressed stem which, like most stems, gives rise to roots on its base and leaves – or, in this case, bulb scales - and flowers at its internodes. As with other flowering plants, new buds are formed in the axils of the ‘leaves’ (in the axils of the bulb scales in this case). The basic structure of a single-nosed bulb is shown in Image 2.



2 Transverse section of a single-nosed round bulb

Photo: Warwick HRI and predecessors

Bulb scales and buds

In the case of narcissus, the ‘bulb scales’ are in fact of two types:

- Leaf bases, which after the death and loss of the green above-ground portions, remain thick and fleshy, looking and functioning like the other bulb scales.
- ‘True’ bulb scales which never have an above-ground part.

In autumn, the central floral bud can be easily found by bisecting the bulb lengthwise. The rapidly growing flower bud is surrounded first by the membranous spathe, and then by the pale yellow leaves that do not, at this stage, look like the bulb scales they will later become. Besides this central (or terminal) bud, there may other buds (lateral buds), composed of leaves but not necessarily having a flower. Careful dissection of terminal or lateral buds will reveal new ‘bulb units’ at the base of bulb scales and leaf bases - equivalent to the new buds that would be found here in the axils of a ‘normal’ plant.

‘Bulb units’ and ‘bulb clusters’

As narcissus bulbs do not produce distinct and easily separated ‘daughter bulbs’ each year as, say, tulips do, the term ‘bulb unit’ is better used to describe an individual set of scales, leaves, stem and flower from its inception until its death about four years later. Using this terminology, what would commonly be called ‘a bulb’ is therefore a group of bulb units of various ages, the whole of which can be called a ‘bulb cluster’.

In the run up to flowering in the spring, the flower and its scape (stem) and surrounding leaves will be growing rapidly within the bulb. The new bulb units are also growing. By early summer, the flower has died and the above-ground parts of the leaves and stem are becoming senescent. The old, peripheral bulb scales shrivel as they become depleted of food reserves, and young bulb scales (as well as the leaf bases and the base of the scape) in the centre of the bulb have swollen with reserves. The next generation of bulb units, and next year’s flowers and leaves, will be developing near the centre of the cluster. In this way the cluster is continually refreshed by the formation of new buds in its centre, displacing the older bulb scales and leaf bases outwards.

The life of a bulb unit

Each bulb unit lives about four years:

- In the first year the bulb unit is initiated and forms its bulb scales.
- In its second year further bulb scales, leaves and - if the bulb unit is large enough, a flower - are initiated.
- In year three the leaves and flowers emerge.
- In year four the remaining bulb scales and leaf and stem bases become thin and depleted and are eventually lost from the outside of the cluster as the dry skin or tunic.

Branching and offsets

The neat, nearly concentric ‘onion-like’ arrangement just described soon becomes more complex. This is because the axis of the narcissus bulb cluster is an abbreviated branching stem: new bulb units are initiated both terminally and laterally. By this means a small, single-nosed, round bulb can be transformed over a number of years to a double- or multi-nosed bulb that will eventually split to form ‘offsets’ and then to form separate clusters.

The annual cycle of growth

The annual cycle of narcissus growth is characterised by alternating periods of growth and ‘dormancy’ which enable the genus in its natural, Mediterranean habitat to condense its above-ground growing into the relatively short period between cool winters and hot, dry summers. Fortunately, the bulbous habit provides horticulturists with an annual opportunity to treat, grade and market the bulbs during the ‘dormant’ summer period. Despite using the term ‘dormancy’ there is, in the summer, active initiation and growth within the bulb of the young bulbs, shoots and root initials. In the UK, initiation of the flower begins in May and its differentiation is completed in July or August, the corolla being the last floral part to be initiated.

Following planting in late-summer or autumn, root outgrowth is rapid; shoot growth within the bulb continues, until slowed by falling temperatures. Narcissus have a ‘cold requirement’ that must be satisfied before rapid, synchronous shoot growth and flowering (anthesis) can take place. Once the need for cold has been met by normal winter temperatures, the shoots grow at a rate determined by ambient temperatures: to achieve a ‘normal’ growth pattern, cool temperatures followed by warmer temperatures are needed. Bulb growth is rapid around the time of flowering, but is soon curtailed by the prompt onset of foliar senescence in summer, perhaps as a means of conserving water.

Tazetta cultivars and the few autumn-flowering Narcissus species do not have this cold requirement, but respond to high summer temperatures. Consequently they can flower from autumn onwards.

The seedling and the juvenile plant

In describing the narcissus life-cycle, the seedling and juvenile stages are often forgotten since, in commerce, we almost entirely deal with flowering-sized bulbs growing vegetatively. Production from seed is obviously used by hybridisers, and some commercial crops may drop a small number of seeds. These stages have also been described in the literature.[68,69,70] On germination the radical (first root) and cotyledonary sheath emerge, followed by one or two adventitious roots and a grass-like leaf. The base of the cotyledonary sheath and of the single leaf begin to swell, the latter enveloping the apical meristem. After the first year of growth the bulb may reach 1 cm in length. There is a long juvenile phase before a bulb capable of flowering is produced, flowering occurring after three (in some *Narcissus* species) to eight years (in some hybrids). In hybrids, leaf number typically increases from one to two in the fourth year and to three or more in the fifth, though small-cup varieties may produce two leaves in the second year and flower in the fourth year.[66,71] Once flowering begins, a flower is usually produced each year, unless growth is restricted for some reason.

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2.0 Economics and management

2.1 Economics

General considerations

The general principles of costing bulb and bulb-flower enterprises were reviewed by Dutch agricultural economist de Vroomen.[1] Production costs were divided into:

Direct or variable costs – the costs specific to a single crop, which would be expected to vary linearly with the size of the operation, such as planting stock, fertilisers, pesticides, temporary labour, transport costs, and so on.

Indirect or fixed costs – all other costs necessary to keep an enterprise functioning, but which are not specific to a single crop, such as depreciation, permanent labour, interest on capital, administration costs, etc.

The gross margin for a single crop is calculated by deducting the direct costs from that crop's returns. The sum of the gross margins of all the single crops can then be compared with the fixed costs of the enterprise, to give the overall profitability. De Vroomen's review includes clear examples of the spreadsheets needed for different bulb-growing enterprises, though not specifically for narcissus, and based on Dutch experience.

Studies in the Netherlands showed that, while there were differences in the profitability of individual farms every year, the same farms, in general, produced either good or poor results each year.[2] The main difference was in the level of gross returns, which accounted for nearly half of the differences; in turn, gross returns were mainly affected by the number of bulbs produced per unit of area. Analyses showed a relationship between the total yield (weight of all harvested bulbs) and the economic yield (number of saleable bulbs and the bulb weight planted).[3] The economic yield was significantly affected by the planting density and the relationship between the sizes of the planting stock.[4] Such effects could be seen as acting via the proportion of the soil surface covered by foliage (the leaf area index).[5] Although these Dutch studies were carried out on tulip bulb production, it is likely that similar considerations would apply to narcissus growing: the grade of the planting stock (or the balance of different sized bulbs in the planting stock) and the planting density exert most effect on productivity, and both would be amenable to a crop modelling approach.

A further factor influencing the profitability of bulb growing was the quality of the planting stock.[6] Using the example of higher yields from 'virus-free' stocks, it was shown that vigorous bulb growth can lead to lower costs (because less planting stock is needed) and higher returns (due to the greater bulb production). The increase in production showed that higher quality planting stock can be economically viable, even though the bulbs are more expensive.

UK narcissus costings

Though advisory organisations and many horticultural businesses will have developed comprehensive costings for their various crops, few accessible accounts of the economics of narcissus production are available in the UK or elsewhere. Most of the following information has been taken from the account written by Jim Briggs in 2002.[7] All sums quoted have been adjusted for inflation from the date when they were derived until 2009, using standard indices. All prices shown are strictly guide prices only.

Capital costs

Some of the capital items required by a narcissus-growing business are common to those growing alliums, potatoes or roots or to any crop requiring drying and storage. This applies, for example, to some lifting machinery, bulk-handling equipment and drying and storage facilities. The items specific to narcissus production are the hot water treatment (HWT) facility, the provision of appropriate drying facilities, bulb planters and bulb grading lines. While some items of equipment might be leased or some operations contracted out, in the UK it is usual for the grower to have his own facilities and to deal with all aspects of growing and handling the crop in-house.

This equipment is listed below, starting with bulb planting and ending with bulb drying and storage, but some other items routinely used throughout the farm (such as spraying and cultivation machinery and the tractors to haul them) have not been included. The prices shown - guide prices only - are for new equipment based on a 10 ha-narcissus operation, planting 175 t bulbs and lifting 350 t bulbs annually.

- Bed former, £6,000 (optional).
- Stone and clod separator, £29,000 (optional).
- Bulb planter, £7,000.
- Haulm topper, £6,000.
- Bulb lifter, £47,000.
- Bulk boxes, £28,000.

This is for boxes suited to a letter-box drying-wall system.

- Post-lifting handling equipment, £36,000.

This comprises hopper, soil remover, riddle, inspection table, bulb sprayer and conveyor/elevator; the bulb sprayer (£2,000) is required only if fungicide are to be applied to bulbs between lifting and storage/drying.

- Drying store, £110,000 for a box-drying system or £160,000 for a bulk (loose, on-floor) drying system.

This includes the building, heater and fans, and either the on-floor or letter-box drying-wall system, with the option of drying bulbs with heated air if required.

- Grading line and associated equipment, £70,000.

This includes a hopper/elevator/conveyor line, barrel cleaner, brush cleaner, dust extraction and a basic grading line without weighing or counting functionality.

- Main bulb store for the post-drying, pre-HWT period, £64,000 for a box-drying system or £97,000 for a bulk drying system.

Including the components listed under 'drying store' above, including the capability to provide controlled-temperature drying/storage and heat treatment (depending on the requirements of the operation, this function could be provided by the drying store).

- HWT tanks, £30,000.

This is the cost for a complete system, but not a building, as it is assumed the HWT tanks are housed in an existing building or covered area.

- Post-HWT cooling/ventilating/drying system, £28,000.

This includes the building and a suitable fan-drying system, although it is often carried out in the open or in an existing store (not recommended because of possibly adverse weather or likelihood of re-contamination of the treated bulbs).

- Cold store for flowers, £50,000.

Based on a prefabricated store built within an existing building.

Indirect (fixed) costs

The fixed costs, especially relating to machinery and labour, will vary greatly between different types and sizes of farm, location and current economic factors, so only general guidance can be given. Farms growing diverse and high-value crops will often have higher fixed costs, for example in the depreciation costs of specialist equipment. Often, there will be a balance to be made between using a contractor or own labour. In the case of land rented, because it is capable of growing higher value crops, the rents will be higher than average. In a recent survey, the indirect costs of a range of small and medium farm types varied from £700/ha to £900/ha.[8]

Direct (variable) costs

Trials at Kirton and Rosewarne in the 1980s established that one-year-down growing of narcissus was uneconomic, and UK growers converted to two-year-down growing, around which most R&D was thereafter based. Subsequently, declining bulb prices and an increased demand for field-grown cut-flowers led growers to leave crops down for three or more years, rather than two. The following are the principal direct costs of narcissus growing, based on two-year-down growing.

- Bulbs, £300 to £600/t, depending on cultivar.

Following start-up, it would be expected that re-planting stocks would be left for the grower once bulbs for sale had been taken out. Bulb value is difficult to predict owing to the large fluctuations that occur, even for commonplace cultivars. The greater cost of stocks of better or newer cultivars can be a considerable disincentive to the investment needed for something that may take several years to be realised (and in an unpredictable market). Since usually the non-saleable small and large grades are re-planted, in subsequent years the value of this material may then be regarded as nominal.

- HWT, £45/t, or £96/t allowing for a 'relatively expensive' fungicide and disinfectant to be added.

HWT is a major cost, and the cost of adding a relatively expensive fungicide (such as a thiabendazole-based product) for treating basal rot-susceptible cultivars may sometimes be prohibitive. If large narcissus fly is a problem, the cost of including a chlorpyrifos-based insecticide would also need to be added.

- Fertilisers, £140 to £170/ha.

Narcissus are relatively undemanding in respect of fertilisers, and they are often needed only for the first year.

- Herbicide and fungicide sprays, £890/ha.

Until alternative means of weed and disease control are available, this cost is largely unavoidable, though there has been a trend for fewer, but better timed, fungicide applications.

- Insecticide sprays.

An insecticide is not normally applied unless large narcissus fly is a significant problem.

- Irrigation.

Irrigation is not normally used with narcissus crops.

- Desiccant.

Depending on weather and crop stage at harvesting, a desiccant may be needed before lifting, if mechanical means of foliage removal are not being employed.

- Post-lifting fungicide spray, £24/t, optional.

On-line spraying with a suitable fungicide is recommended for basal rot-susceptible cultivars.

- Bulb drying and storage, £12/t.

Costs will vary according to the systems used, and this figure is a rough guide for fuel costs.

- Grading, £1,200/ha.

- Marketing and packing costs, £720/ha.

Labour costs

The main labour costs would be:

- Ploughing £55/ha.
- Power harrowing £29/ha.
- Fertiliser application £45/ha.

Including three applications – pre-planting, pre-emergence and possibly in the second year.

- Planting £120/ha.
- Spraying £170/ha.

Including 12 applications, eight at high-volume.

- Topping or other defoliation £23/ha.
- Harvesting £340/ha.
- Transport to store £96/ha.

Gross margins

Gross margins are greatly affected by bulb prices and flower cropping.

Bulb prices

Approximate farm-gate selling prices of some commonly grown cultivars are currently £350/t ('California', 'Ice Follies'), £370/t ('Golden Ducat'), £375/t ('Golden Harvest'), £380/t ('Carlton') and £720/t ('Actaea'). If buying bulbs as a grower, about £100/t should be added. There is pronounced cyclical variation in the supply of bulbs, hence bulb prices fluctuate widely over cycles of a few years. This creates an interplay between the relative prices of bulbs and flowers, the areas of field-grown bulbs cropped for flowers, and the numbers of bulbs used for forcing in glasshouses. A Dutch simulation model of the supply and demand of bulbs demonstrated there were relationships between the price asked and the quantity demanded, and between the price asked and the acreage grown.[9]

Flower cropping

Flower picking is now more widely practised in the UK because of the increased demand for good quality stems. Whether flowers are cropped (or not) depends on current demand, and will be affected by weather and the relative cropping times of the different areas of the country and the availability of forced flowers. Flowers are usually cropped in the second and subsequent years of the crop, avoiding any damage caused by HWT in the first crop year, but flowers can be cropped in the first year if warm-storage regimes have been used. Cropping flowers may result in a bulb yield loss of around 15% as a result of crop damage, infection of the cut stem ends, and reduced photosynthetic area, though this may be mitigated by reduced disease (resulting from the presence of decaying flowers) and by the allocation of photosynthetic resources to bulbs rather than flowers and seed capsules.

Some estimates of gross margins for narcissus bulb production have been given as between £1,900 and £2,900/ha/year. Cropping flowers might add some £2,500/ha over the two-year cycle.

Non-quantifiable benefits

The following are some of the less quantifiable benefits of growing narcissus:

- A high-value crop to add to the rotation.
- Options for sharing stores and equipment.
- No major pests common to narcissus and potatoes, alliums or roots.

2.2 Predictive crop management

Despite the UK industry's considerable expertise in the husbandry of narcissus and other crops, the yield, quality and timing of crops are variable and unpredictable from year to year, or even within a field.[10] In the case of narcissus, wet autumns, mild winters and climate change are among the factors appearing to contribute to the observed year-to-year differences in flower numbers, in cropping periods, in bulb yields and even in the speed with which bulbs may be forced. There are probably many anecdotal examples linking the weather to crop performance, such as a warm, dry autumn leading to late flowers in the next spring. Predictive crop models could be used to remove some of this uncertainty.

Predictive crop models have been developed since the 1970s for several field vegetable crops.[11] With field crops, of course, there are only limited possibilities for manipulating the environment (such as by altering planting dates or using a heat-insulating mulch), and therefore such models are often purely predictive and cannot be used directly to allow crop scheduling or other manipulations. Nevertheless, they can provide useful management support systems to help plan production and supply. For example, they could be used in predicting flower supplies, prices and the integration of supplies from various parts of the country, or provide an expectation of the coming season's bulb yields, and hence likely price.

Until recently, little was known of the precise way in which the prevailing weather affects narcissus growth and development. Pioneering studies in Norway and Poland showed that weather could indeed have a marked effect on the growth and development of the crop. Thus, experiments were carried out in Norway to study the effects of varying autumn temperatures.[12] Narcissus bulbs were either stored at ambient outdoor temperatures and planted in September or stored at 20 or 23°C and planted in October.

Shoot emergence, but not flowering or senescence, was delayed by storage at 20 or 23°C and later planting, and the yields of bulbs and flowers were higher when the temperatures were higher. Thus, in warm winters the best yields might be obtained from ambient storage before planting, while in cool winters yields should be greater when 23°C storage is used.

Data from some Polish research showed that weather conditions in December had a major effect on bulb yield.[13]

If the mean monthly air temperature was above 0°C or slightly below, and the soil was not frozen, bulb yield was high. However, if the temperature was below –3.6°C and the soil was frozen, yield was decreased by between 14 and 48%.

These examples demonstrate the potential value of modelling narcissus growth. Regarding the techniques of developing predictive crop models, first, the key relationships between aspects of crop growth and development - such as flowering time or bulb yield - to the environment – such as soil temperature or water availability – are studied experimentally. For example, changes in flowering time with respect to temperatures, could be examined in either (ideally) a range of controlled environment facilities, or (more practically) at different sites in different years in the field. Once relationships between crop development and environmental factors are discovered, mathematical expressions can be derived and used, for example, to predict flowering time under specified temperatures. At the start of the season, historical weather data are used in making predictions, but as the season progresses historic data are replaced on a weekly basis with the current weather data, either from a supplier or, better, from an on-site weather station.

A project to develop a narcissus crop model was funded by Defra and carried out at HRI. Data was gained growing 'Carlton' bulbs two-years-down at Kirton from 1995 to 2000. Weather patterns varied considerably between these years, making a good 'test bed' on which to develop models. As a result of the obvious importance of temperatures as a factor controlling the growth and development of spring-flowering bulbs, the temperature to which the bulbs were exposed was varied by different means:

- Altering the pre-planting storage temperature.
- Planting bulbs on different dates.
- Applying a mulch over the crop for different periods.

Crop growth and the weather were recorded, and mathematical modelling techniques used to determine which factors were critically affecting growth and development across the years of the experiment.

Narcissus might be thought of as too complex a crop for which to attempt predictive modelling - it has a perennial structure, a growing cycle of two or more years, and there are conflicting demands between bulb production and flower production. Nevertheless, several relationships were discovered, relating shoot emergence date, flower picking date, flower yield and bulb yield to various weather factors.[14] These are summarised in Table 3. Overall there was good agreement between the observed crop data and the predictions made using these models; Figure 8 shows this for bulb yield. Further work is needed to validate these models for other cultivars and sites and using three-year-down crops.

As well as providing the basis of a narcissus crop model, the experimental treatments used in this project showed how much the growth cycle could be shifted within the calendar year by the simple expedients of varying pre-planting storage temperature, planting date and mulch treatments. Within a year, for example:

- Mean flower cropping date varied by 6 weeks between the various treatments.
- The date of 'Stage Pc' (completed flower initiation) varied by seven weeks.
- The percentage of foliar senescence in late-June varied from 10 to 75%.
- The percentage bulb weight increase varied from 100 to 160%.

Figure 8 The observed bulb yields (plain bars) and predicted or fitted bulb yields (pink bars) for bulbs in 12 treatments in each of three crops (planted 1995, 1996 and 1997)

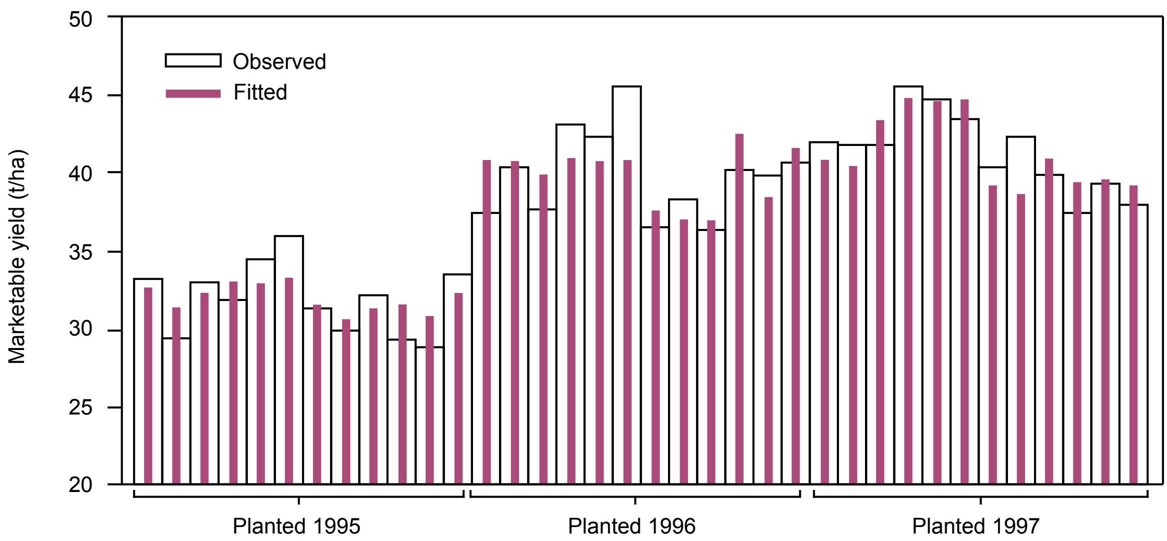

Table 3 Some crop parameters and the environmental factors affecting them

Crop measurement	Critical environmental factors
Shoot emergence date	Soil temperature in the current year
Flower picking date	Air temperature in current year
Flower yield	Rainfall in previous year
Bulb yield	Rainfall in previous and current years and thermal time

This showed it would be possible to vary, say, the cropping date of a single cultivar to cover a range of target dates depending on important marketing dates (such as the variable date of Easter), by using simple treatments such as mulching with straw. A further example is the value of irrigation – not usually employed by bulb growers – in increasing yields in dry years. These possibilities have yet to be exploited, and, ideally, integrated with financial data relating to the supply and demand for bulbs and flowers.

2.3 Integrated pest and disease management

The demand for more 'environmentally friendly' or 'organic' production of ornamental crops is small in relation to that for edibles, but it is probably inevitable that it will follow the same trends as food crops, increasing as multiple retailers promote more 'sympathetic' production protocols. Similar considerations might also apply to plants being grown for the production of pharmaceuticals (such as galanthamine), where it may be desirable to exclude pesticides for various reasons. As well as environmental reasons for encouraging less reliance on pesticides, there is also the practical consideration that relatively few pesticides are approved for use on horticultural crops, so in the future the sales of pesticides, other than for use on major crops, are unlikely to justify development and registration costs.

In the Netherlands the intensity of horticultural production, high use of pesticides and fertilisers to reduce losses due to pests and diseases and to increase yields, and the vulnerability of the water table and water courses, led to major restrictions on the use of agrochemicals in bulb growing. It was reported that 10% of the pesticides used in the Netherlands was used in the production of flower-bulbs, a 12-fold higher input/ha than the average.[15,16] The 'Multi-year Crop Protection Plan' indicated a need to develop integrated crop management (ICM) systems for narcissus crops.[17] Trials were set up on experimental farms to test prototype ICM for bulbs.[15,18] A model that optimises production as regards environmental goals (nitrogen residues and pesticide inputs) and financial goals (income) for crops including narcissus, has been described,[19] the options for environmentally friendly flower-bulb production systems explored,[20] and the prospects for pest and disease control in bulb crops in a world less dependent on agrochemicals reviewed.[21] An assessment of three systems for growing narcissus – 'integrated', 'experimental integrated' and 'biological crop management' – suggested there were good prospects for the integrated system.[22]

In the UK the approach seems to have been relatively unstructured. Up to now, little research has been conducted in the UK specifically on more environmentally friendly narcissus production, although several possibilities are evident from previous Defra-funded R&D, including the importance of physical and cultural methods alongside chemical ones. Thus, in handling narcissus bulbs, emphasis has been laid on using rapid drying and correct storage conditions for bulbs, to reduce the levels of basal rot.[23,24] Cultural methods of basal rot control include early lifting and late planting to avoid high soil temperatures, and there is also scope for using mulches or controlled weed growth to reduce soil temperatures, conserve water and reduce reliance on herbicides. For example, Dutch trials on the development of low-dose herbicide treatments for bulbs, involving leaving straw mulches in place to prevent weed germination, covering the soil with intercrops between bulb crops, and optimising the use of mechanical weed control, have been described;[25] these might involve changes to the system of bulb planting currently used. Some techniques used in the Netherlands, however, are specific to the situation there, such as utilising the controllable water table: for example, in trials to control the nematode *Pratylenchus penetrans*, flooding was found to be an effective alternative to soil sterilisation.[26] Alternatively, it has been suggested that solar sterilisation (solarisation), using a polyethylene mulch to trap heat, may be useful in narcissus growing[27] - it has been used effectively to control the bulb mite *Rhizoglyphus robini* to a soil depth of 30 cm in Israeli research.[28]

The biological control of the basal rot pathogen by antagonistic fungi has been reported by researchers in the Netherlands[29,30,31,32] and the UK.[33] Non-pathogenic micro-organisms (*Penicillium* and *Trichoderma* species, *Minimedusa polyspora* and a *Streptomyces* species) were shown to inhibit pathogen growth, reduce disease development, or improve the effects of using thiabendazole fungicide alone. In Dutch experiments in soils inoculated with *Pratylenchus penetrans* or Trichodorid nematodes, the population of *P. penetrans* was reduced by planting 'biofumigant' marigolds (*Tagetes patula*), and bulb yield in the subsequent narcissus crop was increased.[34] It is encouraging to see some of these techniques now being investigated for tazetta narcissus production in the Isles of Scilly.[35,36] Unfortunately the effect of *Tagetes* on the stem nematode (*Ditylenchus dipsaci*) appears to be unknown. A useful recent proposal is to investigate the potential biological control of basal rot by treating narcissus crops with compost seeded with *Trichoderma* species, uses an approach previously successful in managing *Fusarium* rots in onions.[37]

2.4 Carbon footprints and socio-economic effects

Carbon footprinting and the horticulture industry

To quote a recent report: "Concern about climate change has stimulated interest in estimating the total amount of greenhouse gases (GHGs) emitted during the production, processing and retailing of many consumer goods, including food products. The process of estimating these emissions is termed 'carbon accounting' and the final description of emissions is termed the 'carbon footprint'… Once the carbon footprint for a product has been estimated it is possible to use this information to inform producers, consumers and other stakeholders about the relative impacts of different products on the climate."[38]

Two reports, one funded by the HDC[38] and the other by Defra,[39] have considered carbon footprinting in relation to the UK horticulture industry. Both included narcissus among the sectors examined.

The HDC-funded study

Three published case studies, involving cut roses imported from Kenya or the Netherlands to the UK, apples produced in Europe and in the Southern Hemisphere and brought to the EU, and lettuce produced in Spain or the UK for the UK market have been considered in this review. The following points were included in conclusions from these studies:

- Carbon footprinting is influenced by new and emerging science and there is no agreed standard methodology for estimating an enterprise's footprint.
- There are potential commercial gains for enterprises that demonstrate a competitive advantage in terms of GHG emissions.
- The combination of the above two factors provides potential for enterprises to misrepresent the carbon efficiency of their production. Therefore, the highest standards of data collection and evaluating carbon footprints must be observed, and growers should demand that this is also ensured by their competitors.

Subsequently, the authors reviewed GHG emissions from the UK horticulture industry in general.

- UK horticulture accounts for 28% of the total energy used by UK agriculture, and within horticulture field crops use 9% of the energy inputs, with 91% accounted for by protected cropping.
- The UK (field-grown) fruit and vegetable sectors contribute 2.5 to 3.0% of total UK GHG emissions. By implication, the contribution of the narcissus industry would also be low.
- Field crops that are grown in season, without heating or protection, and which have low spoilage rates, are the least energy- and GHG-intensive crops. Flowers produced at temperatures of 15°C or less, and without supplementary lighting, are similarly benign. Nevertheless, energy might be added through refrigeration beyond the farm gate, by trimming, bagging, etc., and by wastage, particularly in the retail and consumer stages. It can be seen that similar considerations might apply to narcissus bulb, cut-flower and pot-plant production, indicating some ways in which the narcissus industry could reduce its energy use and GHG outputs.

No specific case study was found in the scientific literature for the UK bulb and outdoor flower sector specifically, although a Defra-funded study found that the primary energy inputs for field-grown narcissus production (for both bulbs and flowers) was relatively low, at 37 GWh, compared with over 125 GWh for field-grown vegetables. It was considered that the main issues in narcissus growing were:

- Fuel for field operations (ploughing, planting, spraying and harvesting bulbs) and for the transportation of bulbs and flowers on site.
- Electricity for cold storage of cut-flowers and gas or oil use for drying bulbs.
- Electricity for on-farm grading and packaging of bulbs.
- Fuel for the transportation of bulbs and flowers to markets.
- Oil or electricity used for HWT.
- The energy used to manufacture pesticides.

It is an advantage for narcissus growers that only low rates of nitrogen fertiliser are needed.

Possible mitigation measures for narcissus growers could include:

- Replacement of old machinery with newer, more efficient versions.
- Store insulation.
- Fuel savings through organisation of cultivations and reduced tillage.
- Use of GPS and precision farming methods.
- Correct tractor ballasting, tyre selection and implement matching.
- Continuing to limit nitrogen applications and ensure accurate timings to limit leaching.
- Applying manure at appropriate times when the crop can utilise it.

The Defra study

In the Defra-funded study, an overall environmental footprint for 12 agricultural commodities included the following full range of indicators:

- The ecological footprint – briefly, how much land and water area the human population requires to produce the resources it consumes and absorb its wastes.
- The pesticides Environmental Impact Quotient (EIQ) rating – the quantity and toxicity of the pesticides applied to grow a crop.
- The Global Warming Potential (GWP) – the greenhouse gases (carbon dioxide, methane and nitrous oxide) it produces.
- The eutrophication and acidification potential (EAP) – the potential for phosphates, nitrates, ammonia and sulphur dioxide to cause environmental damage.
- Water use.
- Labour use.

For each commodity, the estimates of the six indicators were scaled and summed to produce a total environmental footprint (given in hectares), shown in Table 4. The narcissus crop was assumed to be a 2-year-down crop that received 38 kg/ha of nitrogen fertiliser and was used to produce both bulbs and flowers. The environmental footprint of narcissus, 22.3 ha, was slightly higher than the average for the field-based horticultural crops (20.5 ha), with pesticide usage having the greatest effect on the footprint. Since the overall area of the crop is small, however, it ranked 11th out of the 12 commodities for environmental impact at the UK scale, accounting for only 0.09% of the total UK footprint. This does indicate, therefore, that a modest reduction in pesticide usage

Table 4 Aspects of the environmental footprint for 12 agricultural commodities

Commodity	Ecological footprint (gha/ha)	Pesticide (EIQ) rating (kg/ha)	GWP (kg/ha)	EAP rating (kg/ha)	Water use (kL/ha)	Labour use (h/ha)	Environ-mental footprint (ha)	UK crop area (kha)	Total UK environmental footprint (no units)
Apple	6.6	205	2,735	8.0	413	452	29.2	4.6	134
Carrot	6.6	109	3,431	23.8	519	123	19.3	9.5	184
Onion	6.5	140	3,271	27.4	504	49	20.3	8.6	174
Cauliflower	6.4	111	3,853	31.1	502	142	20.3	9.9	201
Lettuce (protected)	21.4	165	57,298	36.0	2,301	317	59.1	0.3	15
Strawberry (protected)	13.0	178	21,511	10.1	2,303	954	54.9	3.8	208
Narcissus	7.4	154	6,065	15.7	107	229	22.3	3.9	87
Potato	7.4	134	7,041	47.2	1,203	61	27.1	138.3	3,740
Sugar beet	6.3	124	2,960	22.0	504	28	18.3	128.9	2,352
Wheat	6.2	83	2,782	12.3	2	12	11.5	1828.4	21,077
Lamb	6.3	106	8,190	45.5	24	85	18.4	1572.2	28,962
Milk	10.9	74	19,481	192.9	96	84	24.6	1313.9	45,420

*gha/ha global hectare per hectare.

The first six indicators were scaled to produce a relative value (between 0 and 100) and averaged to produce the Environmental footprint. This has then been scaled up based on UK production area to obtain the total UK environmental footprint.

would have a further beneficial effect on perception of the sustainability of narcissus growing. Stakeholders perceive the amount of energy used in bulb drying as a problem, and there is also a strong requirement for seasonal labour, though the sector does not have a demand for water as do some field-grown crops.

Socio-economic footprint and impact

The same Defra-funded study[39] also considered the socio-economic aspects of various agricultural and horticultural sectors. Although this is beyond the scope of the present manual, the main conclusions in respect of the narcissus industry will be summarised. As a result of the difficulties in sourcing data for specific commodities, for this exercise field-grown narcissus were grouped with HONS production as "outdoor horticultural holdings mainly non-edible crops", though in some respects narcissus fits more with other field-grown crops like vegetables. The study concluded that, despite the relatively small areas occupied by the more specialised commodities such as narcissus, they rate among the most socio-economically sustainable of sectors. Much of horticulture (as opposed to agriculture) was regarded by the authors as lean, economically viable, competitive and resilient, though with some weaker aspects, particularly in terms of human development.

Horticultural producers face pressures on margins combined with retailer demands for higher quality, but, as they have existed in a subsidy-free environment, they may be better placed to respond to such challenges. Rising energy costs, however, present a problem for a sector where energy use for some operations (such as bulb drying) is high. Some horticultural commodities, and particularly the narcissus sector, are labour-intensive; it is substantially dependent on a steady supply of migrant labour that is valued for its reliability and work rate in comparison with local labour. Narcissus production is especially dependent, for flower cropping and bulb cleaning, on the Seasonal Agricultural Workers Scheme (SAWS), which is seen as more socially acceptable and sustainable than immigrant labour from the 'A8' countries (such as Poland and the Baltic States).

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3.0 Pests, diseases and disorders

3.1 Introduction

Contemporary narcissus husbandry means using high planting densities, mechanical and bulk handling (with reduced sorting and inspection of bulbs by hand) and growing cycles of two or more years. All these factors exacerbate plant health problems, but it has to be accepted that, under present conditions, it would be uneconomic to return to less challenging methods of production. Any control measures used must, therefore, be robust enough to be effective under the current practices.

As with most crops, the application of pesticides in the field is important, but bulbous plants are also conveniently treated in the bulb-handling phase between lifting and re-planting. The narcissus crop is unique in that hot-water treatment (HWT) is the principle means of pest and disease management. Also, as with other crops, many sorts of good cultural practice – hygiene, crop inspection, rotations, etc. – are seen as increasingly crucial, the more so as growers and farmers have to cope with increasing restrictions on the use of 'chemicals'.

Much of the information cited in this section has been derived from MAFF/ADAS publications. These include the reference books *Bulb Pests*,[1] *Diseases of Bulbs*[2], *Hot-water Treatment of Plant Material*[3] and *Bulb and Corm Production*,[4] the booklets *Control of Diseases of Bulbs*[5] and *Hot Water Treatment of Narcissus Bulbs*,[6] the *Identification Cards*[7] and a series of advisory leaflets.[8,9,10,11] Other useful texts consulted include *A Colour Atlas of Pests of Ornamental Trees, Shrubs and Flowers*,[12] the BCPC's *Pest and Disease Control of Protected Crops, Outdoor Bulbs and Corms*,[13] *Pest and Disease Management Handbook*[14] and *A Guide to Seed Treatments in the UK*,[15] the HDC Pests and Diseases Identification Cards,[16] the *European Handbook of Plant Diseases*,[17] and *Diseases of Floral Crops.*[18] Several other useful reviews were consulted.[19,20,21,22,23] Additional information has come from several Dutch and US texts, primarily the IKC's *Ziekten en Afwijkingen bij Bolgewassen*,[24] the MLNV/CADB's *Het Telen van Narcissen*[25] and the WSU Bulletin *Diseases of Narcissus*.[26] To avoid repetition, these standard references are not cited individually in the rest of Section 3.

Pest and disease identification

A general problem encountered is the identification of pests, diseases and their symptoms. Prior to the advent of the Single Market, the presence of pests and diseases may have been more often brought to the grower's attention through the statutory plant health inspection regime. Following the advent of the Single Market, narcissus bulbs for sale within the EU became subject to statutory inspection solely in respect of their one 'quarantine' pest – stem nematode. Under the EU Marketing Directive, other 'quality' pests and diseases became the responsibility of the producer.

Over the same period, the number of specialists and plant clinics available in the UK to make diagnoses – previously available through ADAS and the horticultural research and experimental establishments, among others - has been much reduced. Diagnostic services are still provided by Fera,[27] ADAS Ltd and some independent consultants, though, with a relatively specialist crop such as narcissus, there may be little direct experience available. Although some progress was made at Wellesbourne towards the development of a rapid serological test for *Fusarium oxysporum* f.sp. *narcissi*,[28,29] and while off-the-shelf diagnostic kits for on-site disease testing are becoming generally more readily available (such as Forsite Diagnostics' 'Pocket Diagnostics'),[30] kits relevant to the pathogens of narcissus do not appear to be yet available.

Pesticide approvals and availability

Despite the efforts being made to find alternative ways of managing pests, diseases and weeds, pesticides will remain of paramount importance in crop production for many years. For non-edible crops in the UK there are currently three main types of pesticide approval:

- Full (on-label) approvals.
- Extension of Authorisation for Minor Use (EAMU) formerly known as Specific Off-Label Approvals (SOLAs). Available on an 'at own risk' basis.
- The Long Term Arrangements for Extension of Use (LTAEU). These, with some restrictions, allow other approved pesticides to be used on an 'at own risk' basis in ornamental plant production. These arrangements are being phased out, with 'extensions of use' being transferred to EAMUs where required and appropriate. At the time of writing, many pesticide products are still available for use in ornamental plant production via the LTAEU, though many others are no longer permitted.

As the situation with pesticide approvals is very fluid, it is always important to check the latest information available. There are three main sources of information:

The UK Pesticide Guide (the 'Green Book')

This is available in hard-copy annually,[31] or on-line via a subscription.[32] It does not list all approved products but contains a great deal of specific and background information on all types of pesticides.

The Chemicals Regulation Directorate (CRD) databases

These provide definitive information on UK approved pesticides on regularly updated databases[33] that may be consulted freely on-line. Various searches and much background information are available. For searching for full approvals there is *The Pesticides Register*

Database and for EAMUs the *Products with Extensions of Authorisation for Minor Use* database. These databases are regularly updated and are regarded as definitive.

HDC LIAISON database

Through HDC Project CP 72, data within the pesticide approvals database has been reprocessed and made available to levy-payers[34] via the LIAISON site on the HDC website, where there is also a user guide.[35] Most usefully, as well as full approvals and EAMUs (SOLAs), information is given on those pesticides that may be used through the LTAEU - and those that may not. This resource only provides guidance on legal approval. Growers will need to then determine if the product is suited to their production system (and doesn't conflict with any restrictions on use) and also if it is crop safe. Detailed information on each product may be brought up on-screen.

Using the pesticide database

The CRD Pesticides Register Database

From the CRD front page select "Databases" and click on *"The Pesticides Register Database"*, then select *"Search for Products by specifying Approval features."* The database can be searched by choosing from 'picklists' for products, active substances, field of use/action (e.g. herbicides), crop, etc., either searching by a single search term or by combining various search terms. For crop, choose 'ornamental plant production' (occasionally, checking 'all non-edible crops' may be useful), as there is no separate category for narcissus or bulbs. The crop terms may be qualified later in the search results, for example 'ornamental plant production (narcissi)' or 'outdoor ornamental plant production'. The way crops have been described has changed over the years: the terms were regularised in 2001 when a 'crop hierarchy' was introduced, but earlier entries, using different terms such as 'ornamentals', were not updated, so these may need to be checked individually. The search results provide details of approval and expiry dates, applicable crops and crop qualifiers, etc., but only the more recent entries include links to the approval documents themselves.

Products with Extension of Authorisation for Minor Use (EAMUs, formerly SOLAs)

This is also searched via picklists for products, active substances, field of use (e.g. herbicides), crop, etc. However, there are many more, sometimes highly specific, crop categories to choose from (e.g. 'daffodils grown for galanthamine production', 'narcissus', 'narcissus bulb (dip)', 'non-edible flower crops', 'non-edible glasshouse crops', 'non-edible ornamental bulbs', 'ornamental bulbs and corms (dip)', 'ornamental plant production', 'ornamental plant production (drench)', 'ornamental plant production (soil treatment)' and 'ornamental plant production grown in synthetic/inert media'). The search results provide details of EAMU numbers, approval and expiry dates, applicable crops and crop qualifiers, etc., and include links to the EAMU document which should be printed off as a record of timings, rates, harvest intervals, etc.

HDC LIAISON database

The database allows selection of a product, active ingredients or field of use (e.g. herbicide) combined with a specified crop, to list approved products (with on- or off-label approval, coded white), other products that are still legal to use (at present) under the LTAEU (coded green), and those that may not now be used under the the LTAEU (coded red). Crop selection uses quite specific terms, such as 'bulbs (outdoor)', 'bulbs (protected)', 'flowers for cutting', 'narcissus (outdoor)', 'narcissus (protected)', 'non-edible plants for propagation', 'ornamentals (outdoor)', 'ornamentals (protected)', 'pot plants (outdoor)' and 'pot plants (protected)', and any of these might be applicable to narcissus growing. The product names provide links to more detailed information on rates of application, maximum number of applications per season, application intervals, harvest intervals (all still legally binding under extensions of use, even in non-edible crops), etc.

Pesticides available through the LTAEU

Access to this information through the HDC's LIAISON database provides a substantial source of alternative active ingredients and products that may be legally used in various situations. For example, searching HDC LIAISON (as at 2013) for herbicides that could be used on narcissus (outdoor) produced 284 products with full or EAMU approvals and 826 permissible via the LTAEU (there were a further 219 products formerly available through the LTAEU that have now been withdrawn). But it should be noted that, in relation to 'extension of use', products are listed without regard for their relevance to specific crops (e.g. a fungicide against powdery mildew might be of little use in narcissus growing) or even their crop-safety (e.g. a sulfonylurea herbicide may be listed for use in narcissus growing, despite being known to cause damage to the flowers). Hence, the information should be used cautiously.

3.2 Pest nematodes

A fuller account of plant nematodes can be found in the MAFF/ADAS reference book *Plant Nematology*.[36]

Stem nematode (*Ditylenchus dipsaci*) (also called stem and bulb nematode)

Stem nematode (often called 'eelworm') is the only quarantine pest of narcissus under EU regulations, and is the greatest threat to the narcissus industry, despite appearing to be successfully managed through routine HWT. The HWT of bulbs before planting is considered essential, since stem nematode is persistent and can destroy a bulb stock in three years. In the UK stem nematode is seen relatively infrequently, though there has reportedly been a significant increase in the number of outbreaks in recent years, accompanied by more openness and increased attempts to keep growers informed.[37] Excellent photographs of stem nematode and its symptoms appear in a recent Defra/CSL leaflet.[38]

The up-to-1.2 mm-long transparent nematodes enter the neck of bulbs from the soil, usually via the newly emerging leaves, but also late in the growing season.[39] In the soil, stem nematode can move in moisture films up to 1 m/year, more in sandy or waterlogged soil or in standing water in flooded furrows. In the bulb nematodes eat their way through one bulb scale at a time: brown, damaged scale tissue macerated in a drop of water and examined under a low-power microscope can reveal vast numbers of nematodes moving with a characteristic thrashing motion. Stem nematode can only be properly identified through laboratory examination, and, as saprophytic nematodes also occur, expert diagnosis is advised.

Multiplying rapidly at summer temperatures or in bulb storage, it has been reported that four nematodes can cause serious damage to a bulb in a year, while 50 can destroy it.[40] The stem nematode completes its life cycle within the bulb. Up to 500 eggs are laid, and there are four larval stages. The first, second and third moults progress rapidly, and the fourth-stage larvae are the infective stage and the stage which can survive adverse conditions. The fourth-stage larvae either enter the leaves or remain in the bulb scales, finally moulting to adults which begin to reproduce, the life-cycle taking about 20 days at an optimal temperature of 10 to 20°C. Reproduction can continue in bulbs in the field or in storage. In decayed bulbs, the fourth-stage larvae can move to the outside of the bulb, forming nematode 'wool', a mass of dehydrated larvae that is a survival mechanism. Wool formation can occur if the bulb becomes desiccated, for example, during warm periods or prolonged storage. The wool exudes around the base plate (which can sometimes become detached from the rest of the bulb), and occasionally around the bulb neck, appearing as pinhead-sized blobs of off-white, wool-like material. The wool is easily dispersed, resistant to desiccation and high temperatures, and can survive for 10 years or more without a host.[41] Wool is rapidly re-hydrated on contact with water. Following some control treatments nematode wool may appear inactive, but care is necessary as the nematodes can revive following overnight contact with water. In moist soil, stem nematode can survive in the absence of host plants for about a year.

The stem nematode attacks a wide range of genera, but biotypes have specific host preferences. The narcissus, tulip and hyacinth races of stem nematode can all attack narcissus plants: the tulip race is very pathogenic and has a wide host range, while the hyacinth race causes only minor lesions. In cultivar tests, no cultivars tested proved immune.[40]

The symptoms of stem nematode (shown in Images 3 to 5) are:

- Characteristic lesions (called 'spikkels'): small, broken, roughened, swollen and yellow areas, usually along the leaf or stem margin.
- In more heavily affected leaves where the lesions coalesce, a distorted, spongy, broad and thickened appearance, especially below ground.
- Distinct brown rings when the bulb is cut across, consisting of brown, degraded bulb scales amongst still healthy white scales; eventually the whole bulb rots, but its appearance is distinct from that due to basal rot.
- Patches of weak, stunted plants in the field from year two onwards.
- Secondary infections of bulb-scale mite, small narcissus fly and various fungi.
- Wool erupting around the base plate and sometimes around the neck of the bulb.

The roots are unaffected.

The management of stem nematode is based on:

- Using an adequately long rotation – at least five years after groundkeepers have been removed.
- Maintaining sensible hygiene including cleaning and disinfecting equipment, tools and work areas, preventing spread on bulbs or crop debris.
- Carrying out regular crop inspections, with the isolation and removal of infested and surrounding plants and soil within a 1m-radius of the outbreak.
- Giving careful HWT (preferably including a disinfectant to replace formalin).
- Prompt cooling and drying after HWT, followed by inspection and removal of affected bulbs, or prompt planting after HWT.
- When infested stocks are present, handling must be arranged to avoid spread to healthy bulbs.

3 A patch of weak, infested bulbs as a result of stem nematode infestation

Photo: Warwick HRI and predecessors

4 Stem nematode leaf spikkel symptoms

Photo: Warwick HRI and predecessors

5 Stem nematode: cut bulbs showing 'brown ring' symptoms

Photo: Warwick HRI and predecessors

Narcissus bulb and leaf nematode (crocus root-rot nematode) (*Aphelenchoides subtenuis*) and related base plate disorders

Damage from *A. subtenuis* has been reported only rarely in South-West England, but has been recorded in the Netherlands on 'Geranium' and 'Van Sion' (*N. telamonius* var. *plenus*). The leaves turn yellow and the outer scales may blister. After storage the bulb scales are grey or brown, dry and granular, and subsequent growth is poor. Control is through rotation, hygiene, inspection and HWT.

Other disorders may be associated with nematode problems. A 'root plate rot' was formerly reported in the South-West and was confused with *Fusarium* basal rot, but only the base plate rotted, resulting in weak rooting and stunted growth. In tazetta narcissus growing in Israel, *A. subtenuis* was associated with premature senescence, a red-brown root rot and base plate rot.[42,43] Although in this case no fungal or bacterial pathogen was identified, a fungicide soak was shown to reduce infections, while longer, hotter or later HWT with a fungicide gave better control.

Root-lesion nematode (*Pratylenchus penetrans*) and 'soil sickness'

Most frequently occurring in the Isles of Scilly where it is not easy to find un-cropped land for new plantings, *P. penetrans,* in association with the fungus *Cylindrocarpon destructans* (also known as *Nectria radicicola*), causes a root rot, 'decline', 'replant disease' or 'soil sickness'. Especially in cultivars with fine roots, the fungus enters through wounds on the roots caused by the nematode, spreads and leads to areas of stunted plants with severe rotting, water stress and premature senescence. The controls include HWT, soil disinfection,[44] growing *Tagetes* (marigolds)[45] and (where available) pre-planting pesticide soil application[46] and bulb fumigation.

Nematodes transmitting narcissus viruses

Through feeding on roots, free-living *Trichodorus* and *Paratrichodorus* species (stubby-root nematodes) transmit tobacco rattle virus, *Longidorus* species (needle nematodes) transmit tomato black ring and raspberry ring-spot viruses, and *Xiphinema diversicaudatum* (dagger nematode) transmit arabis mosaic and strawberry latent ring-spot viruses. These viruses multiply slowly and the nematodes remain infective for three to 12 months; they tend to occur on sandy soils. Where virus-tested bulb stocks are being grown, soil sterilisation has been used to control these vectors.

Potato cyst nematode (*Globodera* species)

Potato cyst nematode (PCN) does not attack narcissus, though its cysts may be carried on soil on dry bulbs. Soil freedom is therefore essential, since the presence of even dead PCN cysts may indicate a risk and prevent export.

Potato tuber nematode (*Ditylenchus destructor*)

The potato tuber nematode is similar to the stem nematode and attacks some flower-bulbs, but is not known to have been recorded on narcissus. Unlike *D. dipsaci*, it feeds mainly underground.

3.3 Pest insects

Large narcissus fly (*Merodon equestris*)

The only serious pest insect of narcissus, large narcissus fly (often misnamed narcissus bulb fly, which can cause confusion with wheat bulb fly) used to cause considerable damage to crops in South-West England before the introduction of aldrin as an insecticide. Damage increased again following the withdrawal of aldrin in 1989. Since the 1980s, large narcissus fly, originally considered at the limit of its range in Cornwall, has also become an established problem in Eastern England.

The bumble bee-like adult (Image 6) is active in warm sunny weather when the temperature is over 20°C, fly emergence starting in May in Cornwall.[47,48,49,50] Some 50 to 75 eggs are laid singly in the soil near to the base of narcissus in May to June. The eggs hatch after about 10 days and the larvae burrow and enter the base of healthy bulbs, the base plate subsequently developing a corky texture. Entry through the bulb scales has also been reported. The larva, which always occurs singly, is grey with a chocolate-brown breathing tube; it reaches 1 to 2 cm in length by autumn, first feeding on the base plate and then on the rest of the bulb, which becomes converted to granular frass (Image 7). At bulb lifting infestation is not usually obvious, and a close examination is needed to find the small entry hole. The larva passes through three instars and usually leaves the bulbs from the following March onwards, pupating just below the soil surface and emerging as an adult in about five weeks. There is one generation a year. Bulbs may survive infestation, though they will be damaged and have weak, grassy leaves.

6 Adult large narcissus fly

Photo: Warwick HRI and predecessors

7 Cut bulb showing large narcissus fly larva

Photo: Warwick HRI and predecessors

Management is mainly through HWT, though this controls only larvae already in the bulbs; adding chlorpyrifos to the tank gives protection during the year after planting. Many insecticides have been investigated for bulb soak, spray-at-planting and growing season applications, but most have drawbacks or involve compounds that are now unavailable. Several HDC Projects (BOF 1[51], 1a[52], 1b[53], 1c[54] and FV/BOF 127[55]) have contributed to understanding the biology of large narcissus fly in order to forecast and control the pest,[56,57] simulation models predicting the timing of several insect attacks have been developed and validated,[58] and an Syngenta Pest Prediction Service is available to growers for identifying target dates when treatments should be applied.[59] Cultural controls, such as lifting bulbs before egg-hatch, deeper planting, surface cultivation, using crop covers and avoiding sources of infection, are inconvenient but possible controls. Alternative controls have been suggested from time to time, for example, baiting stocks with unwanted bulbs[47] or, unsuccessfully, biocontrol using parasitic nematodes.[50] Current management of the pest is summarised in an HDC Factsheet.[60]

There appear to be some varietal preferences, with 'Tête-à-Tête' and 'Jack Snipe' selected in preference to 'Golden Harvest', 'Ice Follies', 'Van Sion' and 'Carlton' in tests.[50] It has also been recorded that *N.* x *bernardii* was attacked more heavily than its parents, *N. pseudonarcissus* ssp. *bicolor* and *N. poeticus*;[61] this raises the possibility of breeding resistant or tolerant cultivars.

Small narcissus flies (*Eumerus strigatus* and *E. tuberculatus*)

The adult flies lay eggs only on weak or damaged bulbs, so the pest is controlled incidentally through other operations, especially HWT and basic hygiene. *E. strigatus* has the wider host range of the two species. In contrast to the large narcissus fly, there are two or three generations a year. Maggots of *Eumerus* species[62] are small (7.5mm long), occur in groups, have a tan-coloured breathing tube and can pupate in storage, so cocoons can be found in stores and on containers.

Garden swift moth (*Hepialus lupulinus*)

The garden swift moth is an occasional pest of narcissus. Eggs are dropped in flight over weedy ground and the caterpillars (Image 8) emerge and attack the roots of many plants, especially grasses. They can make large holes in the sides and bases of narcissus bulbs. There are no recognised controls but, if garden swift moth is known to be a problem locally, attention should be paid to keeping the areas around narcissus crops weed-free. The ghost swift moth (*H. humuli*) may also be a pest.

8 Swift moth caterpillar

Photo: Warwick HRI and predecessors

Aphids

Although aphid colonies have been reported on narcissus under exceptionally favourable conditions, this is not normal[63,64,65] and does not seem to have been confirmed in the UK over many years.[66] Migrating winged aphids rarely feed on narcissus, though several common species may spread viruses (such as narcissus yellow stripe virus) through exploratory probing (known as stylet-borne or non-persistent transmission). These species include the potato aphid (*Macrosiphum euphorbiae)*, rose aphid (*Macrosiphum rosae)*, peach-potato aphid (*Myzus persicae)*, cherry black-fly (*Myzus cerasi)*, black bean aphid (*Aphis fabae)*, glasshouse-potato aphid (*Aulacorthum solani)*, pea aphid (*Aulacorthum pisum)*, mottled arum aphid (*Aulacorthum circumflexum*), rosy aphid (*Dysaphis plantaginea*) and mangold aphid (*Rhopalosiphoninus staphylae*). Aphid control, which is advisable for virus-tested and other elite stocks, is by frequent preventative sprays of antifeedant pyrethroid insecticides or mineral oil sprays.

Narcissus leaf miner (*Norellia spinipes*)

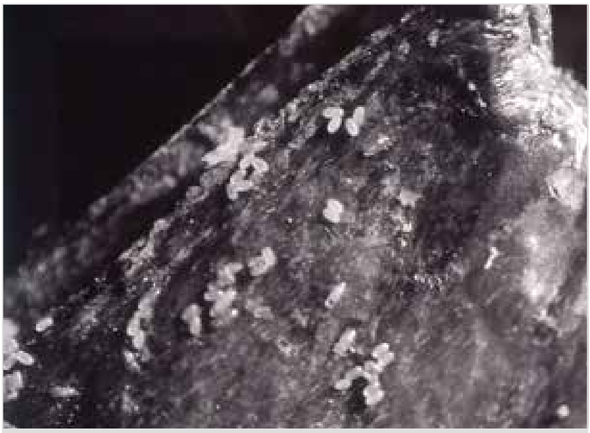
The leaf miner does not appear to have been reported in the UK, though it has spread to the Netherlands from Eastern Europe and survives in sheltered areas such as woods. Leaf mining results in wilt and yield loss, but the leaf miner does not attack the bulbs.

3.4 Pest mites

Walter and Proctor's text *Mites* is a useful text for further general information.[67]

Bulb-scale mite (*Steneotarsonemus laticeps*)

The bulb-scale mite is hardly visible to the naked eye, being light in colour and up to 0.2 mm-long in the case of the female (the male is smaller) (Images 9-11). It feeds on healthy bulb scale surfaces from internal spaces in the bulb, often starting at the nose of the bulb and spreading deeper as the bulb scales are depleted during the growing season. Feeding leads to the development of brown marks at the angular points of the bulb scales; later, when the shoots have grown, the feeding marks become exaggerated and are obvious as saw-tooth marks on the edges of leaves and stems. In storage, bulb-scale mites are said to spread actively, and perhaps also passively on air currents. At temperatures of 17°C or more, multiplication is rapid and feeding damage is significant. After planting, the mites persist in the tops of the bulbs, attacking the shoots and (presumably) spreading to surrounding plants. In field-grown crops the saw-tooth marks may be seen, but are unlikely to be severe except in a mild spring. In glasshouse-grown crops, however, the damage can be severe. As the leaves die-back, the mites enter the bulb.



9 Bulb-scale mites feeding on bulb (much enlarged)

Photo: CSL Crown Copyright

Management is through HWT and hygiene (such as disinfecting stores and equipment); fumigation is generally no longer an option. Due to the fact HWT causes crop damage in the year after treatment, bulbs for sale are not subject to HWT, though bulbs for forcing are now often given a short HWT. For pot-plant or cut-flower production, where a single infested bulb can ruin a whole pot or sleeve, it is particularly important to ensure that healthy bulb stocks are chosen. No information is presently available about varietal susceptibilities, though it is suggested that bulbs that have relatively 'loose-packed' scales (such as 'Actaea') may be more favourable to bulb-scale mite.[68]

10 Bulb-scale mite feeding marks in angles of bulb scales and showing as vertical tracks when bulb cut downwards from marks

Photo: Gordon Hanks

Despite the only sporadic appearance of damage due to bulb-scale mite, and the apparent success of their treatment with HWT, periodic concerns about bulb-scale mite have resulted in a series of projects aimed at a better understanding of their biology and epidemiology and hence of their control. In HDC Projects BOF 25 and 25a, carried out by CSL and ADAS, the subject was fully reviewed,[69] an *in vitro* method of culture was developed for use in life-cycle studies,[70] the origins of infestation were studied in the field and in storage,[71] and control by HWT was re-examined.[72] In the field, bulb-scale mites were found on foliage as it emerged through the soil in spring, numbers thereafter declining very rapidly, with mites being found only occasionally and in small numbers. In bulb handling facilities, although bulb-scale mites were found inside bulbs of an infested stock, none was found on the outside of the bulbs, on the boxes used to store the bulbs, on the bulb-handling machinery, or on the fabric of the building, though four other species of mite were found. The difficulties in finding and trapping bulb-scale mites, in the field or in storage, showed that foliar or in-store pesticide treatments were unlikely to find the target, and that monitoring the pest through trapping (using sticky traps or water traps) was unlikely to succeed. HWT and 'dry heat' treatments were confirmed as successful in controlling bulb-scale mites. In a later Defra-funded project, it was found that bulb-scale mite could survive outside the narcissus bulb for five to six days, and that only dead mites and eggs could be found in the soil surrounding an infested narcissus crop. However, crop residues (bulb fragments, etc.) were found to support colonies of the mites for long after the crop had been harvested, and were therefore a potential source of re-infection: non-infested narcissus bulbs planted in soil collected from around the infested plants, became infested.[73]

11 Bulb-scale mite leaf/stem symptoms, tracks from feeding marks along centre of leaf and saw-tooth edges

Photo: Gordon Hanks

A project jointly funded by HDC (Project CP 36 and BOF 63) and the HortLINK Programme (HL0178) was recently completed at Wellesbourne to investigate further the biology and control of the bulb-scale mite. This produced new information on the dynamics of the mite population in the bulb, and highlighted the importance of using the recommended duration and temperature of HWT.[74]

Bulb mites (*Rhizoglyphus* and *Histiostoma* species)

Bulb mites are also pale coloured mites, but have two dark spots dorsally and are up to 0.9 mm-long, and therefore easily visible to the naked eye. Unlike the bulb-scale mite, they attack only damaged or senescing tissue and, in conjunction with invading fungi, cause further damage leading to the production of a musty smell (Image 12). Control is by HWT and hygiene.

In a review of bulb mites of the genus *Rhizoglyphus*, *R. echinopus*, *R. fumouzi*, *R. narcissi* and *R. robini* were variously reported as occurring on narcissus in Canada, New Zealand, Russia and China as well as the UK.[75] Despite the accepted role of bulb mites (at least in the case of narcissus) as feeding only on already damaged bulbs, in some reports bulb mites infesting bulbs and corms have penetrated the base plate or outer skin layer and become established in the inner layers. Although not reported for narcissus, in other cases *Fusarium*-infestation has been found to enhance *R. robini* populations.[76]

12 Bulb mites feeding on decaying bulb

Photo: CSL Crown Copyright

3.5 Other pests

Slugs and snails

It is evident that slugs (e.g. *Arion hortensis* and *Deroceras reticulatum*) and snails can cause extensive damage to narcissus both above and below ground, especially in mild damp weather on heavy soils (Image 13).

The coronas of *Narcissus poeticus* varieties are especially prone to attack. Wild populations are damaged extensively by slugs.[77] Despite this, molluscs are not generally listed amongst the serious pests of narcissus. Slug pellets can be used, though this is not usual and they are effective only for molluscs on the surface. Good soil structure is important in denying slugs and snails hiding places, so cultivation is a key factor. A useful review of a wide range of slug management strategies is available from an EC project involving IACR Rothamsted and Long Ashton.[78]

13 Garden slug (*Arion hortensis*)

Photo: Warwick HRI and predecessors

Vertebrate pests

Vertebrate pests are not usually troublesome in narcissus crops, though exploratory damage and digging by birds and rodents may occur. Examples of rodents and domestic animals avoiding the foliage have been reported,[79] and single-choice feeding trials with captive prairie voles (*Microtus ochrogaster*) in the USA demonstrated that voles were deterred from consuming both narcissus bulbs and food (apple sauce) containing dried narcissus.[80,81] In an earlier study to develop animal-repellent plant extracts, narcissus extracts were among the most effective of several species.[82] Despite this, fatal cases of cattle and human poisoning by narcissus consumption have been reported.[83,84]

3.6 Fungal bulb diseases

Basal rot (*Fusarium oxysporum* f.sp. *narcissi*)

The effects of basal rot (also called base rot or Fusarium rot) are of sufficient severity that many of the procedures in narcissus growing have been designed to manage it, with other pathogens being controlled incidentally by the measures. Initially, basal rot was confused with damage due to stem nematode, but the causal organism of basal rot was identified in the UK in the 1930s.[85,86,87] Basal rot in UK crops once appeared to be a periodic concern linked with hot summers, but in contemporary bulb growing areas problems with basal rot have now persisted since the 1970s. R&D up to 1994 was reviewed in detail in HDC Project BOF 31.[88]

Basal rot first appears as a small dark spot within the base plate, spreading to affect the whole of the base plate and then upwards through the bulb scales which become characteristically moist and dark chocolate to reddish-brown in colour. In a store at 17°C a bulb can rot completely in four weeks. When the whole bulb is affected, it becomes soft, with a pinkish-white mass of mycelium and spores forming near the base plate. Bulb mites can move in to feed on the damaged tissues, and the bulb becomes brittle and mummified. Affected bulbs produce pale, prematurely senescing foliage, and sometimes short-lived, crooked shoots. The roots may fail to emerge from the base plate, or may emerge to be attacked later, becoming dark in colour. The symptoms are shown in Images 14-16.

14 Effects of Fusarium basal rot (right) compared to healthy plant (left)

Photo: Warwick HRI and predecessors

15 The progression of Fusarium basal rot

Photo: Warwick HRI and predecessors

16 External signs of Fusarium basal rot

Photo: Warwick HRI and predecessors

A particular problem is when apparently healthy bulbs are marketed, only to manifest basal rot a few weeks later. There are as yet no ways of detecting incipient disease non-destructively, so bulb samples need to be incubated under suitable conditions to allow disease development; tests based on lectin concentrations[89] and on using detached scales[90] have been investigated without success. The physiological basis of basal rot resistance or susceptibility is not known, though one study showed that resistance involves an interplay between the accumulation of antifungal compounds, cell wall modifications and the formation of lignituber-like structures.[91]

Basal rot infection occurs through the roots or damaged base plate (via mechanical damage or wounds caused by root emergence)[85,86,92,93,94] and is either soil- or bulb-borne.[93,95] The pathogen advances intercellularly before invading damaged cells.[96] Temperature appears to be the key factor in understanding basal rot epidemiology. Soil-borne infection is encouraged by high temperatures.[86] It can occur late in the season when moribund roots are present,[93,97] though it can also occur in temperatures as low as 5°C.[98] Young roots are infected, but not old decaying roots: the former have not yet developed a protective, corky outer layer, while the latter are isolated by the formation of a corky layer where the root leaves the base plate (suberisation). Control during the first months of planting is important as tissues are affected only above 13°C.[94] Infection and disease development were related to soil temperatures above 13°C and were maximal at 29°C.[99] In the soil the pathogen remains viable for up to 10 years, at least under artificial conditions.[100] The optimal temperature for bulb storage is 17°C, and storage at 20-30°C should be avoided because this range favours basal rot development.

Many studies on basal rot have been carried out at GCRI and Wellesbourne. Spores of both pathogenic and non-pathogenic strains were found on healthy bulbs.[101] The incidence of rotting bulbs, and the numbers of *Fusarium oxysporum* propagules isolated from the base plates of healthy bulbs, increased as storage temperature rose from 15 to 24°C, then declined somewhat to 30°C. When apparently healthy bulbs were taken from storage and grown for a year, the percentage rotting was similar in all treatments. Pathogenic isolates were found on base plates of 21% of samples, and on soil from both bulb-growing land and land where bulbs had not been grown. The fungus moves through roots but moves little through soil.[92, 102] Little infection was recorded when infective material was placed 30 cm below bulbs.[103] When healthy bulbs were placed 0, 10 or 20 cm laterally from infected bulbs, after one growing season 60, 27 and 6% of bulbs were affected.[104] It was suggested that, because of the relatively sparse spread of narcissus roots and the high concentrations of chlamydospores needed to produce infection, bulb-borne disease was more important than soil-borne disease, especially with high planting rates, reduced sorting by hand (meaning that more infested material is planted) and two-year-down growing.[93,105] Variations in the pathogenicity of *F. oxysporum* f.sp. *narcissi* isolates, and the cross-infectivity of the *formae speciales* of *F. oxysporum*, have been studied.[106,107]

In the 1930s it was shown that *F. oxysporum* f.sp. *narcissi* could enter and attack the roots of all cultivars tested except 'Seagull'.[86] Historically, basal rot susceptibility is linked with cultivars with a white perianth, specially 'Mme de Graaf', 'Mitylene', 'Evening' and 'Niphetos'. There are large varietal differences in basal rot susceptibility, and the susceptible 'Golden Harvest' and resistant 'Saint Keverne' are often used as representatives of the extremes in R&D programmes. In the UK the problem was made worse as the two cultivars once most widely grown – 'Golden Harvest' and 'Carlton' – are highly susceptible to the disease, however, the area of 'Golden Harvest' and 'Carlton' grown has fallen in the last decade in both the Netherlands and the UK.

Seedlings of most crosses are susceptible to the basal rot pathogen, with differences in susceptibility developing by the time the seedling bulb is one or more years' old (adult plant resistance).[108] Under some circumstances even normally 'resistant' cultivars may succumb to basal rot, as has been shown with 'Saint Keverne' growing in a high-nitrogen substrate,[109] in twin-scale propagules growing under glass,[110] in supposedly resistant poetaz cultivars,[110] and in some of the generally resistant new 'Rosewarne' cultivars.[111]

Much reliance for basal rot management has been placed on using an MBC fungicide (such as thiabendazole) and formalin. However, resistance of *F. oxysporum* f.sp. *narcissi* to MBC fungicides was recorded in narcissus first in 1991.[117] Advice on the control of basal rot has long involved a broad programme of measures. A poster[112] from the 1980s declared "There is no single effective method of controlling basal rot but a high degree of control can be obtained by carrying out all the following 10 points". With the exception of no longer advising one-year-down growing and no longer being able to use formalin, this general advice stands. In 2002, following completion of HDC Project BOF 42[113] on the handling of narcissus stocks with basal rot, the HDC issued a factsheet *Fourteen Tips for Good Basal Rot Management*.[114] Table 5 is a revision of this advice, taking account of the loss of formalin and current pesticide approvals. Recent advice for narcissus growing in the Pacific Northwest stresses a very similar set of recommendations.[115] Using these procedures will also help to control other fungi, and pests such as stem nematode, large narcissus fly and bulb-scale mite.

Neck rot (*F. oxysporum* f.sp. *narcissi* and others)

Neck rot (or top rot) has been recognised since the 1930s,[86] but has caused serious concern only since the 1980s, perhaps because it was seen more often as a result of pre-export bulb inspections. Having usually started after harvest, neck rot may be seen on the remains of the old flower stalk. The rot can progress downwards and eventually invade the base plate, the tissues becoming dark-chocolate to reddish-brown (Image 17). Eventually the new shoot is attacked, and seriously affected bulbs will be blind or produce weak shoots. Neck rot appears to affect a wider range of cultivars than basal rot.[98,95]

Neck rot is usually associated with *F. oxysporum* f.sp. *narcissi*, and recently the general term 'Fusarium rots' has been preferred to cover both base and neck rot since both are considered different expressions of the same disease. Neck rot can be induced by inoculating the bases of senescing leaves with *F. oxysporum* spores or water, the latter implying there is some predisposition to the condition.[98] However, other fungi – including *Penicillium hirsutum* (Image 18), *Botrytis narcissicola* and *Stagonospora curtisii* – as well as 'greasy skin' condition and mites, have also been associated with neck rot.[116,117,118,119,120]

It is important to distinguish this pathological neck rot – a rot clearly spreading down from the bulb neck – from 'physiological' neck rot. The latter is simply the presence of the dead bases of leaf laminae in the bulb neck. In non-spreading forms of the condition, the damaged tissue may become dry and ginger or brown in colour.[121]

Table 5 Managing basal rot of narcissus - without formalin

Tips for good basal rot management
Leave at least eight years between growing narcissus in the same field. A long rotation helps to reduce the amount of basal rot fungus in the soil.
Avoid sites and situations that expose bulbs to high temperatures in the soil. The optimal temperature range for growth of the basal rot fungus is 20 to 30°C. Relatively deep planting helps to keep bulbs cool in summer.
Whenever practical, grow narcissus for no longer than two-years-down. However, it is recognised that growers will often wish to plant narcissus bulbs for longer – try not to exceed three-years-down.
If practical, use a lower planting density to reduce bulb-to-bulb transfer of the basal rot pathogen in the soil.
Clean bulb equipment, stores, etc., thoroughly with a suitable farm disinfectant before use.
Lift bulbs early in order to minimise the time they spend in warm soil. Take steps to keep bulb damage to a minimum during lifting and handling.
Maintain air circulation around the bulbs at all times. Do not park bulb containers in direct sunlight.
Spray bulbs of basal rot-susceptible cultivars with a fungicide on the same day as lifting. A variety of spray applicators and conveyors or roller tables can be used, arranged to maximise coverage. For conventional hydraulic sprayers, use 1L Storite Clear Liquid + 4L water for each tonne of bulbs treated. For ultra-low volume application with suitable equipment, use 1L Storite Clear Liquid (undiluted) for each tonne of bulbs. (These treatments may not be used in the Isles of Scilly.) Until there is a replacement for formalin, bulbs should not be 'cold dipped' (as an alternative to applying fungicide by spray) because of the likelihood of spreading pests and diseases if no disinfectant is present.
Dry bulbs promptly and at suitable temperatures, either at 17°C for as long as required, or at 35°C for three days followed by rapid cooling and continued drying at 17°C. The aim is to achieve 'first-stage bulb drying' (surface-drying), including the necks and basal plates quickly; this will reduce the spread and growth of the basal rot fungus. Where 17 or 35°C drying is not available, make every effort to keep the bulbs at temperatures below 18°C, by ventilation and shading.
During bulb drying and storage, use the recommended airflows, air exchange rates and humidity. Temperatures should be checked inside the mass of bulbs, as these may be warmer than the ambient air in the store.
Store bulbs at 17°C, this will also have a major effect in reducing basal rot. (Storage at lower temperatures may delay plant development.)
It is likely that many infected bulbs are re-planted, so it is important to inspect bulbs thoroughly at every opportunity. Any bulbs that look or feel soft or lightweight, or are damaged, should be removed and destroyed.
When planning HWT: • When there is any doubt that a bulb stock is free of stem nematode bulbs should not be 'pre-soaked' (cold dipped prior to HWT to re-activate nematode wool) because of the likelihood of spreading pests and diseases in the absence of a disinfectant. This also means that neither 'pre-warming' (say for 1 week at 30°C) nor a higher-than-usual HWT temperature should be used, as these procedures depend on pre-soaking. • Only stocks known to be free of stem nematode should be pre-warmed at 30°C (and should then be pre-soaked and treated at the higher HWT temperature of 46°C). • However, bulbs could still be 'partially pre-warmed' (i.e. stored at 18°C for two weeks before HWT) as this does not require pre-soaking; following 18°C storage HWT is at the usual temperature of 44.4°C. This will still give protection from HWT damage (including late HWT).
Apply HWT to bulbs using the current treatment of 44.4°C for three hours (timed from when the dip temperature regains the target temperature after immersing the bulbs). At present it is not usual to vary the duration of HWT to account for the size of bulbs being treated. HWT is normally applied between mid-July and mid-August, but earlier treatment is more effective at controlling pests and diseases, though at the expense of incurring some foliage and flower damage in the next spring (no damage will be seen after the first year).
For basal rot susceptible varieties, 1.25 L of 'Storite Clear Liquid' should be added per 1,000 L water in the tank; note that this material may only be used once per year, so a post-lifting treatment and treatment in HWT cannot both be used in one year (see the EAMU; this treatment may not be used in the Isles of Scilly). If required, sodium bisulphate can be added to the tank, at the recommended rate, to acidify the dip and increase the availability of the fungicide. Alternatively, use a chlorothalonil-based fungicide such as 'Bravo 500' at a maximum rate of 1 L product/1,000 L water in the tank. In cases where large narcissus fly is a problem, a chlorpyrifos product ('Pyrinex 48 EC', 'Cyren' or 'Alpha Chlorpyrifos 48 EC') at a rate of 5 L product/1,000 L of water in the tank (see the EAMUs). An approved non-ionic wetter should be added to the tank in accordance with its manufacturer's recommendations, provided this is not deemed incompatible with other chemicals being added. An anti-foam agent may be added if the system tends to produce foam.

Table 5 Managing basal rot of narcissus - without formalin continued

Tips for good basal rot management
Between HWT, top-up tanks according to the manufacturer's recommendations, or, if not specified, top-up at the same rate as used originally. Dips can be topped-up and re-used many times before disposal, but ensure there is not an excessive build-up of soil and debris.
Immediately after HWT, quickly cool, dry and ventilate the bulbs under powerful fans, and then either re-plant promptly or following storage at 17°C. Consider planting in September, when the soil will be cooling down.
Consider a programme to replace basal rot-susceptible varieties by relatively basal rot-resistant varieties (such as some of the 'Rosewarne' varieties).

17 *Fusarium* neck rot

Photo: Warwick HRI and predecessors

18 Penicillium bulb rot in the neck (top) and affecting whole bulb (bottom)

Photo: Warwick HRI and predecessors

In HDC Project BOF 31b, only a low incidence of neck rot could be induced by inoculating defoliated, damaged shoots with high concentrations of spore and mycelial suspensions of *F. oxysporum* f.sp. *narcissi*, *B. narcissicola* or *P. hirsutum*; *Fusarium* was the most effective of the three.[122] Important controls include not flailing off leaves too early or too deeply prior to lifting,[123] and following the procedures used to control basal rot, such as correct HWT and drying. HDC Project BOF 28 was a study by ADAS of the incidence of these three pathogens in neck and basal rot tissue.[32,33] *F. oxysporum* f.sp. *narcissi*, *B. narcissicola* and *P. hirsutum* were found in 51, 76 and 92%, respectively, of a total of 101 bulb stocks sampled. Through a questionnaire, cultural factors that may have favoured the incidence of these rots were examined, and a summary of the findings is given in Table 6. Not all these findings were easily explainable.

- *Fusarium*, but not *Botrytis* or *Penicillium*, was a stock problem.
- *Fusarium* was more likely to occur on heavy silt and peat soils.
- The lack of a correlation between *Fusarium* and nitrogen fertilisation contradicted the findings of several experiments.
- Foliar fungicides were ineffective in controlling *Fusarium*, but dicarboximide fungicides controlled *Botrytis.*
- The ineffectiveness of either a post-lifting fungicide application, or using an MBC fungicide in HWT, in controlling *Fusarium* contradicted the findings of other trials.
- The lack of an association between height of top-bashing and the occurrence of the neck rot pathogen also contradicted the findings of other research.

Table 6 The effect of cultural factors on the incidence of neck rot in bulbs affected by three pathogens

Factor	*F. oxysporum* f.sp. *narcissi*	*B. narcissicola*	*P. hirsutum*
Stock problem	Yes	X	X
Soil type	More on heavy silt and on peat	X	X
Previous cropping	X	Fewer following cereals	X
Nitrogen fertiliser	X	X	Fewer following nitrogen application
Planting depth	X	X	Fewer following shallow planting
Foliar fungicides (year 1)	X	Fewer following dicarboximide	X
Foliar fungicides (year 2)	Fewer following no fungicide	Fewer following dicarboximide	X
Foliar fungicides (both years)	Fewer following no fungicide	Fewer following dicarboximide	X
Weeds	Fewer with clean crops	Fewer with weedy crops	Fewer with weedy crops
Trash in trailer	Fewer with trash	Fewer without trash	Fewer without trash
Pre-storage fungicide	Fewer without fungicide	X	X
Bruising	X	X	Fewer without bruising

There were no apparent associations between any of the following for any of the pathogens: flower picking, presence of foliar disease, ridge- or top-bashing, topping height, acid defoliation, harvester agitation (compared with picking by hand), using MBC fungicide in HWT, drying time, stack height, phosphorus or potassium fertiliser, nitrogen top-dressing or re-ridging in first or second autumn.

Grey bulb rot (*Rhizoctonia tuliparum*)

Grey bulb rot is characterised by the distal ends of leaves developing grey-brown areas in early spring, becoming crooked and withered. The disease is usually mild in narcissus, and the bulbs are not damaged.

Soft rot (*Rhizopus* species)

Soft rot affects bulbs that are stored in unsuitable conditions, usually at a relative humidity >80% and a temperature >30°C. The bulbs rot to a mushy, grey-white mass covered with coarse mycelial growth. Soft rot can occur in warm storage, in the incubation of chips, and in transit, and can be corrected – though only if early enough – by rectifying storage conditions. In propagation the temperature of chips should be maintained at 20°C or lower. *Rhizopus* species are common and it may be normally present on bulbs without causing damage, rapidly causing damage if conditions deteriorate (Image 19).

19 *Rhizopus:* bulbs with soft rot

Photo: Warwick HRI and predecessors

Penicillium rots (*Penicillium* species)

P. corymbiferum occurs on damaged tissues after lifting, for example where the outer scales are torn or where offsets have recently been removed. Aggressive strains may spread rapidly under damp conditions, causing a dark-brown rot, though often the symptoms are limited to the damaged outer bulb scale. The outer scales may show blistery markings. Grey-green mould can be found under the tunic; a 'puffer' is a completely rotted bulb under an intact skin, that, when broken, releases a cloud of spores.[124] In some cases *P. corymbiferum* has been linked with basal rot-like symptoms and has caused necrosis when inoculated to healthy bulbs.[117,125] *Penicillium* is a particular problem in propagation (chipping),[126] and the dwarf cultivars such as 'Tête-à-Tête' are prone to *Penicillium* and other fungal pathogens. Control is generally through the use of appropriate fungicides and storage conditions.[127]

Black slime (*Sclerotinia bulborum*)

Black slime has been observed only in the Netherlands and following a heavily infested crop of another host, such as hyacinth or *Muscari*. The underground parts of the leaves become soft and black, and the bulb is superficially or completely attacked, with the development of large sclerotia. Other *Sclerotinia* species have been reported on narcissus.

White root rot (*Rosellinia necatrix*)

There used to be occasional but significant outbreaks of white root rot in the Isles of Scilly, but it has not been seen for many years.[128] Affected bulbs have black, rotted outer scales and roots and white fungal strands near the base plate. Soil disinfection is the only control measure reported.[129]

Dry-scale rot (*Stromatinia gladioli*)

This is reported to cause a dry rot with sharp margins and black sclerotia. It occurs in heavy, wet soils and control is through HWT and planting on a better drained site.[130]

Honey fungus (*Armillaria mellea*)

Honey fungus can cause a bulb rot, particularly on newly cleared ground; bulbs are covered with white mould and rhizomorphs may be present.[130]

Crown rot (*Corticium rolfsii*)

Crown rot occasionally causes a rot of the outer scale of narcissus bulbs in the US Pacific Northwest. The rot is initially brown and wet, later dry and woody. The bulbs may have a white mycelial mat and small reddish-brown sclerotia.[130]

'Skin diseases'

Dutch texts refer to several conditions in which the surface of the bulb is degraded, with the skin becoming darker (*huidziek*), greasy (*vethuidigheid*), multi-layered or irregular. These conditions detract from appearance and make bulb cleaning more difficult. Dwarf cultivars such as 'Tête-à-Tête' are susceptible. The fungi associated with these conditions include: *Ophiostoma narcissi*, *Fusarium oxysporum*, *Stagonospora curtisii*, *Botrytis narcissicola* and *Phoma leveillei*. No specific advice is given in the UK, but clearly appropriate fungicide, HWT and hygiene treatments should be used.

Other fungi

Several other fungi have been recorded on narcissus, including:

- *Phytophthora megasperma* (bulb rot).
- *Pythium* species (root rots).
- 'Scale speck fungi' including *Stromatinia narcissi.*
- *Ophiostoma narcissi.*
- *Puccinia schroeteri.*
- *Puccinia narcissi.*
- *Cleosporium narcissi.*
- *Tubercinia (Urocystis) colchici*.

3.7 Fungal foliar and other diseases

The main foliar diseases of narcissus in the UK – smoulder, white mould, leaf scorch and fire – all ultimately result in early foliar die-down, so their effects may be mistaken for normal senescence and diagnosis can be difficult if left too late. Table 7 reproduces a published table of distinguishing characteristics.[131] The premature dieback of infected foliage leads to reduced bulb yields and subsequently poorer yields of flowers. Fungal foliar diseases tended to be regarded as either ubiquitous, exacting a steady but probably small effect on yield (such as with smoulder), or sporadic or local (as in the case of white mould, fire or leaf scorch). Higher standards now make even a low level of leaf disease increasingly unacceptable. In the UK, foliar diseases are exacerbated by the practice of growing narcissus two or more years-down, which allows a build-up of inoculum in the bulbs, debris or soil (hence smoulder is seldom of importance in the Netherlands, where mainly one-year-down growing is practiced).

Smoulder (*Botrytis narcissicola*, also called *Sclerotinia* or *Botryotinia narcissicola*)

Smoulder is common on narcissus wherever they are grown. Smoulder spreads through both infected bulbs and sclerotia in the soil. At or shortly after shoot emergence, infected shoots ('primaries') become evident, having become infected with the pathogen through contact with germinating sclerotia either in or on the bulb or in the soil. Infected leaf tips may be dark brown or black, with a yellowing zone below, stuck together, crooked and torn. Leaf lesions are characteristically along one side of the leaf, the death of the leaf tissue on one side of a leaf resulting in uneven growth producing a curved, sickle-like leaf. In severe cases the plants have pale, broken leaves, a dwarfed stem, and misshapen flower buds. Under damp conditions a mass of grey spores (conidia) is formed on these primaries, the spores spreading by wind and rain-splash and causing secondary leaf and flower spotting through the crop, sometimes late in the season.[132] The fungus also colonises the cut end of the stem when the flower is cropped.[133,134] Sclerotia develop on and in the bulb, over-wintering particularly on the thin, papery bulb scales in the neck of the bulb, and in leaf debris; sclerotia may also produce ascospores, but the role of these if uncertain. The bulb skins may become 'greasy' and the base plate corky, and the bulb may partly rot. The symptoms are shown in Images 20-24.

Table 7 Some distinguishing features of the four main fungal foliar diseases of narcissus

Symptom and spread	Smoulder	White mould	Leaf scorch	Fire
Leaf lesions	Some sickle-shaped, on leaf edge, brown	Usually oval, often in centre of leaf, off-white	At leaf tips, reddish	Pale brown spotting
Sclerotia	1.5 mm diameter	0.15 mm diameter	No	Up to 1.5 cm long
Pycnidia	No	No	0.2 mm diameter	No
Flower damage	Bud rot	No	Spotting	Spotting, browning and withering
Carried in or on	Bulbs, debris	Debris	Bulbs, debris	Debris

20 Bulb showing smoulder sclerotia

Photo: Warwick HRI and predecessors

21 Smoulder 'primaries'

Photo: Warwick HRI and predecessors

22 Examples of flower damage caused by smoulder

Photo: Warwick HRI and predecessors/Gordon Hanks

The development of smoulder lesions, as the leaves grow through the infected neck of the bulb, is enhanced by wet soil conditions, cold wet weather at emergence, harvest damage, and multiple-nosed bulbs.[135,136,137] In one study in Scotland with a stock with a low level of infection, smoulder incidence did not increase over four years, while where flower-heads were removed, or flowers were cropped, smoulder had increased by the third and fourth year, respectively.[133, 134] The fungus does not easily enter undamaged tissue, and infection is enhanced by damage to the leaf tissues (such as frost or hail damage or flower cropping).[132] It has been suggested that infection is linked with tissues already colonised by bulb-scale mite, while controlling *Rhizoglyphus* bulb mites did not reduce the incidence of smoulder.[136,138] This is reasonable, as bulb-scale mites can cause significant damage to the margins of the young leaves, whereas the bulb mites feed only on bulbs that are already damaged.[139]

23 Typical leaf lesions and curling leaves as a result of smoulder

Photo: Warwick HRI and predecessors/Gordon Hanks

24 Cut stems act as point of infection for smoulder

Photo: Warwick HRI and predecessors

Since *B. narcissicola* is a wound pathogen, crops should be sprayed with fungicide particularly after damage has occurred. The effect of crop damage was investigated in Scotland;[140,141] conidial infection by both *B. narcissicola* and *B. cinerea* occurred more readily later in the growing season, and infection by *B. narcissicola* was enhanced by light mechanical wounding of leaf and bulb tissues. The addition of nutrients (e.g. narcissus pollen grains) enhanced infection, particularly at higher (18°C) temperatures. In this study eight cultivars were tested for infection by the smoulder fungus, and all were susceptible, though 'Golden Harvest' was the most susceptible and 'Dutch Master' and 'Geranium' the least so. Conidial inoculations of bulb scales with either *B. narcissicola* or *B. cinerea* resulted in cell wall lignification and phytoalexin accumulation, but neither was detected at the time when *B. narcissicola* was forming spreading lesions.[142] In recent trials in Poland, three *B. narcissicola* isolates were tested on five narcissus cultivars; all isolates were pathogenic and none of the cultivars was totally resistant, though 'Dutch Master' was least susceptible and 'Ice Follies' most susceptible.[143]

Control of smoulder has been largely through a fungicide spray programme, though it is assumed that fungicide soaks and HWT aid control of fungi generally. A programme involving pre- and post-flower sprays has long been used, though with little definite knowledge of the relative benefits of particular fungicides and spray timings, a situation that has changed with a recent 'Horticulture LINK' project part funded by the HDC (Project BOF 41[132]; and HDC Projects BOF 41a[144] and 59[145]). Since the fungus persists in crop debris, re-ridging crops between growing seasons and burning debris are sensible measures but, like fungicide sprays and bulb soaks, were not always found to be effective in reducing the disease across a number of trials in the UK, nor was the repeated removal of disease primaries.[135,146,147,148] Where any fungal foliar disease is a concern, new plantings should not be situated close to existing plantings, so that the spread of infection from the older to the new plantings is not facilitated. Other cultural controls include rotation, early bulb lifting, avoiding low, wet areas, and removing rotted bulbs and loose bulb skins.

The ubiquitous grey mould (*B. cinerea*) also occurs on narcissus, resulting in grey sporulating areas on leaf and stem bases.[140] It is not easy to distinguish *B. cinerea* from *B. narcissicola*.

White mould (*Ramularia vallisumbrosae*)

White mould is generally associated with the warmer parts of bulb-growing areas, such as South-West England, where it is associated with mild, wet springs. In some recent years, white mould has caused severe epidemics in Cornwall. It has also been recorded in the English Midlands and in Scotland, and was confirmed for the first time in eastern England in 2002.[149] It occurs occasionally elsewhere in Europe and in the USA.

White mould causes pale spots or streaks on leaves and stems, which under moist conditions develop a creamy-white spore layer; the lesions spread downwards and coalesce (Image 25). The conidia are spread by wind and rain-splash, often resulting in serious outbreaks with rapid, dieback and severe loss of bulb and flower yield. Moisture is needed for the spores to enter through the stomata; if the leaves are dry the spores are unlikely to survive for more than a few days. Many minute sclerotia are formed within the infected leaves, forming the means by which the fungus over-winters in the soil; the sclerotia germinate and produce conidia about the same time as the bulb shoots are emerging in the spring. White mould is often considered not to be carried on the bulb, though this has been debated.

As with smoulder, control of white mould is largely by using a fungicide programme throughout the growing season. A programme involving pre- and post-flower sprays has long been used, though with little definite knowledge of the relative benefits of particular fungicides and spray timings, a situation that has changed with a recent 'Horticulture LINK' project jointly funded by the HDC (Project BOF 41[132]; and HDC Projects BOF 56[150] and 56a[151]). As the white mould pathogen is carried on crop debris, hygiene is also important, ideally clearing and burning debris. Late-flowering cultivars such as 'Actaea', 'Cheerfulness' and 'Double White' are susceptible, as well as mainstream cultivars ('Dutch Master', 'Fortune' and 'Magnificence' are cited as examples).

25 White mould leaf lesions and lesions coalescing with leaf die-back

Photo Warwick HRI and predecessors

Leaf scorch (*Stagonospora curtisii*)

Leaf scorch is a widespread disease of narcissus under suitable conditions, and in the UK can be damaging in the South-West. Affected leaf tips can appear soon after emergence, with yellowish, brownish or reddish lesions, usually separated from healthy tissues by a yellowish zone (Image 26). The lesions spread downward in damp weather, producing eye-shaped spots. Further spread within the crop, optimally at 15-20°C, gives secondary infection with water-soaked spots that can turn scabby and coalesce, leading to rapid leaf dieback. All parts of the plant can be affected, so stems and flowers can be spotted, and infections can develop during cut-flower storage. The primary and secondary lesions produce minute pycnidia, which are a useful diagnostic feature that can be used to distinguish infections from that of fire. The fungus persists in the neck of the bulbs between the scales, spreading downwards, but it does not apparently cause a bulb rot. Shoots are infected as they grow out through the neck. As well as being bulb-borne, leaf scorch is also spread in leaf debris.

26 Reddish leaf-tip lesions, symptoms of leaf scorch

Photo: Warwick HRI and predecessors

In the South-West leaf scorch is common on 'Grand Soleil d'Or' and 'Magnificence', but most cultivars seem susceptible to the disease. It is reportedly more serious in poorly drained sites. Specific control of leaf scorch has been little investigated in the UK, but it is probably controlled through the fungicide spray programme and routine HWT (the formalin in the HWT tank was considered important for control).

Fire (*Sclerotinia polyblastis*, also known as *Botryotinia polyblastis*)

Fire is more prevalent under mild, humid conditions. In the UK, it occurs mainly in the far South-West, attacking tazetta cultivars and, to a lesser extent, standard cultivars such as 'Carlton' and 'Golden Harvest'. Initially affecting the flowers, fire causes water-soaked spots that turn brown and in which conidia are produced. The conidia infect the foliage, producing small, elliptical, pale brown spots, often near the leaf tips, becoming accompanied by yellow streaking distal and proximal to the lesions, with premature dieback (Image 27). The flower symptoms appear to be seen less than formerly, perhaps because flowers are now picked before the flower has opened. It has been reported that, if not controlled, fire can destroy a crop within three to six weeks. The fungus over-winters as sclerotia in soil and leaf debris, but not in bulbs; in spring, the sclerotia produce ascospores that can infect only flowers.

Good results were reported using copper fungicides on tazetta cultivar 'Grand Soleil d'Or',[152] but, since little research on specific fungicides has been done, the main control is through a standard fungicide spray programme, particularly with applications post-flowering. As debris from the flowers is a main source of infection, de-heading or flower cropping, along with general hygiene and crop rotation, are the main controls. Fire also occurs in the Netherlands and in the US Pacific Northwest. In the Netherlands topping-machines have been tested with narcissus crops;[153] their use would not be expected to be economic in the UK.

27 Leaf lesions as a result of fire

Photo: CSL Crown Copyright

Rust (*Aecidium narcissi*)

Aecidium narcissi is a parasite of the grass *Phlaris arundinacea*, sometimes used as a covering crop in the Netherlands.[154] It can result in abundant, typical rust pustules growing on senescing leaves, but does not attack the bulbs and is not transmitted in them. Other rust species have been recorded on narcissus. These true rust infections should not be confused with 'physiological rust'.

Other foliar fungi

Other fungi have been reported as occurring on narcissus foliage, including a smut (*Urocystis colchici)* and a leaf spot *(Phyllosticta* species).

3.8 Viruses, bacteria and mycoplasmas

For narcissus viruses, the main source of information is the 1995 review by Alan Brunt.[155]

Virus diseases

Most narcissus stocks are infested with viruses, and while their effects are usually much less dramatic than those of stem nematode or basal rot, they should not be under-estimated. As well as detracting from the appearance of foliage and flowers, virus infection leads to serious loss of vigour – it has been estimated that virus infection might decrease bulb yields by up to two-thirds.[156] In stocks seriously infected with narcissus yellow stripe virus (NYSV) and narcissus white (or silver) streak virus (NWSV), yields were reduced by between 10 and 35%.[157]

As at 1995, some 21 viruses were known to infect narcissus, although some had a restricted geographic spread or had only minor effects (Table 8).[131] About 13 of these are probably of significant economic importance, of which the aphid-borne NYSV, narcissus late seasons yellows virus (NLSYV) and NWSV are most important, leading to rapid, early leaf senescence and yield reductions (Images 28 and 29). NYSV symptoms may be confused with those of HWT damage, bulb-scale mite feeding marks, and stem nematode damage. Some narcissus viruses have a wide host range, while others are specific to narcissus and perhaps some other bulbs. Most have aphid or nematode vectors, although for some the vector is not known or mechanical transmission has been demonstrated. Some additional viruses of narcissus have been reported since 1995, for example lily mottle virus,[158] but the significance or otherwise of these awaits expert review.

The spread of aphid-transmitted viruses is slow and local, typical of the 'non-persistent' transmission where aphids do not colonise the crop but spread virus when carrying out exploratory probing.[159] Since the most important narcissus viruses are aphid-borne, applying foliar insecticides and the early lifting of bulbs are important management techniques.

The aphid and nematode borne viruses are considered unlikely to be spread by bulb-to-bulb contact or by alternately handling healthy and infected plants, but a very low level of NYSV transmission was reported from experiments under glass.[160] However, narcissus mosaic virus (NMV), which is neither aphid nor nematode transmitted, is easily spread by the mechanical inoculation of sap.[161] For narcissus tip necrosis virus (NTNV) no evidence for spread by mechanical means, such as handling and flower cropping, has been shown,[162] but it appeared likely that NMV could be spread by flailing at least at some stages of the crop.[163] The ring-spot viruses are seed borne, but none of the other narcissus viruses are seed or pollen borne.

Cultivars originating from *N. tazetta* are susceptible to viruses and those from *N. pseudonarcissus* relatively resistant, with *N. jonquilla* having an intermediate rating.[164] Dwarf cultivars such as 'Tête-à-Tête' are susceptible to viruses, especially tobacco rattle virus. Wild *N. pseudonarcissus* appears relatively immune.[165]

Table 8 Viruses reported for narcissus in 1995, with the more significant viruses highlighted in bold

Virus and abbreviation	Occurrence (on narcissus)	Vector (if known)	Symptoms (on narcissus)
Arabis mosaic (AMV)	Common in NW Europe	Nematodes	Symptomless (on its own)
Broadbean wilt (BBWV)	Tazetta in Japan	Aphids	-
Carnation latent (CarLV)	Israel	Aphids	-
Cucumber mosaic (CMV)	Tazetta cultivars usually; wide host range	Aphids	Occurs with other viruses, symptomless or mosaic
Narcissus degeneration (NDV)	Tazetta cultivars	Aphids	Chlorotic leaf stripes, chlorosis, decline, potentially serious
Narcissus late season yellows (jonquil mild mosaic) (NLSYV)	Common, widespread, jonquils	Aphids	Mild chlorotic streaking or mosaic late in season. May be responsible for white/silver streaks attributed to NWSV
Narcissus latent (NLV)	Widespread narcissus, other bulbs	Aphids	Symptomless or mild chlorosis alone, exacerbates effects of other viruses when together
Narcissus mosaic (NMV)	Widespread	Not known (mechanical)	Mild mosaic leaf symptoms or dark brown oval spots, late season
Narcissus tip necrosis (NTNV)	Widespread	Not known (mechanical)	Symptomless; or late-season leaf tip chlorosis leading to leaf senescence
Narcissus Q (NVQ)	-	Not known	-
Narcissus white (or silver) streak (or white stripe or silver leaf) (NWSV)	Widespread	Aphids	When >18°C (high temperature and light intensity), green to purple leaf streaks, later white, yellowish or grey streaks, coalescing; rapid premature senescence, seriously reduced yield
Narcissus yellow stripe (or grey disease or mosaic) (NYSV)	Ubiquitous	Aphids	Plant stunted, distorted green, grey or yellowish leaf streaks or mottling early in season, flower breaking, rapid premature senescence, seriously reduced yield
Onion yellow dwarf (OYDV)	USA	Aphids	-
Raspberry ringspot (RRSV)	Scotland	Nematodes	-
Strawberry latent ringspot (SLRV)	Common in NW Europe	Nematodes	Symptomless (on its own)
Tobacco necrosis (TNV)	-	Fungus	-
Tobacco rattle (TRV)	Widespread; especially 'Golden Harvest' and 'Carlton'	Nematodes	Symptomless; or yellow streaks in leaf bases, leaf distortion, mild flower breaking
Tobacco ringspot (TobRSV)	Netherlands	Nematodes	Inconspicuous; or twisting, pale chlorosis of leaf centres
Tomato black ringspot (TBRSV)	Common in NW Europe	Nematodes	Symptomless (on its own)
Tomato ringspot (TomRSV)	Japan	Nematodes	Mild mosaic leaf symptoms
Tomato spotted wilt (TSWV)	-	Thrips	-

28 Yellow stripe virus

Photo: Gordon Hank

29 White streak virus

Photo: Warwick HRI and predecessors

Current crop production protocols mitigate against an intensive antifeedant insecticide programme being applied, except perhaps in some specific instances, and there have been some adverse effects of mineral oil sprays. A control programme for viruses should include roguing and the selection of healthy stocks and non-susceptible cultivars, and, where appropriate, isolation, soil sterilisation and (in some cases) taking sensible precautions to avoid possible sap transmission. Plants with NYSV should be rogued before flowering, whereas those with NWSV should be rogued after flowering. There are limited options for replacing standard commercial bulb stocks by virus tested stocks, although virus tested stocks have been successfully bulked in a programme in Scotland.

Bacterial diseases

Bacterial diseases are not normally associated with narcissus. However, rots due to *Pectbacterium carotovorum* (formerly called *Erwinia*) have occasionally been seen in bulbs of tazetta cultivars 'Paper White' and 'Grand Soleil d'Or' from the Isles of Scilly. Infection can result in complete destruction of the bulbs into a stinking black mass.[166] No specific control is available, so management depends on visual inspection and sorting of planting and saleable bulbs.

A bacterial streak caused by a *Pseudomonas* species has been reported in the Pacific Northwest.[167] In the field, stems collapse from their base. A vascular discolouration can be seen in infected bulb tissues. With stored cut-flowers, though not normally if they have been correctly cold-stored, a dark, soft decay of the stem begins near the rubber band holding the bunch. Dipping in an antibiotic solution, or storage at low temperatures (2°C), can control it.

Mycoplasma-like organisms

A mycoplasma-like organism has been reported in unhealthy narcissus plants, but there is no information as to the wider significance of this discovery.[168]

3.9 Disorders

Narcissus crops may be affected by a number of physiological disorders. These are often due to damage from weather (frost, waterlogging and sun scorch), chemicals (herbicides, and formerly formalin), HWT or mechanical damage. The disorders 'chocolate spot', 'physiological rust', 'soft rot', 'root rot' and 'physiological neck rot' may have the appearance of fungal diseases, but no pathogen has been isolated from their lesions. Many of the damage symptoms might be difficult to distinguish from basal rot, but only the latter will show a white/pink mycelium. There are also numerous disorders of flower development.

Frost damage

A variety of symptoms can occur:

- Soil temperatures below –2°C persisting for several days result in stunted plants, leaves with yellowish roughened areas, flattened, cavitated and brittle stems, and the base plate becoming grey and glassy. With severe damage, plants may not emerge at all, may die prematurely, or fail to open properly.
- In a very cold winter frost 'heave' may occur, damaging the root system.
- Shoots are susceptible to hard frosts. Recently emerged leaves freeze first, bend and wilt, and flower buds may develop blisters and fail to open properly.
- Less severe frost damage can result in chlorotic bands across the leaves, with horizontal bands in periods of rapid and slow growth (Image 30).
- Late frosts can cause fully grown flowers and leaves to collapse, but these recover as temperatures rise with no adverse effects

A wide range of symptoms was noted on Cornish narcissus following sudden, severe cold weather, with many mainstream cultivars being damaged in addition to the more tender tazettas.[169] Damage ranged from the loss of whole plants (with a 'burnt' appearance), to the more usual damage to leaf tips, also including weak stems, rusty-speckled stem bases, failure to 'goose-neck', petals failing to burst from the spathe ('ballooning'), flowers remaining constricted after release from the spathe, small or distorted perianth segments, and fatally weakened leaves.

30 Frost damage on leaf tips

Photo: Warwick HRI and predecessors

Waterlogging

In waterlogged areas narcissus may grow slowly, producing irregular yellowish spots or yellowish transverse bands on their leaves. More severely damaged plants show weak development, with non-emerging flowers, withered leaf tips, rotting roots and damaged base plates. A frozen layer of sub-soil can result in waterlogging.

Sun scorch

Exposure of bulbs to strong sunlight can damage tissues several scales deep, turning them grey, shrivelled, hard and prone to attack by *Botrytis*. Flowers and leaves can also be damaged, even if there is no external damage, with withered perianth tips and thickened areas near the leaf tips; in extreme cases plants may be stunted and blind. Sun scorch is one danger of drying lifted bulbs naturally on the soil surface ('windrowing') before harvesting.

Herbicide injury

Damage can include flower distortion, leaf chlorosis, stunting and internal bulb damage.

Formalin damage

Where bulbs were lifted early while the roots were still active and the foliage had not senesced, and were then dipped in formalin, they sometimes developed brown corky areas around the base plate, though this was not believed to affect yields.[170] Reportedly, formalin dipping could result in damage similar to 'physiological neck rot'.[171] Using a high rate of formalin in HWT led to reduced flower numbers, deformed flowers and corky base plates.[172, 173]

HWT damage

HWT can cause mild crop damage (such as leaf tip mottling) even under normal circumstances, and more severe damage if recommendations are not followed. Types of damage include small flowers, perianth and corona damage, dead flower buds, blind plants, leaf distortion, and base plate and root damage.

Mechanical damage – bulbs

Impact injuries to bulbs during handling are common, especially immediately after harvesting, and can cause bruising several scales deep, producing discolouring under the tunic. Drop tests have been carried out, and showed that bruising increased markedly with drops over 25 cm, was greater when followed by ambient storage than when stored at 17°C, and increased when the damage was done later after lifting.[174] Affected areas are not usually attacked by fungi, though severely bruised bulbs can be affected by *Rhizopus* soft-rot, especially if dried at high temperatures.

Mechanical damage – foliage and flowers

Narcissus shoots may sustain a variety of mechanical damage symptoms as a result of growth through the soil as well as weather and predator effects, and many leaf lesions may look initially like lesions due to pests or disease (Image 31 and 32). Occasionally leaf damage resembling tearing may be seen in forced crops; when forced narcissus were cooled for forcing by standing outdoors covered in a layer of straw – later removed using a fork – such damage was called 'fork damage'. Similar damage is still occasionally seen, presumably, now, having another cause.

31 'Fork damage' in forced bulbs

Photo: Warwick HRI and predecessors

32 A common but unexplained disorder – leaf protuberances

Photo: Warwick HRI and predecessors

Grassiness

Also known as horses' teeth or crowns, this occurs in bulbs where apical dominance has been lost and many offsets are produced, giving a 'grassy' plant with many small leaves, usually no flower, and producing many small bulbs (Image 33). This may be due to damage to the growing point by large narcissus fly, bulb-scale mite, HWT or viruses. No pathological cause has been identified, but persistence of the condition for many years has been reported.[171]

33 'Horse's teeth', a very multi-nosed bulb

Photo: Warwick HRI and predecessors

Chocolate spot

This condition is unrelated to 'chocolate spot' of beans. Narcissus leaves develop elongated spots the colour of dark chocolate (Image 34), from which no pathogen has been isolated.[175] It has been suggested that the condition results from rising ambient temperatures or other environmental conditions. It is seen in many cultivars in the field, and especially in 'Dutch Master' and 'Mount Hood', but does not appear to occur in forced crops.[171] In a project investigating the cause of 'physiological rust' (see below), chocolate spot was incidentally observed in five of the cultivars being used; its symptoms were more common in cool and intermediate temperature regimes, but were unrelated to soil moisture levels.[176]

34 Chocolate spot lesions

Photo: Warwick HRI and predecessors

'Physiological rust'

Lesions resembling rust marks along leaves and stems used to be reported occasionally but have become widespread and more severe in UK field-grown crops since the 1980s (Image 35); the results of a 2002-2003 survey of 'rust' by the HDC have been summarised.[176] In a significant number of cases the flowers are affected seriously enough for the crop to be downgraded or even made unfit for sale. Many cultivars are affected and the disorder appears in both the East and South-West and in first- and subsequent-year crops. It occurs in field crops but not, apparently, in forced crops.[171] No pathogen is known to have been isolated from these lesions, and no definite cause has been described. Impaired water relations and boron deficiency have been suggested as causes, but without any confirmation at this time.

35 'Physiological rust', typical lesions on leaves and stems

Photo: Gordon Hanks

In HDC Project BOF 62 the hypothesis that 'physiological rust' (and perhaps some other related conditions) was due to impaired water relations was investigated at Wellesbourne. Bulbs of six cultivars were grown in a wide range of temperature and soil moisture regimes in a Wellesbourne 'thermo-gradient tunnel'. However, despite a wide range of conditions being tested, it proved impossible to simulate conditions that led to the appearance of the 'rust' symptoms.[176] This suggested that impaired water relations were probably not the cause of the disorder.

Soft rot

Where large quantities of freshly lifted or hot-water treated bulbs are stored in poorly ventilated conditions, much heat and water are produced, conditions ideal for composting (fresh bulbs produce some 280 J/sec/t from respiration).[177] Fungi are found on the tissues but the condition is thought to be non-pathological.

Root rot

Some root rots do not have a known cause. Roots may become glassy and brown and rot from the tip, the plant wilting and having poor growth and skin diseases.

Physiological neck rot

This 'disorder' is simply the natural presence of dead bases of leaves persisting in the bulb neck. It may be confused, on a quick examination, with pathological neck rot, but is non-spreading.

Malformed perianth segments

Some cultivars, especially 'Carlton', are prone to produce perianth segments with notched margins, sometimes a quality problem in forced crops. In the field it could be confused with HWT damage.

Bullhead

In this condition up to 10% of the flowers may fail to emerge from the spathe, which remains dry and membranous.[177] Single-flowered blooms of the double cultivar 'Cheerfulness' are often affected, with extra perianth segments (often green in colour), dissected corona and petaloid styles fused with the corona, poor ovary development and non-elongating stem. Marked plants produce bullhead flowers the next year.

Flower bud death

The bud may die and remain within a dry spathe, resembling a drumstick (Image 36).

36 Dead buds ('drumsticks') in forced bulbs

Photo: Warwick HRI and predecessors

The disorder is common in *N. poeticus* 'Flore Pleno', where it occurs most on warmer slopes and when there are temperature extremes, hot dry growing seasons and wet autumns. It may be related to poor rooting and adverse water relations, though irrigation, mulching and shading treatments failed to prevent it in trials.[177,178] It is common in the double cultivars 'Golden Ducat' and 'Texas', occurs especially in 'Golden Ducat' when forced, and occurs occasionally in single cultivars. From HDC Project BOF 27 flower bud death in several glasshouse-forced double cultivars appeared to result from a failure to take up sufficient water for the large growing bud.[179]

'Melting'

A flower defect of tazetta narcissus in the South-West, locally called 'melting', 'nubbles' or 'heating damage' (the last because of its similarity to some types of HWT damage) is reported to have been increasing in incidence over the last 30 years.[180] Most commonly, the terminal florets emerge from the sheath reduced or distorted, with perianth, corona and stamens ragged, shortened or absent; in severe cases these florets may fail to emerge from the sheath. 'Grand Soleil d'Or' and 'Avalanche' are most affected, while 'Paper White' is usually trouble-free. The disorder did not appear to be related to bulb storage temperatures, but, on the basis of limited evidence, may be corrected by application of boron.

Reversion

Reversion of double flowers to single ones occurs particularly in *N. poeticus* 'Flore Pleno'[177] and also in 'Ice King', 'Dick Wilden' and 'Planet' (which are double sports of 'Ice Follies', 'Carlton' and 'Golden Harvest', respectively).[171]

Fasciation

Fasciation – a 'doubling-up' of the stem and sometimes flower-heads – is seldom severe in narcissus, but has been reported in a few percent of a stock.[177]

Lodging

Under some conditions the shoots of forced crops (such as 'Quinirus') are liable to fall over.[171] Visually serious, but temporary, wilting of narcissus plants grown under protection can occur in bright morning sunshine following a cool night.[181]

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4.0 Cultivar selection and the acquisition of stocks

4.1 Cultivar selection

The exact choice of cultivar will depend on the requirements of the specific enterprise, for example:

- Will bulb or flower yield be more important, or both?
- Will bulbs be produced for growing-on and/or for wholesale or retail sale?
- Will flowers be sold over a long season, including early and late flowers?
- Will bulbs or flowers to be sold adhere to the specification of the customer? Multiple retailers or exports to the North American market for example can have different requirements to other UK or EU sales?
- Will the business supply 'bulk standard' bulbs and flowers, or more specialist or niche-market produce?
- Will any special characteristics be needed (e.g. early- or late-season flowering, scent, disease-resistance, good vase-life, high visual quality for pre-packs, or suitability for forcing or pot-plant production)?

How many cultivars?

About 27,000 narcissus of garden origin are listed in *The International Daffodil Register and Classified List 2008.*[17] However, it has been estimated[18] that only 5% of listed cultivars are "widely grown" and only 1.5% "extensively cultivated", percentages which would today equate to about 1350 and 450 cultivars, respectively. BKD statistics for 2008-2009[19] listed 423 named cultivars as being grown commercially in the Netherlands (excluding cultivars grown by a single grower), which corresponds closely with the estimate just quoted.

Popular cultivars in the UK

In the UK 'King Alfred' is well fixed in popular memory, but it was supplanted many years ago by 'Carlton' and 'Golden Harvest' which gave higher yields, stronger flowers and were much less prone to virus (Image 37). Despite their susceptibility to basal rot, and the fact that they have been known since at least the 1920s, these two cultivars made up 50 to 60% of the narcissus grown in the UK until the 1990s.[20] When effective management of basal rot can be achieved, they are ideal commercial cultivars, archetypal 1Y-Y (yellow trumpet) or 2Y-Y (yellow large-cup) cultivars with large bright flowers and high yields. The unremitting problems with basal rot, however, combined with pressures to reduce fungicide use, subsequently led many growers to reduce their areas of these cultivars, so that by 2005 their contribution had dropped to an estimated 30%.[4]

The reason for the popularity of 'Carlton' and 'Golden Harvest' was, and is, regarded by many traders as the perceived near-universal demand by customers for large, yellow narcissus, and so there has been intense interest among UK growers in programmes to breed 'Carlton' and 'Golden Harvest' like replacements with resistance to basal rot. Contrariwise, customers are often intrigued and impressed when shown a range of cultivars of different colour combinations and flower forms, and the more unusual cultivars are important in niche marketing and mail-order sales. Generally, however, UK growers have concentrated on producing a relatively restricted range of large yellow cultivars for bulk markets, robust and easy to handle, whereas Dutch growers produce a wider range including many choice, more expensive, cultivars. Dutch statistics may indicate the development of more discerning consumer tastes, and a study of these listings can indicate cultivars with potential for greater commercialisation. To understand the overall cultivar trends in narcissus growing it is important to consider Dutch and UK production together, because of the way that the two industries have assumed different roles.

37 Side-view of flower of 'Golden Harvest' and 'Carlton'

Photo: Warwick HRI and predecessors

Cultivar trends in the UK

In the UK, the lack of detailed statistics makes it impossible to be precise about the cultivars grown and their relative areas and popularity. However, as an example, some data from a major UK bulb trader are shown in Table 9.[21] The main findings were as follows.

- Perhaps surprisingly, the most bought-in cultivar in both years was 'Carlton', which formed 24 to 25% of the total intake in both years.
- Three other cultivars occurred in the 'top ten' at each end of this period – 'Ice Follies', 'Golden Ducat' and 'Golden Harvest'.
- Perhaps the greatest change over time was the reduction in the intake of 'Golden Harvest', from 24% in 1982 to only 3% by 2009.
- The 'top ten' cultivars made up 73% of the total intake in 1982, but only 56% in 2009.
- The reduction in the contribution of 'Golden Harvest' was countered to some extent by small increases in the intake of many of the minor contributors, and a small increase in the number of different cultivars being bought-in: 77 in 1982 and 83 in 2009.

While these figures may represent just a 'snapshot' of the trends occurring in one business, most of the main conclusions would seem to fit general impressions within the UK industry. However, despite the strong preference for yellow varieties, two cultivars with white flowers – 'Mount Hood' and 'Ice Follies' – appeared to remain popular in 2009; the rest of the top ten were all-yellows. In contrast, in 1982, four of the top ten had white or partly white flowers, and four varieties with orange and red elements were listed.

In Table 10 the same data have been classified by flower type and colour.[5] The percentage of intake (by weight) of all-yellow trumpet and large-cup varieties had increased from 58% in 1982 to 67% in 2009.

Table 9 The 'top ten' cultivars bought in as dry bulbs by a major UK merchant in 1982 and 2009 (cultivars in the 'top ten' in both years highlighted in bold)

1982 intake		2009 intake	
Cultivar	**% of intake (by weight)**	**Cultivar**	**% of intake (by weight)**
'Carlton'	24.7	**'Carlton'**	24.0
'Golden Harvest'	23.5	'California'	9.0
'Fortune'	6.6	'Dellan'	3.8
'Ice Follies'	4.4	'Mount Hood'	3.4
'Golden Ducat'	2.8	**'Ice Follies'**	2.8
'Verger'	2.4	**'Golden Harvest'**	2.8
'Unsurpassable'	2.3	'Tamara'	2.8
'Yellow Cheerfulness'	2.2	Mixed stock	2.7
'Cheerfulness'	2.1	**'Golden Ducat'**	2.6
'Sempre Avanti'	1.9	'Dutch Master'	2.4
Total of the 10	72.9	Total of the 10	56.4
Total number of cultivars in all	77	Total number of cultivars in all	83

Table 10 Cultivars bought in as dry bulbs by a major UK merchant in 1982 and 2009, classified by flower type and colour

1982 intake			2009 intake		
Flower type and colour code	**% of intake (by weight)**	**Total number of cultivars**	**Flower type and colour code**	**% of intake (by weight)**	**Total number of cultivars**
1 or 2 Y-Y	58.2	21	1 or 2 Y-Y	66.8	30
1 or 2 Y-O or Y-R	12.2	16	1 or 2 W-W	6.3	3
1 or 2 W-O or W-R	8.2	15	4 (double) Y	5.8	9
1 or 2 W-W	8.2	10	1 or 2 W-O or W-R	4.9	6
4 (double) Y	7.3	5	1 or 2 Y-O or Y-R	4.4	8
4 (double) W	3.0	6	4 (double) W	3.4	5
8 (tazetta)	1.8	4	Mixed stocks	2.7	1
Mixed stocks	1.2	1	8 (tazetta)	2.4	11
1 or 2 W-P	<1	3	1 or 2 W-P	1.8	6
Miscellaneous	<1	0	Miscellaneous	<1	1
4 (double) P	<1	0	11 (split corona)	<1	1
11 (split corona)	<1	0	4 (double) P	<0.1	1

In 1982 a MAFF publication[22] illustrated 32 "major and minor commercial varieties and promising new varieties", but many of them are now little grown, having been superseded by better cultivars, having become in less demand as fewer bulbs are forced, or having disease susceptibility or other specific faults. Table 11 (pages 56-58) gives further information on these 32 cultivars, supplemented with other cultivars that have become significant since the early 1980s[4] and with some additional information from *The International Daffodil Register and Classified List 2008*.[17]

Cultivar trends in the Netherlands

Only in the Netherlands are detailed statistics available for the area of each cultivar grown. Table 12 shows the 'top-ten' Dutch-grown cultivars for 2008-2009.[19] Of the 423 cultivars listed as occupying a total of 1561ha:

- One cultivar, 'Tête-à-Tête', makes up 38% of the total, and the 'top-10' together make up 61%. The widespread growing of 'Tête-à-Tête', a scented 'cyclataz' (N. cyclamineus x 'Soleil d'Or' cultivar) important in pot-plant production and for garden use, has given a new face to narcissus growing in the Netherlands since the 1990s.
- The other nine top cultivars include a mixture of trumpet ('Dutch Master' and 'Standard Value'), large-cup ('Carlton' and 'Ice Follies') and large double narcissus ('Bridal Crown', 'Dick Wilden' and 'Tahiti'), as well as the dwarf cultivars 'Jetfire' and 'Minnow'.

Table 12 Areas of the 'Top-10' cultivars grown in the Netherlands in 2008-2009

Cultivar	Classification	Area (ha)
'Tête-à-Tête'	12Y-Y	592
'Carlton'	2Y-Y	59
'Dutch Master'	1Y-Y	55
'Bridal Crown'	4W-Y	50
'Jetfire'	6Y-O	47
'Ice Follies'	2W-W	45
'Minnow'	8Y-Y	39
'Dick Wilden'	4Y-Y	32
'Standard Value'	1Y-Y	19
'Tahiti'	4Y-O	17
Total	-	955

Table 13 shows the changes between 1990 and 2008 in the types of narcissus grown in the Netherlands.[19,23] The main features were:

- The total area of cyclamineus cultivars grown increased by 2008 to 360% of the 1990 area. Most of this increase was due to 'Tête-à-Tête' ('Tête-à-Tête' is generally regarded as a cyclamineus narcissus in the Netherlands, though classified as an 'other narcissus' under the RHS scheme).
- Large increases in the areas of jonquilla (to 240% of 1990 area), triandrus (220%) and species narcissus (567%).
- Smaller increases in the areas of tazetta cultivars (to 114% of 1990 area) and poeticus cultivars (133%).
- Large declines in the areas of large-cup (to 37% of 1990 area), yellow trumpet (39%), bicolour trumpet (37%) and small-cup cultivars (41%).
- A 28% increase in the number of cultivars grown (though this figure peaked higher in the intervening years), even in some cultivar groups for which the overall area has declined (yellow trumpet, large-cup and small-cup cultivars).
- Little change (<10% of the 1990 area) in the area of other types (white trumpet, double and split-corona cultivars).

Cultivar trials

One of the most extensive narcissus cultivar trials was the MAFF-funded programme carried out at Rosewarne from 1955 to 1989, later transferred to and continued on a smaller scale at Kirton under HDC funding until 1998 (HDC Projects BOF 17 and 17a). Small plots of each variety were grown for a number of years, and emergence and flowering dates, flower and bulb yields, stem lengths, flower sizes and characteristics and vase-life were recorded. Reports were issued of the Rosewarne data for 1955 to 1963[24], 1964 to 1967[25], 1968 to 1971,[26] 1972 to 1984[27] and 1972 to 1987[28]; all the Rosewarne data, covering 1,667 separate cultivars (and other taxa), were consolidated in a report to the HDC in 1993.[29] The data from the trials at Kirton, covering 320 varieties (61 not previously tested at Rosewarne) were published as an HDC report in 1998.[30] The consolidated reports provide growers with a snapshot of the characteristics of each variety. The results of cultivar trials in other countries have been published, including Poland,[31] Germany,[32] the former Czechoslovakia[33] and the USA.[34,35]

Cultivars have also been trialled for specific purposes, often for landscaping, for example:

- In Milan, Italy, a large number of varieties of narcissus and other spring-flowering bulbs have been evaluated for co-planting with an equally wide range of herbaceous perennials, the latter to 'take over' when the bulb plants senesce, with a view to creating large (80 m^2), low-maintenance flower beds,[36] and narcissus cultivars are pictured with, for example, *Lunaria*, *Achillea*, *Viola*, *Ruscus*, *Hosta* and *Miscanthus.*
- In Osaka, Japan, a wide range of geophytes has been trialled for planting in landscaping under deciduous trees and in clearings,[37] including *N. tazetta* var. *chinensis* which was among the three best performing bulbs under trees.

Cultivar trials – dwarf varieties

The production of 'Tête-à-Tête' and other dwarf cultivars in eastern England was studied at Kirton in HDC Project BOF 23.[38] Bulbs of 28 dwarf and similar cultivars were evaluated against three stocks of 'Tête-à-Tête'. The highest bulb yields were found in 'February Gold', 'Little Beauty', 'Little Gem', 'Minnow', *Narcissus canaliculatus*, *N. obvallaris*, 'Tête-à-Tête', 'Sweetness', 'Topolino' and 'W P Milner'. Poorer yielding cultivars were 'Beryl', 'February Silver', 'Garden Princess', 'Hawera', 'Itzim', 'Jack Snipe', 'Jenny', 'Jetfire', 'Jumblie', 'Larkwhistle', 'Little Witch', 'Midget', 'Peeping Tom', 'Quince', 'Rip van Winkle', 'Rippling Waters', 'Satellite', 'Trena' and 'Winged Victory'. Many of these varieties produced attractive pot-plants, with a long shelf-life and high numbers of flower stems.

Table 11 Narcissus cultivars popular now or over the past 30 years, with the currently most widely grown cultivars highlighted in bold

Cultivar and classification		Year registered if known (or year first flowering), with parentage if known	Cropping time [a]	Flower yield [b]	Bulb yield [c]	Comments
'Actaea'	9W-YYR	Pre-1919	L	M	H	Large for poeticus cultivar. Popular in retail trade. Scented. A minor cultivar.
'Apotheose'	4Y-O	1975 ('Double Fortune' hybrid)	L	-	-	Widely grown for late-season flowering in the East.
'Banallan'	2Y-Y	1985 ('Rijnveld's Early Sensation' x 'Finland')	E	-	-	New 'Rosewarne' variety, widely grown for early-flowering in the South-West.
'Barrett Browning'	3WWY-O	Pre-1945	E	M	H	Mainly for forcing. Can be short outdoors. A minor cultivar.
'Bleasby Gorse'	1Y-Y	1983 ('Topnotcher' x 'Brabazon')	E	L	L	Good flower on good stem. Very little now grown.
'Brabazon'	1Y-Y	Pre-1950 ('Constantine' x 'King of the North')	E	M	M	Good flower though not large. Good for forcing and garden use. Little now grown.
'California'	2Y-Y	Pre-1927	M	H	H	Productive. Long-stemmed. Generally known as 'California' but considered a synonym of 'Pentewan'. Widely grown for mid-season flowering in the South-West and in the East.
'Camelot'	2Y-Y	1962 ('Kingscourt' x 'Ceylon')	L	-	-	Widely grown for late-season flowering in the East.
'Carlton'	2Y-Y	Pre-1927	M	M	H	Classic yellow trumpet, once the predominant cultivar grown in the UK. Basal rot susceptible and now being supplanted by better cultivars; little grown in the South-West and fast reducing in the East, though still making up a sizeable area. Good for forcing, but affected by reduced demand for forcing.
'Cheerfulness'	4W-Y	Pre-1923 (sport of 'Elvira')	L	M	VH	Double poetaz, scented. Formerly a major cultivar. Affected by reduced demand for forcing. Small bulbs. 'Primrose Beauty' (4Y-Y) is similar. 'Yellow Cheerfulness' (4Y-YYO) is a sport of 'Cheerfulness'.
'Court Martial'	2Y-O	1956 ('Big Game' x 'Narvik')	M	M	H	Good colour. Little now grown.
'Dellan'	2Y-Y	1989 ('Brandon' x 'Saint Keverne')	E	-	-	New 'Rosewarne cultivar', grown for early-flowering in the South-West.
'Dutch Master'	1Y-Y	Pre-1938	E	M	M	Can be earlier than 'Golden Harvest'. Formerly a major cultivar and still widely grown for early-flowering in the South-West and mid-season flowering in the East, though being replaced by better cultivars. Affected by reduced demand for forcing. Can produce short stems on exposed sites.
'Finland'	2W-Y	Pre-1940 ('Tunis' x 'St Just')	M	M	H	Good, early bicolour. Little now grown.
'Flower Drift'	4W-Y00	1966 (sport of 'Flower Record')	L	H	VH	Now very little grown. Short-stemmed outdoors. Good late forcing. Variable degree of doubling.
'Fortune'	2Y-O	Pre-1915 (possibly `M.J. Berkeley' x (`C.J. Backhouse' or 'King Alfred'); or `Sir Watkin' x `Blackwell')	E	M	M	Formerly a major cultivar. Good for forcing, but affected by reduced demand for forcing. Stem can be brittle, susceptible to weather damage.

Table 11 Narcissus cultivars popular now or over the past 30 years, with the currently most widely grown cultivars highlighted in bold continued

Cultivar and classification		Year registered if known (or year first flowering), with parentage if known	Cropping time [a]	Flower yield [b]	Bulb yield [c]	Comments
'Geranium'	8Y-O	Pre-1930 (poetaz)	L	M	M	Scented. Multi-headed. Mainly for forcing and retail. Short-stemmed outdoors. Tazetta cultivars are a niche market.
'Golden Anniversary'	2Y-Y	1997 ('Saint Keverne' x 'Malvern City')	M	-	-	CABGA cultivar. Widely grown for early-flowering in the South-West.
'Golden Ducat'	4Y-Y	Pre-1947 (sport of 'King Alfred')	L	L	L	Attractive early double. Tall and heavy-budded, requiring shelter outdoors. Widely grown for mid-season flowering in the East and late-season flowering in the South-West. Similar to 'Planet' but easier to force.
'Golden Harvest'	1Y-Y	Pre-1920 ('Golden Spur' x 'King Alfred')	E	M	M	Classic yellow trumpet, formerly a major cultivar and once one of the predominant two cultivars. Basal rot susceptible and now being supplanted by better cultivars; little grown in the South-West. Good for forcing, but affected by reduced demand for forcing.
'Hollywood'	2Y-O	Pre-1939 ('Fortune' hybrid)	E	M	M	Now very little grown. Similar to 'Fortune'. Important in South-West as it responds well to pre-cooling. Now superseded by newer yellows.
'Ice Follies'	2W-W	Pre-1953	M	H	VH	Formerly a major cultivar. Productive except on exposed sites. Forces well, but affected by reduced demand for forcing. Some still being grown despite the unpopularity of white cultivars.
'Investment'	1Y-Y	1961	E	M	M	Early. Susceptible to basal rot, little now grown. Similar to 'Dutch Master'.
'Jedna'	2Y-Y	1985 ('Forerunner' x 'Rijnveld's Early Sensation')	E	-	-	New 'Rosewarne cultivar', widely grown for early-flowering in the South-West.
'Kerensa'	1Y-Y	1989 ('Saint Keverne' x 'Malvern City')	E	-	-	New 'Rosewarne variety', widely grown for mid-season flowering in the South-West.
'Lotherio'	2Y-O	Pre-1987	L	-	-	Red-cup but acceptable at the end of the season and grown in the East. Also spelled 'Lothario'.
'Malvern City'	1Y-Y	Pre-1951	M	-	-	Widely grown for mid-season flowering in the South-West.
'Mando'	1Y-Y	1959	E	-	-	Widely grown for early-flowering in the South-West and the east. Sweetly scented.
'Mount Hood'	1W-W	Pre-1938	L	L	L	Low yield and short-stemmed. Once the main white cultivar for forcing, so now affected by reduced demand for forcing. Some still being grown despite the unpopularity of white cultivars.
'Quirinus'	2Y-O	Pre-1939	M	M	M	A minor cultivar. Mainly for mid-season forcing. Tall.
'Rembrandt'	1Y-Y	Pre-1926	L	M	M	A minor cultivar. Good for gardens. Good for late forcing. Can be short outdoors. Resembles 'King Alfred'.
'Rosenwyn'	1Y-Y	1989 ('Dominator' x 'Toorak Gold')	VE	-	-	New 'Rosewarne variety', widely grown for early-flowering in the South-West.
'Scarlett O'Hara'	2Y-R	Pre-1950	E	M	M	Superior to 'Fortune' but susceptible to basal rot, little now grown.

Table 11 Narcissus cultivars popular now or over the past 30 years, with the currently most widely grown cultivars highlighted in bold continued

Cultivar and classification		Year registered if known (or year first flowering), with parentage if known	Cropping time [a]	Flower yield [b]	Bulb yield [c]	Comments
'Silver Standard'	2W-W	Pre-1944	M	M	M	Earlier and longer than 'Ice Follies'. Stem brittle if not sheltered. Responds well to pre-cooling. White flowers less popular than yellows.
'Standard Value'	1Y-Y	Pre-1949	L	M	M	Good mid-season trumpet. In strong demand for its later flowering and widely grown in the South-West and in the East.
'Saint Keverne'	2Y-Y	1930 ('Royalist' hybrid)	M	M	M	Good flower substance and colour and stiff stem. The brown spathe makes it unattractive to flower markets. Very susceptible to virus. Once regarded as resistant to basal rot, but basal rot does occur.
'Tamara'	2Y-Y	1980 ('Trenance' x 'Rijnveld's Early Sensation')	E	M	VH	Tall and early for outdoor flower production. Basal rot resistant. The most successful of the new 'Rosewarne varieties', widely grown for early-flowering in the South-West and the east.
'Tamsyn'	1Y-Y	1980 ('Saint Keverne' x 'Joseph MacLeod')	E	L	H	Earlier than 'Golden Harvest', basal rot resistant, resembles 'Saint Keverne'. A successful new 'Rosewarne cultivar.' Well regarded in the trade, but stock exclusively held by a single grower.
'Tibet'	2W-W	Pre-1942 ('Tunis' x 'Askelon')	M	M	M	Thick stems. Good white flowers. Scented. Little grown now as whites less popular.
'Toorak Gold'	2Y-Y	1964 ('Malvern Gold' hybrid)	E	M	M	Tall, early, bright flower. Some grown, but has a small bud compared with similar cultivars. Resembles 'Malvern Gold'.
'Unsurpassable'	1Y-Y	Pre-1923	E	M	M	A minor cultivar. Large bulbs for retail trade.
'Verger'	3W-R	Pre-1930	L	M	M	A minor cultivar. Good late but small flower.
'Veryan'	1Y-Y	1989 ('Unsurpassable' x 'Malvern City')	E			New 'Rosewarne variety', widely grown for early-flowering in the South-West.
'White Lion'	4W-WYY	Pre-1949 ('Mary Copeland' x 'John Evelyn')	M	M	L	A minor cultivar. Good double but flowers in foliage. Prone to foliar diseases.

[a] For guidance only: E, early-season; M, mid-season; L, late-season.

[b] L, low (up to 2.0 flowers/bulb in second year); M, middle (2.1-2.5); H, high (2.6-3.0); VH, very high (>3.0).

[c] L, low (up to 140% weight increase in 2 years); M, middle (141-180%); H, high (181-220%); VH, very high (>220%).

Table 13 Areas of cultivar groups grown in the Netherlands in 1990-1991 and 2008-2009*

Cultivar group	1990-1991		2008-2009		Area as % of 1990-1991 area
	Area (ha)	Number of cultivars	Area (ha)	Number of cultivars	
Cyclamineus	185	25	666	22	360
Large-cup	666	107	246	126	37
Trumpet (yellow)	375	40	147	52	39
Double	189	40	207	56	110
Tazetta	58	10	66	15	114
Jonquilla	20	18	48	39	240
Triandrus	15	9	33	10	220
Split Corona	30	33	29	34	97
Trumpet (white)	27	15	10	10	37
Small-cup	34	14	14	31	41
Species	6	10	34	13	567
Trumpet (bicolour)	16	7	15	6	94
Poeticus	6	3	8	7	133
Named but unclassified	9	na	1	4	na
Others	na	na	9	na	na
Totals	1639	331	1570	423	96

* Data on cultivars grown by only one grower are excluded. Some numbers may not total due to non-classified cultivars. 2008-2009 figures provisional. 'Tête-à-Tête' is recorded as a cyclamineus narcissus in the Netherlands, though classified as an 'other narcissus' in the RHS scheme.
na not available or not applicable.

Other sources of information on cultivars

Further information on cultivars is available from a wide range of resources.

- Narcissus displays and collections in the UK include those at Springfields Festival Gardens[39] (Spalding, Lincolnshire), the RHS Wisley Garden[40] (Wisley, Woking, Surrey) and the National Daffodil Showgarden at Trevarno Country Estate Gardens[41] (Crowntown, Helston, Cornwall). The Trevano collection currently holds over 2,500 cultivars.
- UK National Collections under the aegis of Plant Heritage (formerly NCCPG) include three collections, covering Alec Gray hybrids (Broadleigh Gardens, Bishops Hull, Taunton, Somerset), Brodie cultivars (Brodie Castle, Forres, Moray) and Guy Wilson introductions (University of Ulster at Coleraine, Coleraine, Co Londonderry).[42]
- The RHS is the International Cultivar Registration Authority (ICRA) for narcissus cultivars and publishes *The International Narcissus Register and Classified List 2008*[17] and its annual supplements,[43,44] all available on-line. As the ICRA for narcissus, the RHS library (the Lindley Library) has an important collection of material on narcissus.[45]
- There is a large trials programme at RHS Wisley Garden that includes narcissus.[46]
- Much information on cultivars, especially newer cultivars, is available in the annual RHS publication currently called the *Narcissus, Snowdrop and Tulip Yearbook*.[47]
- Narcissus societies publish journals or newsletters, including The Narcissus Society [UK],[48] The South East of England Daffodil Society, The Scottish Rock Garden Club,[49] The Northern Ireland Narcissus Group,[50] The American Daffodil Society,[51] The National Narcissus Society of New Zealand,[52] The Victorian Narcissus Society[53] and The Tasmanian Narcissus Council.[54]
- 'DaffSeek', the database of the American Daffodil Society, can be freely searched on-line. Its features include an extensive photographic content and cultivar pedigrees.[55]
- Dutch collections include the historic spring-flowering bulbs of 'Hortus Bulborum' (Limmen).[56] Other Dutch gardens noted for their bulbs include CNB-Showtuin 'Hein Schrama' (Heemstede), Narcissen Showtuin K.J. van der Veek (Burgervlotbrug), and HOBAHO Keurtuin 'De Buitenhof' (Lisse).
- Dutch information on the cut-flower trade can be found in the periodical *Vakblad voor de Bloemisterij*.

Characteristics required for commercial cultivars

General characteristics

A good commercial cultivar should have many of the following characteristics:

- Large yellow flowers (except for niche markets and mail-order sales).
- Pest- and disease-resistance (see below).
- Sturdy stems and foliage, which are wind-resistant.
- Stems >30 cm in the 'pencil' stage for cut-flowers.
- High flower yields (a high flower number to bulb weight ratio is two flowers per bulb in the second year).
- A flowering season that contributes to an overall continuity programme.
- Substantial bud size and attractive buds (for cropping in pencil stage).

- A short neck in large-budded cultivars.
- A spathe that splits normally and remains green (not going brown before splitting), leaving the flower bud free to 'goose neck' and open without restriction.
- Flowering period of seven to 10 days.
- Flowers presented above the foliage.
- Flowers with the characteristic 'goose-neck' angle.
- An acceptable vase-life (see below).
- Flowers opening normally in the vase.
- Scent (but not excessive scent).
- Multi-purpose use (suitability for outdoor flowering, forcing and garden sales).
- Good bulb yields (150% yield increase after two years; that is lift two and a half times more than planted).

Characteristics required for specific markets

For selling to certain markets, some other characteristics required might include:

- For bulb forcing, the style of 'Golden Harvest' and 'Carlton', conforming to the popular image of the narcissus.
- For garden sales, a considerably greater variety of colours, forms and sizes.
- Dwarf cultivars with appealing flowers, especially 'Tête-à-Tête', are in demand for pot-plant production and for garden sales.
- An attractive skin finish is an advantage for garden centre sales.
- For pre-packs, smaller bulb sizes are preferred (though some retailers seek large bulbs because of the enhanced flower size and numbers they can give).
- For amenity and garden use abroad, the suitability of plants for different climatic zones – both cooler and warmer - may need to be considered.

Continuity of flower supply

For cut-flower production a succession of flowers is needed, which normally means growing a small selection of cultivars to cover most of the flower season.[20] With the growing of newer 'very early' cultivars largely bred at Rosewarne, the seasons have shifted earlier compared with 20 to 30 years ago, so that varieties once considered 'early' (such as 'Golden Harvest') are now considered 'mid-season'.

One challenge is having an adequate supply of cut-flowers for the late markets of Mothering Sunday and the Easter holiday, the more so as these dates are moveable. Appropriate planning is needed each year to achieve sufficient supplies on these dates: for example Mothering Sunday was 14 March in 2010 and 3 April in 2011, while Good Friday was 2 April 2010 and 22 April 2011, differences of nearly three weeks in successive years.

Climatic zones, naturalisation and longevity

For sales of bulbs to countries spanning several climatic zones, varietal differences in hardiness and longevity may need to be considered. In the USA, narcissus will generally naturalise (perennialise) in climatic zones 4 to 8 (increasing numbers indicate increasingly warmer climates), covering a large part of the continental USA, and some will naturalise in zone 9, which is generally marginal for narcissus growing.[84,85] Using appropriate bulb preparation and planting dates, narcissus can be planted for outdoor flower production across zones 4 to 9. For zone 4, narcissus can be planted in September, graduating to early-December in zone eight, and pre-cooling is not required, though it is an option in zone 8. For zone 9, bulbs should be pre-cooled (eight to 10 weeks at 5 to 7°C) and planted in early-December.

Areas of the USA generally too cold for narcissus growing (zones 1-3) are N.E Montana, most of North Dakota, north Minnesota, a pocket of Wisconsin, some inland parts of New York, Vermont, New Hampshire and Maine and small mountainous pockets of Idaho, Wyoming and Colorado.

Zone 9 includes the extreme coastal fringes of Washington, Oregon and northern California, much of southern and western California, S.W Arizona, S.E Texas, southern Louisiana, the coastal fringe of Mississippi, and northern Florida together with the adjoining parts of Georgia and South Carolina.

Areas generally too warm for narcissus growing (zone 10) comprise southern Florida and some extreme coastal fringes of southern California.

Thirty cultivars and other narcissus were trialled for performance in full sun over three years in central Florida, USA.[86] Many did not emerge or emerged but were moribund or flowered weakly. Four emerged as the most vigorous and floriferous: 'Erlicheer', 'Grand Primo', *N. intermedius* and 'Minor Monarque' (also called 'Early Pearl'). In trials of spring bulbs in Oklahoma, *narcissus* 'Music Hall' and 'Tahiti' were planted in raised field beds. The rates of naturalisation were low, and after two years, only 32 and 30% of bulbs, respectively, flowered.[87]

In Osaka, Japan, the heat hardiness of a range of geophytes, including *N. tazetta* var. *chinensis*, was evaluated for landscape planting.[88] The plants were grown for about two months in growth chambers at ambient temperatures or at ambient temperatures +5C or -5C, before being planted outside. The only adverse reaction of these tazetta narcissus was delayed sprouting with the high temperature regime.

Several countries with warm climates are becoming important producers of ornamental plants; now, with increasing living standards, some are becoming markets, not only for species native of warmer areas (such as tazetta narcissus) but also for thermo-periodic bulbs (such as other narcissus) which can be programmed to flower in warm climates even if used only as annuals.[89] The IFBC produces literature on the growing of flower-bulbs in warm regions,[90] which is also the subject of some textbooks.[91,92]

For the South-West, the following are likely to be included in programmed cropping:

- Early season: 'Tamara', 'Jedna', 'Banallan', 'Mando', 'Rosenwyn', 'Veryan', 'Dutch Master' and 'Golden Anniversary'.
- Mid-season: 'Kerensa', 'California' and 'Malvern City'.
- Late season: 'Standard Value' and 'Golden Ducat'.

For the East, the following cultivars are likely to be included:

- Early season: 'Tamsyn', 'Tamara' and 'Mando'.
- Mid-season: 'California', 'Carlton', 'Dutch Master' and 'Golden Ducat'.
- Late season: 'Apotheose', 'Lotherio' (sometimes spelled 'Lothario'), 'Camelot' and 'Standard Value'.

Vase-life

Vase-life is generally relatively longer in small-cup, cyclamineus, jonquilla, poeticus and tazetta cultivars, and shorter in trumpet cultivars. There appears to be no relationship between the 'robustness' or 'flimsiness' of the flower and its vase-life.[57] The vase-life, colour changes and other characteristics of cut narcissus have been recorded, based on studies at Rosewarne.[58]

Resistance to basal rot

'Carlton' and 'Golden Harvest' were the most popular commercial cultivars for many years, but on-going problems with basal rot and the falling number of fungicides available, meant that growers increasingly switched to cultivars less susceptible to basal rot. Oddly, 'Tête-à-Tête' achieved huge popularity despite its susceptibility to fungal and viral diseases.

Apart from basal rot, little is known about the susceptibility of cultivars to other pests and diseases, and little, if any, breeding has been carried out with that in mind. While anecdotal information may be freely given and can provide some guidance, it can be unreliable because of the range of cultivars grown and the differences between different sites in terms of in growing conditions, husbandry practices and the duration of crops.[18] Another problem has arisen as a result: 'Saint Keverne', used in breeding to confer basal rot-resistance, is susceptible to viruses (or their vectors), so some new resistant cultivars may be prone to virus.

There have been successive exercises to screen cultivars for their resistance to basal rot, providing growers and breeders with valuable guidance.[59] As no reliable laboratory screening method for basal rot-resistance has yet been discovered, it is necessary to use a field test. This may involve planting bulbs of each cultivar alongside 'Golden Harvest' bulbs that have been previously infected with authentic basal rot. Some of the results obtained at Rosewarne[43] are summarised in Table 14, where cultivars are grouped as resistant (≤5% rotted), moderately resistant (≤10% rotted), moderately susceptible (≤20% rotted) or susceptible (>20% rotted). In these examples, more than half the cultivars tested fell into the 'susceptible' group. The results in this table should be treated with caution: for example, 'Saint Keverne' is not absolutely resistant to basal rot, and in some circumstances can be affected despite its general resistance to the pathogen.

More recently, in HDC Project BOF 57, assessments of basal rot susceptibility have been made for a range of newer cultivars, including progeny from the Rosewarne/CABGA and GCRI breeding programmes. A summary of the findings (up to 2008) is given in Table 15.[60]

- A high proportion of the numbered Rosewarne/CABGA and GCRI cultivars tested fell into the 'resistant' category (<5% of bulbs with basal rot symptoms), though a few of each fell into each of the other categories.
- Of the older 'Rosewarne' cultivars tested, these were about equally split between the 'resistant' category ('Kerensa', 'Talwyn' and 'Veryan') and the 'moderately resistant' category (<10% of bulbs with basal rot symptoms) ('Jedna', 'Dellan', 'Emblyn' and 'Tamara').
- 'Moderately susceptible' and 'susceptible' categories were defined as having <20% or >20% of bulbs with basal rot symptoms, respectively.
- A comparison was made between the results of field tests carried out between 1980 and 1989, and those of 2005 to 2008: it showed a reasonable correspondence over time (Figure 9).

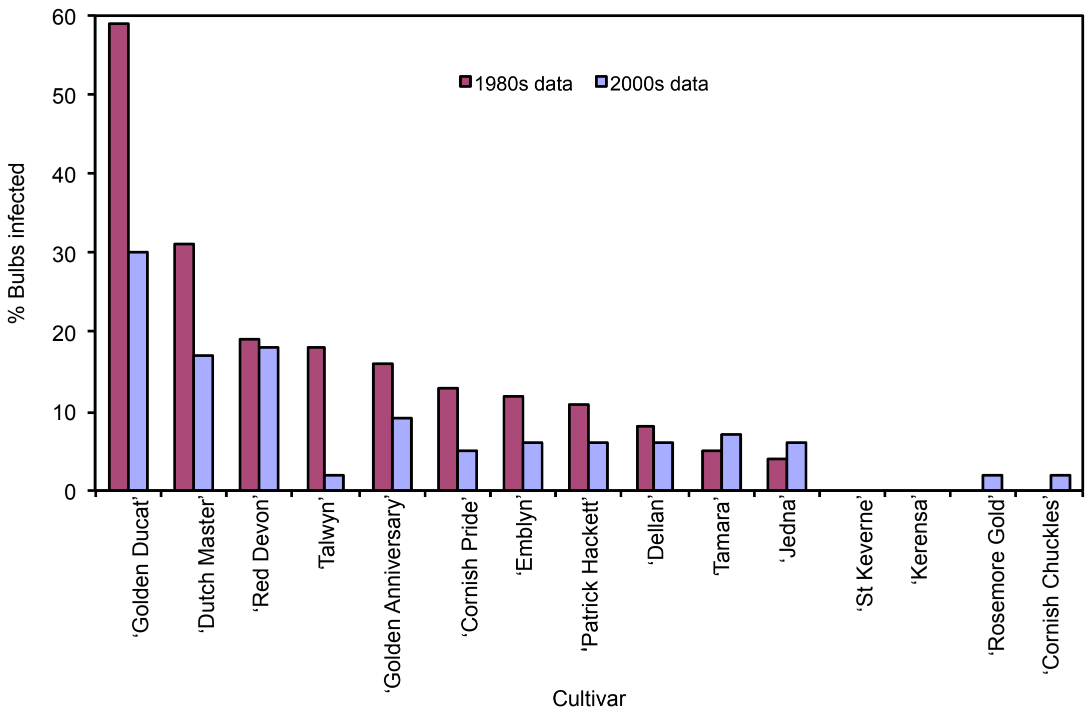
Table 14 Resistance or susceptibility of some cultivars to basal rot

Category	Cultivar	Percent with basal rot in test
Resistant	'Saint Keverne'	0
	'Ice Follies'	0
	'Dawley'	0
	'Paper White'	0
	'Dulcimer'	2
	'Silver Standard'	3
	'Grand Soleil d'Or'	4
Moderately resistant	'Lawali'	7
	'White Lion'	8
Moderately susceptible	'Forescate'	11
	'Rijnveld's Early Sensation	13
	'Malvern City'	14
	'Gaytime'	16
	'Red Devon'	19
Susceptible	'Scarlett O'Hara'	25
	'Hollywood'	30
	'Dutch Master'	31
	'Trenance'	36
	'Finland'	37
	'Toorak Gold'	40
	'King Alfred'	44
	'Divot'	59
	'Golden Ducat'	59
	'Brandon'	65
	'Nuage'	67
	'Forerunner'	81
	'Golden Harvest'	83
	'Carlton'	85
	'Moonstruck'	100

Table 15 Results of basal rot resistance/susceptibility testing of narcissus cultivars, including new Rosewarne/CABGA and GCRI lines. The cultivars are ordered by the percentage of rots and then alphabetically

Resistant		Moderately resistant	Moderately susceptible	Susceptible
'Abba'	CABGA 65/45/2	'Furbellow'	'Marjorie Hine'	GCRI 530
'Actaea' seedling	CABGA 50	'Seagreen'	'Treglisson'	'Nanpusker'
GCRI 134	CABGA 51	'Jersey Torch'	CABGA 48	'Camelot'
GCRI 24Q	'Foxhunter'	'Lady Sainsbury'	'Flambards'	CABGA 49
GCRI 323	GCRI 23G	CABGA 47	'Tibet'	'Knight of St John'
GCRI 35D	'Rose of May'	'Jedna'	'Kingscourt'	CABGA 55
GCRI 650	'Articol'	'Dellan'	'Irish Minstrel'	'Golden Ducat'
GCRI 66C	GCRI 29K	GCRI 635	GCRI 70H	CABGA 52
GCRI 68H	'Talwyn'	'Emblyn'	GCRI 47B	CABGA 43
'Saint Keverne'	'Cornish Chuckles'	GCRI 2E	'Brabazon'	
'Kerensa'	'Camilla'	GCRI 344	GCRI 470	
GCRI 104	GCRI 19F	CABGA 21	CABGA 19	
GCRI 106	GCRI 45J	'Tamara'	'Ganilly'	
'Brackenhurst'	GCRI 718	CABGA 20	'Dutch Master'	
GCRI 121	CABGA 37	CABGA 39	GCRI 194	
GCRI 124	GCRI 36D	'Tripartite'	'Red Devon'	
GCRI 2J	GCRI 77	CABGA 8	CABGA 24	
GCRI 30D	'Veryan'	CABGA 22	GCRI 38H	
GCRI 401	GCRI 10P	'Gold Crest'	'Loch Owskeich'	
GCRI 51C	'Beauvallon'	'Mellen'	GCRI 232	
Poetaz seedling	'Double Actaea'	'Golden Anniversary'		
'Chinita'	'Trelawney Gold'	CABGA 38		
'Estramadura'	GCRI 68K	'Gold Crown'		
GCRI 442	GCRI 385	'High Life'		
'Lancaster'	'Jersey'			
'Pink Charm	'Roundabout'			
'St Peter	'Cornish Pride'			
'Cornish Vanguard'	'Eden Gold'			
'Rosemore Gold'	'Smiling Maestro'			

Figure 9 Cultivar resistance or susceptibility to basal rot: data from 1980s and 2000s compared



Narcissus breeding

Narcissus breeding is largely in the hands of enthusiasts in the Anglophone world – Northern Ireland, Great Britain, the USA, Australia and New Zealand; Lithuania is another centre of narcissus breeding. There have been huge changes in the forms of narcissus available in recent years.[61] Dwarf cultivars (defined by the RHS as <32.5 cm tall) and 'intermediates' (defined by the ADS as single-headed cultivars from Divisions 1, 2, 3, 4 or 11 with smaller flowers, 50 to 80 mm in size) are considered very appealing. New cultivars are bred primarily for the show-bench, and those cultivars introduced into commercial production were often show-bench varieties spotted as having commercial potential. However, there have been some breeding programmes aimed directly at producing commercial cultivars with resistance to basal rot.

The Rosewarne breeding programme

A MAFF-funded programme ran at Rosewarne in the 1970s and 1980s, aiming to produce early-flowering cultivars for Cornish flower cropping outdoors and with resistance to basal rot.[62,63,64,65,66] Some of the important parents used were 'Rijnveld's Early Sensation' (for earliness) and 'Saint Keverne', 'Malvern City', 'Toorak Gold' and 'Dawley' (for disease resistance). Following testing,[67,68] selected cultivars were sold to UK growers in the 1980s, and started to become available in commercial quantities in the early-2000s (Table 16; examples in Image 38).[69,70] Each of these cultivars was sold exclusively, so no stocks became available for R&D or independent testing purposes, and consequently, trials experience with these cultivars is limited. Basal rot has, however, subsequently been observed in some them.[30] On the closure of Rosewarne in 1989 the remaining lines, still under selection, were transferred to CABGA, by whom the programme is being continued.

The project also encompassed the breeding of improved tazetta cultivars for the Isles of Scilly and of double narcissus, for which a demand was then perceived. The tazettas were crosses from selections of 'Grand Soleil d'Or', 'Newton', 'Matador' and *N. tazetta aureus.*[48] They were transferred in 1989 to Trenoweth, the former ADAS sub-station on the Isles of Scilly, where assessments were continued under industry and other funding. The 'Rosewarne Doubles' were largely based on 'Gay Time', one of the few fertile doubles.[48] They were transferred to Kirton in 1989, multiplied, evaluated and later sold to the industry.

GCRI/HRI breeding work

Susceptibility to basal rot is linked to 'Mme. De Graaff', a white trumpet narcissus derived from *N. pseudonarcissus* and its sub-species and formerly used in breeding.[71] Cultivars of the triandrus, jonquilla, tazetta and poetaz (*N. poeticus x N. tazetta*) groups are resistant to basal rot, while some poeticus cultivars are very susceptible.[72,73,74] At HRI a range of species was tested against soil-borne basal rot inocula, confirming that *N. bulbocodium*, *N. poeticus*, *N. tazetta* and *N. jonquilla* were resistant to basal rot; *N. triandrus*, *N. pseudonarcissus*, *N. watieri*, *N. scaberulus, N. rupicola* and *N. requienii* were all susceptible.[75,76] Further screening of 33 *Narcissus* species and other taxa, and of 17 cultivars with recent species parentage, was later carried out.[77] Testing offspring for resistance to basal rot was hampered by the lack of resistance shown by one-year-old bulblets: disease resistance appeared in older bulbs, as when two- and three-year-old bulbs were tested.[78,79]

In the 1970s MAFF-funded research was initiated at GCRI to study the genetic basis of basal rot-resistance, and this involved not only cultivar x cultivar crosses, but crosses between cultivars and naturally basal rot-resistant species and mutation breeding.[80,81] Conventional cultivar x cultivar crosses and mutation breeding produced a large number of seedlings which were screened on *Fusarium*-infested growing medium. The relative resistance of progeny from the cultivars indicated that inheritance of basal rot resistance was polygenic. About 11% of the progeny survived, and these putatively resistant lines were grown-on at Wellesbourne and, in the 1990s, evaluated for their agronomic characteristics at Kirton. Over 50 selected lines were then released for commercial evaluation.

In further work at Wellesbourne, the completely resistant *N. jonquilla*, a diploid species, was crossed with 'Saint Keverne' and 'Golden Harvest' (Images 39 and 40) and the offspring screened for resistance.[82] A continuous distribution of survival rates from 0 to 100% was found in both the hybrid progenies, but more lines with 100% survival were found in the *N. jonquilla* x 'Saint Keverne' crosses. Progeny from self-pollinated *N. jonquilla* were also grown-on and displayed very high survival rates indicating homozygous resistance to basal rot in this species.

38 Examples of cultivars from the Rosewarne breeding programme: 'Banallan', 'Talwyn', 'Tamara', 'Kerensa', Melyor' and 'Veryan'

Photos: Warwick HRI and predecessors

Table 16 Narcissus cultivars released from the Rosewarne breeding programme between 1979 and 1989

Cultivar	Classification	Parentage	Year of release
'Bob Minor'	1Y-Y	'M J Berkeley' x 'Tanagra'	1979
'Small Fry'	1Y-Y	'M J Berkeley' x *N. asturiensis*	1979
'Dawn Chorus'	1Y-Y	'Rijnveld's Early Sensation' x *N. asturiensis*	1980
'Radical'	6Y-Y	'Cornet' x 'Cyclone'	1980
'The Alliance'	6Y-Y	*N. cyclamineus* x 'Saint Keverne'	1980
[65/63/2]	6W-Y	*N. cyclamineus* x 'Trousseau'	1980
'First Hope'	6Y-Y	'Jana' x 'Rijnveld's Early Sensation'	1981
'Post Horn'	6Y-Y	'Cornet' x 'Priority'	1981
'Tamara'	2Y-Y	'Trenance' x 'Rijnveld's Early Sensation'	1981
'Tamsyn'	1Y-Y	'Saint Keverne' x 'Joseph MacLeod'	1981
[65/64/1]	6W-W	*N. cyclamineus* x 'Woodgreen'	1981
'Amwell Lady'	6Y-Y	*N. cyclamineus* x 'Saint Keverne'	1982
'Martinette'	7Y-O	'Matador' x *N. jonquilla*	1982
'Innisidgen'	8Y-O	'French Sol' x 'Autumn Sol'	1982
'Wingletang'	8Y-Y	'French Sol' x 'Autumn Sol'	1982
[65/63/1]	6W-Y	*N. cyclamineus* x 'Trousseau'	1982
'Banallan'	2Y-Y	'Rijnveld's Early Sensation' x 'Finland'	1984
'Crewenna'	1W-Y	'Rijnveld's Early Sensation' x' Foresight'	1984
'Feena'	2Y-Y	'Rijnveld's Early Sensation' x 'Victorious'	1984
'Hugh Town'	8Y-O	'Matador' x 'Grand Soleil d'Or'	1984
'Jedna'	2Y-Y	'Forerunner' x 'Rijnveld's Early Sensation'	1984
'Martinsville'	8Y-O	'Matador' x 'Grand Soleil d'Or'	1984
'Millgreen'	1Y-Y	'Golden Marvel' x 'Mulatto'	1984
'Melyor'	2W-Y	'Rijnveld's Early Sensation' x 'Foresight'	1984
'Armynel'	2Y-Y	'Dawley' x 'Saint Keverne'	1985
'Barenwyn'	1Y-Y	'Priority' x 'Rijnveld's Early Sensation'	1985
'Eaton Song'	12Y-OOY	'Matador' x *N. cyclamineus*	1985
'Gold Top'	2Y-Y	'Saint Keverne' x 'Rijnveld's Early Sensation'	1985
'Loveday'	2Y-O	'Scorpion' x 'Armada'	1985
'Spring Dawn'	2W-Y	'Rijnveld's Early Sensation' x 'Finland'	1985
'Dellan'	2Y-Y	'Brandon' x 'Saint Keverne'	1989
'Emblyn'	2Y-Y	'Dutch Master' x 'Saint Keverne'	1989
'Kerensa'	1Y-Y	'Saint Keverne' x 'Malvern City'	1989
'Rosenwyn'	1Y-Y	'Dominator' x 'Toorak Gold'	1989
'Shepherd's Hey'	7Y-Y	'Seraglio' x *N. fernandesii*	1989
'Talwyn'	1Y-Y	'Dutch Master' x 'Saint Keverne'	1989
'Veryan'	1Y-Y	'Unsurpassable' x 'Malvern City'	1989

39 Narcissus jonquilla, a species with resistance to basal rot useful in breeding

Photos: Warwick HRI and predecessors

40 A 'Golden Harvest' x N. jonquilla cross from the HRI breeding programme: flower from a 7-year-old seedling bulb

Photo: Warwick HRI and predecessors

Research related to narcissus breeding at Wellesbourne

Clonal propagation

Narcissus shoot cluster explants were grown in an automated tissue culture system where they were temporarily immersed in liquid culture medium for set periods each day. How long and how often the cultures were immersed was crucial to the success of the system. With full optimisation it should be possible to achieve 1,000 bulblets (bulbils) per starting bulb within 18 months.

Although genetic variation induced by tissue culture is known to be rare in monocotyledons like narcissus, it was necessary to be entirely sure of this. A methodology was developed using molecular markers to produce DNA profiles (like those used to identify individual humans). No variation was found in the bulblets of the test subjects, 'Golden Harvest' and 'Saint Keverne' from tissue culture systems. When plants propagated from tissue culture were compared with conventionally propagated plants, no differences in flower colour, shape, size or flowering time was seen.

Basal rot resistance

Molecular markers are used to speed breeding for disease resistance. One difficulty in selecting basal rot-resistant narcissus was the time needed to build up enough bulbs to do the resistance testing in the first place – initially this also involved multiplying non-resistant lines, since the status of the seedlings could not be determined other than by the test itself. It was necessary to be able to identify the DNA profile of resistant plants, to enable them to be selected as seedlings before they produced bulbs. As commercial cultivars are often tetraploid, it was more difficult to identify the required DNA profile.

To circumvent this problem the work on identifying molecular markers made use of diploid *Narcissus* species in which it was easier to identify the markers. A diploid population was being produced by crossing *N. poeticus recurvus, N. jonquilla* and *N. henriquesii* (resistant) and *N. pseudonarcissus* and *N. rupicola* (susceptible). As these species also showed natural variation for other traits – such as scent and flower colour, shape and number – it was hoped to identify molecular markers for some of these traits as well.

Chromosome doubling

When basal rot-resistance was found in diploid *Narcissus* species, it was aimed to introduce this into commercial tetraploid cultivars. But, by crossing a diploid and a tetraploid parent, it is likely that a sterile triploid would be formed – which may not be acceptable in terms of its flower and other characteristics. As there are ways of doubling chromosomes using chemical treatments, chromosome doubling was attempted with the resistant diploids. Once converted to tetraploids, crossing to commercial tetraploids would be straightforward.

Core collection

The project exploited the natural variation in basal rot resistance found in diploid *Narcissus* species. However, it was important to maintain a source of the variation present in commercial narcissus. Using the collection of over 400 narcissus cultivars formerly at Kirton, a 'core collection' of about 100 cultivars, covering a diverse genetic background and range of genetic traits for future narcissus use, has been selected. Basal rot-resistant lines produced will be added to the core collection. The collection is now held at Springfields Gardens and the RHS Wisley Gardens, with the intention that it will be available to the industry for crop improvement.

Narcissus breeding and underpinning research at Wellesbourne

Further strategic research funded by Defra continued at Wellesbourne until 2010, when funding ceased. This brought the work into the biotechnological age, with an emphasis on making available the tools for future narcissus breeding, i.e. rapid multiplication and genetic analysis.[83]

4.2 Bulb grade, shape and appearance

Bulb size and grade

Bulb and flower yields are largely determined by the grade of bulbs planted, their planting rate and the length of the growing cycle (one, two or more years). In the UK, narcissus bulbs are usually graded by cm circumference using long (slotted) riddles. Under this system flat bulbs may have a high weight in proportion to their grade.

In current commercial UK practice the bulb grades used have become standardised to even numbers, such as 10-12 cm (often written 10/12 cm), 12-14 cm, etc. Prior to that, bulbs of trumpet and large-cup cultivars were traditionally graded to 12-15, 15-17 and >17 cm, and other (generally smaller) bulbs to 12-14 cm, etc. But, with the adoption of higher planting rates, bulbs are now generally smaller, and even-numbered grades have been adopted for all types. For most types the minimum bulb size (circumference) required for flowers to be formed is about 10 cm.

In the following list, the bulb grades refer to cultivars with 'standard sized' bulbs, not small-bulbed types.

Small bulbs (<10 cm)

Small bulbs are usually replanted, though there is a good trade in such 'planters'. Bulbs of 7-10 or 8-10 cm have a high growth rate and can make good planting stocks, and many will not flower. The smaller the bulbs, the more difficult it will be to clean and inspect them effectively. Very small bulbs are sometimes discarded.

Small flowering-size bulbs (10-12 cm)

These give a high percentage weight increase and make ideal planting stock. As a result of their small size, they are also favoured for sales in pre-packs, and they produce more flowers for their weight compared with larger bulbs. Some growers aim to maximise yields in this grade.

Middle size bulbs (particularly 12-14 cm)

The middle sizes are in demand for dry bulb sales and bulb forcing.

Large bulbs (mainly 14-16 cm)

Large bulbs are usually sold, but they may produce relatively fewer flowers per tonne. However, these larger bulbs are in demand by some retailers who regard them as of high quality: large bulbs will be more expensive, but may emerge sooner and produce larger and more flowers.[93]

Very large bulbs (>16 cm or 16 cm +)

Very large bulbs are not in demand, and are often re-planted along with small bulbs, a practice traditionally said to 'increase vigour' in a stock.

Dwarf and some other cultivars that are naturally small-bulbed may be sold in smaller grades, such as 8-10 cm. Bulbs of *Narcissus* species are often much smaller, and the minimum bulb size that will flower may be as small as 5 cm-circumference.[94]

In the Netherlands bulbs are more usually graded on round, not long-slot, riddles, so, for example, a Dutch 12-14 cm bulb may be about equivalent to a British 10-12 cm bulb. Often, packers require a specific count of bulbs per tonne, so growers will sometimes vary the riddle size to achieve this, resulting in less usual grades such as 9-12 cm. Sometimes, also, Dutch suppliers may use an older system of grading double-nosed (DN) bulbs in increasing sizes as DN III (roughly 12-14 cm), DN II (14-16 cm) and DNI (>16 cm), which corresponds approximately to 375, 275 and 175 bulbs/25 kg. This grading system may be found in retail outlets or in the mail order trade.

Planting bulbs as a mixture of sizes (or as un-graded bulbs) will maintain a variety of shapes and sizes in the harvest.

Bulb shape and appearance

Some other general points are listed here (see Images 41 and 42).

- Stocks with a good proportion of 'flat offsets' have high growth rates.
- Many small round bulbs in a stock are said anecdotally to indicate declining vigour.
- Some growers suggest that small round bulbs (<8 cm) should be discarded.[95]
- Large offsets grow into large round or DN bulbs in one year, while small offsets take two or three years.
- Bulbs from 'chipped' stocks are round and uniform and so well suited to planned production or pre-pack sales,[96,97] but it may take three or four years from chipping to produce a flowering-sized bulb.
- Some cultivars are long-necked and can be more easily damaged during handling.
- Bulb skin colour is variable, and cultivars with dark skins – if lifted at the right stage and carefully cleaned so that the skin remains intact – can be favoured by pre-packers and retail consumers.
- Dutch textbooks describe various 'skin conditions' that are detrimental to the appearance of a bulb.

41 Good quality small bulbs likely to give high flower yields (top) and a poor sample (bottom)

Photo: Warwick HRI and predecessors

42 Bulb shapes – offset and single-, double- and multi-nosed bulbs

Photo: Warwick HRI and predecessors

4.3 Bulb source and quality

Quality issues

Bulbs can be purchased through private sales or auctions, or may be grown under contract arrangements. A number of quality issues should be considered.

- All bulbs purchased for growing-on for commercial purposes within the EU must be accompanied by a valid Plant Passport. For bulbs from non-EU countries, the required phytosanitary (plant health) certificate must be in order.
- Plant Passport conditions largely relate to freedom from stem nematode and soil. Under the EU Marketing Directive, growers are responsible for other aspects of plant quality.
- The source should be reputable and ideally, stocks should be inspected in the previous season for trueness-to-type and freedom from pests and diseases.
- Stocks should be checked in growth and storage for symptoms of the main pests and diseases:
    - Stem nematode – leaf 'spikkels', brown rings in bulbs, weak patches in the field.
    - Bulb-scale mite – saw-tooth-edged leaves, brown feeding marks in scales.
    - Large narcissus fly – stunted plants, damaged base plates, eaten-out bulbs.
    - Viruses – streaky or patchy colours on leaves.
    - Fungal rots – brown scales, rotted base plates and bulb necks; note that base plate damage may be due to mechanical damage at lifting or to an earlier infection by large narcissus fly.
    - *Fusarium* (basal and neck rots) is known to be a stock, rather than an environmental, problem.[98]
    - Fungal foliar diseases – leaf lesions.
- There are sometimes particular problems over bulb health in stocks of dwarf cultivars such as 'Tête-à-Tête'. In one UK trial of dwarf cultivars, many stocks had unacceptably high levels of bulb rot, virus, stem nematode or rogues; there is a need for stock improvement.[99]
- Stocks should be obtained in sufficient time to carry out HWT and planted by an appropriate date. If received after mid-August, storage at 18°C for two weeks before HWT will enable HWT to take place in September with less crop damage. If planting non-treated bulbs is unavoidable, they should be planted in isolation and lifted for HWT one year later.

Plant health requirements

Incoming bulbs

Bulbs purchased should be accompanied by a Plant Passport (if from within the Single Market) or other phytosanitary certification (if from a third, i.e. non-EU, country). The Plant Passport is traceable, and the system is designed to control the spread of quarantine pests and diseases (stem nematode in the case of narcissus) within the EU. EU plant health checks are focused on the place of production: there are no border checks for plants travelling between EC countries, although spot checks may take place anywhere in the trade chain.

Bulbs for future sales

For bulb sales in the future, arrangements will need to be put in hand with the competent authority (PHSI in England and Wales, SGRPID in Scotland) well before the growing season. Producers will need to be registered:

- For issuing Plant Passports (or other phytosanitary certificates) and arranging the necessary GSI and DBI.
- Under the EU Marketing Directive, to ensure quality of produce sold within the EU.
- (And possibly) under other voluntary schemes (e.g. for inspection and certification of virus tested bulbs).

If in doubt about the requirements, the local PHSI or equivalent should be consulted. Further information on plant health, imports and exports may be found at Fera's plant health website.[100]

Virus tested bulbs

Virus tested bulb stocks have been produced in England and Scotland, and give a number of advantages, including improved vigour and often better flower colour (Image 43). Although the PHSI certification scheme for virus tested narcissus in England and Wales no longer appears to be used, significant virus tested stocks are being produced in Scotland and may be subjected to a voluntary certification scheme administered by the SGRPID.

43 Good flower colours in an 'ex-virus tested' stock of 'Fortune'

Photo: Warwick HRI and predecessors

Acclimatisation

Bulbs bought from a different region or country may take a few years to become synchronised with local stocks. In one study, Dutch narcissus bulbs took three years of growing in South-West England before they were growing and flowering at the same time as local stocks.[101]

Reclaimed (ex-forced) bulbs

Bulbs from glasshouse forcing are often reclaimed for growing-on if current bulb prices and the value and health of the stock justify it. When planning to sell reclaimed bulbs the stock should be submitted to PHSI for inspection and issuing of a plant-passport; if sold, they must be labelled as reclaimed bulbs.

Reclaimed bulbs are generally small and desiccated, but if given HWT and grown-on for two or three years, they can give satisfactory yields for an economic price. Reclaimed bulbs are sometimes used for retail sales, but, as this will result in a lower percentage of flowering bulbs, and may damage the reputation of the seller or producer: this is a practice to be discouraged.

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5.0 Site considerations

5.1 Location – choice of region and site

South Lincolnshire and the East of England

South Lincolnshire is an area with strong historical links to the Netherlands – as indicated by the district name, South Holland. The area is one of large fields with well-mechanised agriculture efficiently producing cereals, potatoes and field vegetables as well as narcissus (Image 44). An important factor is that some equipment and facilities can be shared between these crops (e.g. bulb drying stores with potato, onion or cereal production). Traditionally in the East, narcissus flowers cropped from the field were considered to be of secondary importance to the bulbs, but this has changed because of market forces and a long period of low bulb prices. Eastern England traditionally supplied the markets of London and the industrial Midlands, but is now a major distribution centre for fresh produce for the UK, the EU and worldwide. Narcissus bulbs are also forced, though to a much lesser extent than formerly, partly because of costs, and partly because of the volume of flowers now being picked from the field.

44 Lincolnshire bulb fields – often large and flat

Photo: Gordon Hanks

South-West England

The South-West, particularly West Cornwall, has been traditionally important for the production of early fresh produce, including potatoes and narcissus flowers, from its mild, relatively frost-free climate. With improved road links eastwards and EU grants, the area has become increasingly significant for narcissus production. Bulb quality is enhanced by soils free of potato cyst nematode (PCN), important when aiming to export bulbs to the USA. However, many Cornish fields have the disadvantages of relatively small size, irregular topography, exposure to sometimes salt-laden winds, and stony soils (Image 45).

45 Cornish bulb fields – often sloping and windswept

Photo: Gordon Hanks

The Isles of Scilly

Cornish horticulture could be said to be taken to an extreme in the Isles of Scilly, where the fields are usually small and surrounded by hedging (often *Pittosporum crassifolium*), trees (often elms) or artificial shelter for protection from the strong, salt-laden winds. However, the mild winters are ideal for producing early potatoes, vegetables and flowers, though the high cost of transport to mainland markets (and of importing almost all sundries and materials required) has meant that the Islands' growers can compete only by growing a crop unsuited for the mainland: tazetta narcissus. Tazettas thrive in the warm, often dry summers, and sandy soils. Tazetta cultivars are prized for their scent and the fact that, unlike standard narcissus, they do not only flower in winter (they do not have a cold requirement) and respond to burning-over and polythene-mulching treatments to give flowers over a season several months long. The situation on the Islands has necessitated innovation on the part of the growers, examples being the setting-up of a co-operative marketing venture and a mail-order business supplying the scented blooms by post.[1] As well as tazetta cultivars, late-flowering double narcissus such as 'Erlicheer', 'Cheerfulness' and 'Sir Winston Churchill' are also grown.

Pembrokeshire, Wales

Daffodils are also a traditional crop in the Welsh South-West (Pembrokeshire), although only a relatively small area remains. Climatic conditions are similar to those in West Cornwall.

Scotland

A significant area of narcissus is grown in North-East Scotland. The cooler climate, compared with southern Britain, provides a useful supply of late-season flowers and, combined with the relative isolation, means some pest and disease problems (aphids, large narcissus fly, basal rot) may be less. The growing season is delayed until light levels are higher, when days are longer and good bulb and flower production is possible. In the main the region is free of PCN, which is crucial for exports to the USA. Potato and bulb crops compete for PCN-free ground, as both have to be fitted into the rotation. The discipline necessary for high-health status production arises from growing other seed crops in the region, and the voluntary certification scheme set up for bulbs in the early 1970s has greatly benefited narcissus growing here, with lower tolerance levels of the main pests and diseases than the UK standards.

Jersey, Channel Islands

Some 150 ha of narcissus are grown in Jersey, where the conditions and practices are similar to those of the South-West. The overall area and the number of large growers have fallen markedly over the past 20 years, but a good range of cultivars is grown for both bulb and flower sales. There is still some reliance on pre-cooled bulbs of the older cultivars, such as ‘Hollywood’ and ‘Fortune’.

Comparing the UK and the Netherlands

How do UK conditions for bulb growing differ from those in the Netherlands? Bulb production in the Netherlands takes place largely in the area around Hillegom, and has a number of advantages over production in the UK: sandy soils, a controlled water table and, traditionally, the availability of family labour for labour-intensive operations. There is also abundant traditional expertise, a strong R&D base, and an exceptional infrastructure for publicity and marketing worldwide. With increasing pressure on land in the central region, however, narcissus production has moved to the heavier soils of the North Holland polders.

Sites to avoid

Some types of site should be avoided:

- Warm sites, such as south-facing slopes, because warm soils favour basal rot development.
- Sites suited to an east to west ridge orientation, which produces higher soil temperatures than north-south ridges.
- Sloping or irregular sites which are difficult for farm operations.
- Sites where soil erosion or surface run-off of water, fertiliser or pesticides occurs, especially when near watercourses.
- Sites near refuges for pests and diseases, such as cultivated or naturalised narcissus in road or ditch sides, field margins, gardens and cemeteries (Image 46).
- Sites where trees, hedges and other shelter give a warmer microclimate favouring the survival of large narcissus fly.

In one Dutch study, infestation levels of large narcissus fly of 23, 5 and 1% were recorded 0, 110 and 230 m from the fringes of a wood, respectively.[2] In commercial narcissus stocks, large narcissus fly infestations as high as 20 to 30% have been recorded, but one study of garden plantings found levels of 50 to 75%.[3]

46 Naturalised bulbs in field margins may constitute a source of infection

Photo: Gordon Hanks

5.2 Climate

Overall climate

Mild, maritime climates such as West Cornwall, West Pembrokeshire or Ireland favour narcissus growing. Here there is an early, long growing season, and summer/autumn temperatures approximate those needed to prepare the bulbs for early flowering. On the other hand the higher rainfall and temperatures here may favour pests, diseases and weeds, there are fewer ‘spray days’ (dry, calm days suitable for crop spraying), and bulb lifting and drying can be more difficult.

The cooler climate of Eastern England has generally been considered to result in fewer pests and diseases, and the soils seldom freeze deeply enough to damage bulbs. Bulb growth begins two to three weeks earlier in Cornwall than in Eastern England, though yields are ultimately higher in the East.[4] The cooler climate of Scotland may result in fewer pests (such as aphids and large narcissus fly).

In the UK, the range of climates found from the Isles of Scilly to Scotland is a great advantage in providing a succession in flower cropping over a period of 12-16 weeks. More continental climates (such as the Netherlands or Eastern Europe) may require the use of mulch to provide protection from frost.

Rainfall

Ideally, rainfall should be well distributed through the year, with 100 cm/year considered optimal for narcissus growth and for facilitating bulb planting and lifting. Irrigation is not often used in the UK, but should be considered because positive responses have been shown in trials[5]), while Defra-funded research at HRI showed that rainfall was a major ‘driver’ for subsequent bulb and flower yields. Rainfall is especially important:

- To establish rooting after planting.
- When bulb growth is rapid in April to June (irregular rainfall may lead to uneven growth and split skins).
- Before bulb lifting, to reduce problems with clods.

However, wet soils aid the spread of nematodes in soil water and in waterlogged furrows.

In a Chinese study of the effects of water stress on narcissus, tulip and hyacinth, seedlings were treated with various concentrations of polyethylene glycol to imitate drought stress.[6] The relative water content, and some other physiological markers, fluctuated less in response to stress in narcissus than in the other species. This suggests that narcissus has the best drought tolerance of the three, but it is not known whether this characteristic persists into the fully grown plant.

Temperature (mainly low temperature)

Standard narcissus cultivars are hardy throughout the UK without the use of any mulch. UK soils seldom freeze deeply enough to damage the bulbs. However:

- Poetaz cultivars such as 'Tête-à-Tête' may need to be mulched in Eastern England in some years.
- Tazetta cultivars such as 'Grand Soleil d'Or' are generally less tolerant of cold conditions, succeeding in the UK only in the Isles of Scilly and West Cornwall.

There is a wide variation in frost-hardiness in the ornamental bulb crops grown in the UK.[7] Shoot growth may be adversely affected if soil temperatures fall below –3°C. Some data have been published on the cold tolerance of different cultivars,[8,9] although discrepancies in methodology between different studies, and the fact that actual sensitivity may depend on durations and fluctuations in low temperatures rather than average temperatures, mean that no clear guidance is currently available.

At the other extreme, soil temperatures of 20 to 30°C favour the development of basal rot.

Wind

In windy situations crops may be flattened, severely affecting flower quality and reducing bulb yields. However, in a study in Scotland it was shown that using shelter to reduce wind run from 164 to 118 km/day was not an economic way to increase yields.[10] In this study, reducing the wind-run led to the production of taller stems in all three cultivars tested, but bulb yield was increased in only one of them.

As narcissus flowers extend laterally from the long axis of the stem, wind exerts torsional (twisting) as well as flexural (bending) stress. The stems, which have low torsional stiffness, respond by twisting so that the flowers face downwind in moderate winds, reducing their drag by 30%.[11]

Climate change

UK narcissus production is likely to be further impacted by climate change. Warmer weather, wetter winters and generally less predictable weather will all affect crop growth, the status of pests and diseases, and the practicality and timeliness of operations such as planting, spraying and lifting.

Warmer weather is likely to affect narcissus growing in several ways:

- In the 1970s large narcissus fly was considered to be at the limit of its range in Cornwall, but subsequently it has been accepted as a problem also in Eastern England.
- Similarly, white mould was considered a disease of narcissus only in South-West England, but it has occurred intermittently elsewhere and was confirmed in Lincolnshire in 2001.[12]
- The basal rot fungus grows most rapidly between 20 and 30°C, often requiring only a small increase in UK summer temperatures to reach its optimal temperature range.
- The bulb-scale mite also multiplies rapidly under warm conditions.

Based on the UKCIP98 'medium high' scenario, the number of calm days ('spray days' when crop spraying is practicable) in weeks 1 to 12 in Cambridgeshire will decline from 24.5 days/year (the average over 1961-1990) to 17.5 (by 2050), while the number of calm days in the South-West will remain at less than one per week over the same period.[13]

5.3 Soil

Soil types

Silts or very fine sandy loams are ideal, though in the UK narcissus are grown successfully on a variety of silt, silt loam, brick-earth and peat soils.

Growing in light sandy soil with a controlled water table – as in much Dutch growing – is generally regarded as the ideal bulb-growing environment. The disadvantage is that nematodes spread easily in sandy soils with high water content, so regular soil sterilisation is needed to control them. Now, however, narcissus are increasingly being grown on the northern polders because of pressure on prime agricultural land further south, and this reduces the need for soil sterilisation. It was previously thought that narcissus bulb quality could not be maintained growing on heavy silt clays.[14]

There have been few critical comparisons of growth in different soils. In Poland, better growth was reported in light black-earth soils than in heavy alluvial soils.[15] In the UK, bulbs were reportedly larger, less dense and more susceptible to basal rot when grown on peat soils, though weed control is more difficult in highly organic soils.[16] A UK survey suggested that *Fusarium* was more likely to be a problem in bulbs grown on heavy silt and peat soils.[17]

Soil characteristics

The soils used for growing narcissus should be:

- Deep and fertile, with a good structure.
- Not compacted; if at risk, permanent tractor wheelings should be considered.
- Free of stones and clods that can damage bulbs and make lifting difficult; if not it may be necessary to use a stone/clod separator.
- Well drained but moisture retentive (water holding capacity >40 mm per 300 mm depth).
- Not prone to waterlogging, though narcissus can tolerate some waterlogging if the water is well aerated,[18] (but water standing in the furrows facilitates the spread of stem nematode).
- Not depleted in organic matter, which should be >3%, suiting many soils in the main UK bulb areas; bulbs are also grown on peat soils with up to 25% organic matter .
- Of a pH value generally between 6.0 and 7.5.
- Not high in clay content as it may be difficult to produce soil-free bulbs unless they are washed, a process spreading diseases and creating disposal problems.[19]
- Certified free from PCN, if required for export to certain countries (notably the USA).

5.4 Crop rotation and site history

Crop rotation

An effective crop rotation should:

- Maintain a good soil structure.
- Make good use of nutrients.
- Reduce pest, disease and weed problems.

The narcissus rotation should provide a minimum gap of five years between alternative hosts of stem nematode and the next narcissus, and where stem nematode or basal rot have been a problem there should be a seven or eight years' gap. Throughout the rotation, good weed control is needed to eliminate stem nematode hosts. Narcissus crops often follow leys, peas, early potatoes or barley, and adequate time must be allowed, following these crops, for ploughing and cultivation.

Narcissus should not follow:

- High residue crops such as brassicas, since high levels of nitrogen favour bruising and basal rot.
- Cereals that have been treated with sulfonylurea herbicides, as the residues can cause distortions of narcissus flowers.
- Tulips, since the tulip race of stem nematode also attacks narcissus.
- Other hosts of the narcissus and tulip races of stem nematode:[20]
- Crops including onion, maize, peas, beans, sugar beet, mangold, carrot, turnip, red clover and strawberries.
- Bulbs such as bluebells and hyacinth.
- Weeds such as speedwells, scarlet pimpernel, chickweed, cleavers, groundsel, knotgrass and black bindweed.

Other rotational factors

Some other rotational factors should also be taken into account:

- Narcissus crops planted in successive years should not be on adjacent land, otherwise the first-year crops may be infected by fungal diseases spreading from the earlier planted crops.
- A soil test for freedom from PCN is required if it is intended to export bulbs to certain countries. Although PCN does not attack narcissus, it can be carried in the soil attached to bulbs.
- Volunteer narcissus bulbs are difficult to eliminate, but may be a source of pests and diseases (Image 47). They should be removed using a contact herbicide (glyphosate) and repeated surface cultivation and manual removal of bulbs. However, cultivation itself can also propagate bulbs through a 'chipping' effect and re-burying. Some narcissus volunteers must arise from seeds dropped by previous crops, which would escape notice because of the small size and slow growth of the seedlings.

47 Narcissus 'groundkeepers' are a potential problem

Photo: Gordon Hanks

- Basal rot spores are widespread and have been found in soils not known to have grown narcissus previously.[21,22] The spores may be able to survive for 10 years under some conditions.[23] Field populations of the basal rot pathogen have been studied with the goal of developing sensitive, specific detection of the pathogen in bulbs and soils, which may lead to diagnostics capable of predicting the disease potential of individual fields.[24]

In appropriate cases, before allocating a field for narcissus growing, soil samples should be taken and sent to a diagnostics laboratory for identification and counts of:

- Stem nematode (either as a precaution or if there is reason to suspect a nematode problem).
- Virus-vector nematodes (if growing virus tested or other high-health status stocks).
- PCN, if exporting bulbs to countries requiring PCN-free certification.

It is better to confirm the presence of PCN or stem nematode as a result of your own sampling, than to have it discovered 'officially'.

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6.0 Pre-planting operations in the field

6.1 Cultivation

Cultivation check list

- In the year before bulb planting, deal with perennial weeds by cultivation and (or) by applying a translocated herbicide (glyphosate).
- The passage of just one tractor can reportedly cause enough soil compaction to reduce growth. The roots of narcissus – which are naturally limited in number, spread and duration – are highly sensitive to compaction.[1] To alleviate compaction the land should be sub-soiled in good time and under the right conditions – when the soil is dry enough to break through the compacted layer without causing smearing.
- Deep-plough land well before planting is due, and when the soil is dry enough to avoid damage to its structure. Plough to 20 to 30 cm deep, depending on soil type.
- Either plough the whole field and take out roadways later, or establish permanent headlands first.
- After ploughing, cultivate (e.g. using power harrow) to a depth of 25 cm in clay or loam, or 35 cm in sand.
- If the bulbs are not ready to be planted and the weather is dry, roll the land to retain moisture.
- Where needed, use a de-stoner.
- Bed formers are sometimes used in the South-West to improve the soil for planting and ridging, and this also assists in marking out the field and aligning planting.

6.2 Applying fertilisers

In addition to the standard texts on narcissus production, the key reference for fertiliser use in the UK is '*RB209*', formerly MAFF's *Fertiliser Recommendations for Agricultural and Horticultural Crops*, now in its 8th edition as the *Fertiliser Manual (RB209)* (Defra/Welsh Assembly Government, 2010).[2]

Nutritional experiments

Nutritional experiments have been carried out on narcissus since the 1930s, though it proved difficult to interpret the findings because the large amounts of reserves held in the bulb confounded the results.[3,4] In the 1960s, long-term experiments demonstrated how applied fertilisers affect growth in later years.[5,6,7] Although showing little short-term response to nitrogen (N) or phosphate (P_2O_5), narcissus benefited from the application of adequate potash (K_2O) by showing better growth in subsequent years. Magnesium (Mg) is also needed for growth. More recently, narcissus nutrition has been extensively studied in culture solutions in Thailand, and the omission of Mg has been described as resulting in severe interveinal chlorosis near the leaf tips.[8,9,10] Narcissus roots have been shown to take up ammonium-N and nitrate-N about equally.[11]

Avoiding excessive fertiliser use

For economic as well as environmental reasons, the application of excessive fertiliser is discouraged.

- Narcissus plants have lower nutritional requirements than other bulbs, but Dutch surveys showed that unnecessarily high quantities of N and P_2O_5 were often used.[12,13,14] Not more than 125 kg N/ha should be applied, making deductions for the mineral N in the soil as measured by analysis.
- Using excessive N leads to increased rots, splits and bruising in narcissus bulbs.[15,16] One trial showed applying 120 kg N/ha was satisfactory, but fungal disease increased when 180 kg N/ha was used.[17]

In HDC Project BOF 39, carried out at Kirton, bulbs of 'Golden Harvest' (susceptible to basal rot) and 'Saint Keverne' (resistant) were planted in soil with various amounts of ammonium nitrate added (giving the equivalent of 0 to 300 kg N/ha) and with no, low or high levels of basal rot inoculum incorporated.[18] These rates of N did not generally increase the incidence of basal rot or reduce bulb yield, irrespective of whether basal rot inoculum was added or not. However, applying ammonium nitrate as a split dose (150 kg N/ha in the growing medium plus 150 kg N/ha top-dressed in April) increased rotting in 'Golden Harvest', and even in 'Saint Keverne' when a high rate of basal rot inoculum had also been used. High levels of N late in the growing season should therefore be avoided. This might apply following a dry winter with little leaching, or when following a high-residue crop such as a brassica. In possible contradiction to these experimental findings, in HDC Project BOF 28 a survey of husbandry practices did not find an association between N fertilisation and the occurrence of *Fusarium*-associated neck rot.[19]

A protocol for assessing fertiliser requirements

The following protocol has been compiled mainly from recent editions of *RB209* and includes the basic methods for determining fertiliser requirements given in the latest (8th) edition, 2010.

Preparations

The fertiliser requirements of each crop and field (or part of the field, if the soil type or previous cropping varies substantially across it) should be separately assessed, and any special factors noted (such as a history of poor growth). Check the fertiliser applicator is in good working order and has been recently calibrated.

Soil sampling

Soil samples should be taken a few weeks before planting is due, and analyses for pH, P_2O_5, K_2O and Mg obtained from a suitable laboratory. Soil samples should be taken following a standard procedure: ensure the samples are representative of the field, are taken to a uniform depth (usually 15 cm), and are bulked from not less than 25 individual sub-samples taken across the whole area (by walking the field in a W-shaped pattern and taking sub-samples regularly).

Correction of pH (liming)

A soil pH of 6.5 is ideal. Acid soils should be corrected by liming with ground limestone, ground chalk or other form of lime of known neutralising value (NV), following standard agricultural procedures. Lime should be applied and ploughed or cultivated in well before planting. Sandy or peaty soils should not be over-limed because this can induce manganese (Mn) and boron (B) deficiencies.

Estimating N indices

N requirements were formerly based on the previous cropping of the land, with the highest rates applied following the most demanding crops, such as cereals, or vegetables grown with lower rates of N fertilisers. A more precise 'soil nitrogen supply' (SNS) system was promoted in recent editions of *RB209*. Since the amount of N available to a crop before any fertiliser has been applied varies widely, the SNS system was developed to assign an index, from 0 to 6, of the likely extent of this background supply of N. The system includes two methods, the 'field assessment method' (FAM) and the 'measurement method', as briefly described here. No soil analysis is required for the FAM.

Estimating N indices using the Field Assessment Method (FAM)

The FAM does not take account of any N that will become available to a crop from organic manures applied since harvest of the previous crop; the available N from manures applied since the harvest of the previous crop, or those applied to the current crop, need to be calculated separately (using other recommendations in *RB209*), and subtracted from the rates shown in the recommendation tables. No soil analysis is required. There are five steps to identify the SNS Index.

- Identify the predominant soil type down to rooting depth, using the guidance provided: peaty, organic, shallow, light sandy, deep silty or medium or deep clayey soil.
- Identify the previous crop using the explanations given in *RB209.*
- Select low, moderate or high rainfall, either using actual rainfall data or the map of average rainfall provided (<600 mm, 600 to 700 mm (which will include much of the eastern bulb-growing area) or >700 mm (which will include the South-West), respectively), or (preferably) using a measurement or estimate of Excess Winter Rainfall (EWR; e.g. from the Met Office, either <150 mm, 150 to 250 mm or >250 mm for low, moderate or high, respectively).
- Identify a provisional SNS index using the tables provided for low, medium or high rainfall if the field has not been in grass in the last three years, or, if the field has been in grass during that time, check a further table (grass history) and use the higher of the index levels based on the last crop grown or the grass history. The tables for moderate rainfall and high rainfall areas and the grass history table are given as Tables 17 to 19, respectively.
- Make specific adjustments to the SNS index (e.g. due to regular organic manure applications or particularly high residues from previous crops) as detailed in *RB209.*
- The SNS index (adjusted if necessary) can now be used to read off the N requirement from the recommendation table (Table 20).

Estimating N indices using the Measurement Method (MM)

- It is appropriate to use the MM when the SNS is likely to be high or uncertain, for example following a history of organic manure applications, following vegetable crops with high residue incorporation, or following pigs. To obtain the SNS, Soil Mineral N (SMN) is measured in soil samples, and crop N content and an estimate of net mineralisable N must be added to the SMN when calculating the SNS. The MM is not suitable for use with peat soils. There are four steps to identify the SNS Index.
- Measure SMN, ideally to 90 cm depth (or to maximum rooting depth in shallow soils over rock), but often in practice to 30 or 45 cm for shallow rooted crops, adding an allowance for SMN in the deeper soil layers. Samples should be cooled and kept at <5°C until analysis, but should not be frozen.
- Estimate the N already in the crop when the crop is present when the soil sample is taken and add this to the measured SMN. In cereals the crop N content can be estimated based on shoot numbers/m2: 500/m^2 will yield 5 to 15 kg N/ha, 1500/m^2 will yield 25 to 50 kg N/ha. For oilseed rape estimate the crop N content from crop height: a 10 cm-high crop will yield 35 to 45 kg N/ha, a 20 cm-high crop 75 to 85 kg N/ha.
- Make an adjustment for net mineralisable N from soil organic matter and crop debris. In mineral soils of less than about 10% organic matter, no adjustment is needed. For more details, consult *RB209*. The adjustment for net mineralisable N is added to the total of SMN and N in the crop, giving the SNS.
- Identify the SNS index: it is 0 where SNS is <60 kg N/ha, 1 for 61 to 80 kg N/ha, 2 for 81 to 100 kg N/ha, 3 for 101 to 120 kg N/ha, 4 for 121 to 160 kg N/ha, 5 for 161 to 240 kg N/ha and 6 for >240 kg N/ha.
- The SNS index can now be used to read off the N requirement from the *RB209* recommendation table (Table 20).

Table 17 Soil nitrogen supply (SNS) indices for various soils for moderate rainfall areas based on the last crop grown (from RB209 8th edition, 2010)

Soil type	SNS index						
	0	1	2	3	4	5	6
	SNS (kg N/ha) (= SMN (0 to 90cm soil depth) + crop N + estimate of mineralisable N)						
	<60	61-81	81-100	101-120	121-160	161-240	>240
Light sands or shallow soils over sandstone	Cereals Oilseed rape Potatoes Sugar beet Low or medium N vegetables Forage (cut)	High N vegetables Peas Beans Uncropped land					
Medium soils or shallow soils not over sandstone		Cereals Sugar beet Low N vegetables Forage (cut)	Oilseed rape Peas Beans Potatoes Medium N vegetables Uncropped land	High N vegetables			
Deep clayey soils		Cereals Sugar beet Low N vegetables Forage (cut)	Oilseed rape Potatoes Peas Beans Uncropped land	Medium N vegetables	High N vegetables		
Deep silty soils		Cereals Sugar beet Low N vegetables Forage (cut)	Oilseed rape Potatoes Uncropped land	Peas Beans Medium N vegetables	High N vegetables		
Organic soils				All crops			
Peat soils					All crops		

Calculating the amount of N fertiliser to apply using the SNS index (from the FAM or the MM)

Use the SNS index to find the amount of N to be applied by reading off the recommendation table for bulbs and bulb flowers (Table 20) If organic manures have been applied since harvest of the previous crop, or will be applied to the new crop, calculate the amount of nutrients that will be available from the manure and deduct this from the tabulated figure, to give the adjusted amount to apply. The amounts of available N (and of P_2O_5 and K_2O) resulting from applications of organic manures can be obtained from the detailed tabulations in Section 2 of *RB209*.

Deciding on a strategy for P and K use

The strategy for P and K can be building-up, maintaining or running down the soil index levels. To maintain levels, allow for any surplus or deficit of P and K applied to previous crops in the rotation, or consider calculating the amount of P and K to be removed in the harvested crop; this is the amount of P and K that must be replaced in order to maintain the soil index at its present level.

Calculating the amount of P, K and Mg fertiliser to apply

Using nutrient indices supplied by analysis, find the amount of P, K and Mg that should be applied by reading off the requirement given in Table 20. For P_2O_5 and K_2O, as in the case of N, if organic manures have been applied since harvest of the previous crop, or will be applied to the new crop, calculate the amount of nutrients that this will make available and deduct this from the tabulated figure (see Section 2 of *RB209*).

Avoiding excessive fertiliser application

For the reasons given above, the maximum recommendations given here should not be exceeded. Allowing for previous and expected applications of manure is important in not applying too much fertiliser. Situations where the N index is 0 may be rare, except after wet winters and in arable rotations. Growers on sandy soils once applied slightly higher amounts of N as insurance against leaching. In areas prone to natural run-off and soil erosion, care should be taken to carry out all fertiliser applications under suitable conditions.

Table 18 Soil nitrogen supply (SNS) indices for various soils for high rainfall areas based on the last crop grown (from RB209 (8th edition, 2010)

Soil type	SNS index						
	0	1	2	3	4	5	6
	SNS (kg N/ha) (= SMN (0 to 90cm soil depth) + crop N + estimate of mineralisable N)						
	<60	61-81	81-100	101-120	121-160	161-240	>240
Light sands or shallow soils over sandstone	Cereals Oilseed rape Potatoes Sugar beet Peas Beans Low or medium N vegetables Forage (cut) Uncropped land	High N vegetables					
Medium soils or shallow soils not over sandstone		Cereals Oilseed rape Potatoes Peas Beans Sugar beet Low and medium N vegetables Forage (cut) Uncropped land	High N vegetables				
Deep clayey soils		Cereals Sugar beet Oilseed rape Potatoes Low and medium N vegetables Forage (cut) Uncropped land	Peas Beans High N vegetables				
Deep silty soils		Cereals Sugar beet Low N vegetables Forage (cut)	Medium N vegetables Oilseed rape Potatoes Peas Beans Uncropped land	High N vegetables			
Organic soils				All crops			
Peat soils					All crops		

Table 19 Soil nitrogen supply (SNS) indices for various soils and rainfall areas following ploughing out of grass leys ('grass history' table from RB209. 8th edition, 2010, note erratum)

Description of ley	Year 1	Year 2	Year 3
Light sands or shallow soils over sandstone, all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1 to 2-year leys, low N 1 to 2-year leys, 1 or more cuts 3 to 5-year leys, low N, 1 or more cuts	0	0	0
1 to 2-year leys, high N, grazed 3 to 5-year leys, low N, grazed 3 to 5-year leys, high N, 1 cut then grazed	1	2	1
3 to 5-year leys, high N, grazed	3	2	1
Medium soils and shallow soils not over sandstone, all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1 to 2-year leys, low N 1 to 2-year leys, 1 or more cuts 3 to 5-year leys, low N, 1 or more cuts	1	1	1
1 to 2-year leys, high N, grazed 3 to 5-year leys, low N, grazed 3 to 5-year leys, high N, 1 cut then grazed	2	2	1
3 to 5-year leys, high N, grazed	3	3	2
Deep clayey soils and deep silty soils, low rainfall areas (500-600 mm annually)			
All leys with 2 or more cuts annually receiving little or no manure 1 to 2-year leys, low N 1 to 2-year leys, 1 or more cuts 3 to 5-year leys, low N, 1 or more cuts	2	2	2
1 to 2-year leys, high N, grazed 3 to 5-year leys, low N, grazed 3 to 5-year leys, high N, 1 cut then grazed	3	3	2
3 to 5-year leys, high N, grazed	5	4	3
Deep clayey soils and deep silty soils, moderate (600-700 mm annually) or high (>700 mm annually) rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1 to 2-year leys, low N 1 to 2-year leys, 1 or more cuts 3 to 5-year leys, low N, 1 or more cuts	1	1	1
1 to 2-year leys, high N, grazed 3 to 5-year leys, low N, grazed 3 to 5-year leys, high N, 1 cut then grazed	3	2	1
3 to 5-year leys, high N, grazed	4	3	2

Table 20 Current recommendations for N, P, K and Mg requirements (kg/ha) for bulbs and bulb flowers, based on SNS, P, K and Mg indices from RB209 (8th edition, 2010). The amounts of nutrients applied in organic manures should be deducted

Nutrient	Index 0	Index 1	Index 2	Index 3	Index >3
N*	150	100	50	0	0
P2O5	200	150	100	50	0
K2O	300	250	200 (index 2-) or 150 (index 2+)	60	0
MgO	150	100	0	0	0

* Apply N as a top-dressing just before crop emergence. A top-dressing of 50kg N/ha may be required in the second (or subsequent) year if growth was poor in the previous year.

Deciding on fertiliser type and time of application

The optimum timings for fertiliser application should be decided (this information is given in *RB209*) and the best match of available fertilisers determined. Note that the N and other requirements shown in Table 20 are the amounts (in kg/ha) of actual N, actual P_2O_5, etc., to be applied. A fertiliser (e.g. ammonium nitrate) will contain a certain percentage of actual N (e.g. ammonium nitrate contains 34% N); the amount of ammonium nitrate (in kg/ha) to be applied is calculated as (100/34) x (the amount of N indicated in Table 20). Thus, for an N indication of 100 kg/ha, the amount of ammonium nitrate to be applied is ((100/34) x 100) = 294 kg/ha.

Keeping records

For future reference, it is important to keep a clear record of the fertilisers applied.

Sulphur

The deposition of the plant nutrient sulphur (S) from the atmosphere is declining, but no information is available on the effects of low S on narcissus. The main bulb-growing areas of the UK receive less than 20 kg/ha of sulphur deposition per annum, a level that with some other crops in some soils would require attention. Deficiency of S is unlikely to occur if there have been regular inputs of organic manure.

Fertiliser applications in the planting year

Depending on the SNS, P_2O_5, K_2O and Mg indices, apply the rates of fertiliser shown in Table 20. Note that:

- N, P_2O_5, K_2O and Mg should ideally be applied as 'straight' fertilisers, avoiding the unnecessary application of an excess of one nutrient, and N should be separately applied just pre-emergence rather than pre-planting. For convenience, however, some growers prefer to use a compound (NPK) fertiliser before planting. In this case, the rate used should be based primarily on the N requirement.
- Otherwise, apply P_2O_5, K_2O and Mg fertilisers after ploughing, and work in before planting. P and K move too slowly down the soil profile to be used as top-dressings.
- Apply N as a top-dressing shortly before crop emergence – if applied later it can scorch foliage. The aim of delaying N application is to reduce leaching by winter rainfall, which would occur with a summer/autumn application.
- If necessary, apply Mg as kieserite or calcined magnesite, unless liming is necessary, in which case use magnesian limestone.
- K is commonly applied as muriate of potash, but in very dry soil conditions and at indices of 0 or 1 there is a risk of excessive salt concentrations and reduced rooting, and sulphate of potash should be used instead.

Fertiliser applications in later years

In the second (or subsequent) crop years no fertilisers should be applied unless growth has been obviously poor in the earlier year, for example, if shown by pale foliage. In this case, a low rate of N (50 kg/ha) can be top-dressed before crop emergence. K_2O is said to be beneficial in the second year of growth.[20]

Regional differences in fertiliser recommendations

The information in *RB209* refers specifically to England and Wales. Equivalent recommendations for Scottish growers have been published recently, and relate to Scottish crops and experience.[21]

Variant application techniques

There may be advantages in applying fertilisers as a split-dose application, pre-planting and as a spring top-dressing, countering the effect of rain.[22,23] However, UK trials showed there is no particular advantage of using a split-dose fertiliser application (compared with applying N as a winter/spring top-dressing and the other nutrients by pre-planting incorporation), of applying repeated high doses of N, or of applying fertiliser into the ridges at planting instead of broadcasting.[24] Applying N and P as different rates of di-ammonium phosphate showed no clear response in plant growth.[25]

Minor nutrients and trace elements

- Manganese (Mn) deficiency may occur on soils with a high pH, so on such soils Mn sprays should be applied before the deficiency becomes evident.
- Specific deficiencies of trace elements – boron (B), copper (Cu), manganese (Mn) and molybdenum (Mo) – have not been reported for narcissus:
  - In general, B deficiency is more likely to occur on sandy soils with a pH >6.5.
  - Cu deficiency may occur on peaty soils or sands or organic soils over chalk, along with, if over-limed, Mn deficiency.
  - Mo deficiency is associated with soils of low pH.
  - Leaf and soil analysis could be carried out if trace element deficiencies are suspected.
- One research report revealed there were no differences in yields between different fertiliser treatments, except that flower yield was increased when B was applied.[26] Omitting B has also been described as resulting in water-soaked areas in the base part of leaves.[9]
- A report on the flower defect 'melting' of tazetta narcissus grown in the South-West suggested that it was a result of boron-deficient soils. In one trial, applying a boron foliar feed (as 2 to 16 kg 'Solubor DF'/ha) greatly reduced the percentage of flowers affected.[27]
- Calcium (Ca) is important for narcissus root growth and bulb yields.[4, 9]
- Omitting iron (Fe) in trials resulted in chlorosis near the base of leaves.[9] It has been reported for hydroponically grown narcissus that bulb treatment with the growth regulator paclobutrazol increased Fe uptake and reduced zinc (Zn) uptake, though with no effects on growth.[28]
- Sodium (Na) fertilisers are not known to result in any response in narcissus.

Organic fertilisers

Organic fertilisers can be used, but high rates must not be applied shortly before planting. The following are some examples of findings from trials:

- In US trials, applying ammonium sulphate (0.5 t/ha), 5:10:5 N:P:K fertiliser (1.5 t/ha) and rotted manure (4 t/ha) each about doubled bulb yield compared with no added fertiliser.[29]
- Well rotted FYM applied to the previous crop at up to 75 t/ha may be useful in soils where organic matter is low. Trials in the UK showed no advantages of using different particular types of bulky organic fertilisers.[30]
- Little is known of the use of sewage sludge on bulbs, but is not recommended where bulbs are being grown for overseas sales because of the possibility of contamination with PCN.
- Care should also be exercised in applying plant and other wastes from processing, because of the possible effects of residual solvents or other harmful materials.

Composted bulb waste

Some Dutch trials showed that properly composted waste from bulb growing (including bulbs with basal rot) could be safely spread on bulb fields.[31] Narcissus growing produces 3 to 5 m³/ha of waste from the field, and 1 t/ha from bulb forcing.[32] Clearly, this practice should be adopted only if there is assurance that the composting process will be properly completed.

Mycorrhizal fungi

Mycorrhizal fungi live in the roots of some plants, where they enhance the uptake of phosphates and possibly other nutrients. Amongst other instances, the endomycorrhizal fungus *Glomus* has been found to be widespread in narcissus in Scotland.[33,34,35,36] In experiments with *Narcissus tazetta*, inoculation with *Azospirillum* improved productivity in sandy soils, even when N fertilisers had been applied.[37] Despite this, as far as is known, no attempts have been made to exploit mycorrhizae in commercial narcissus growing.

6.3 Soil sterilisation (disinfestation)

Soil disinfestation in Dutch bulb growing

In the Netherlands bulbs are usually grown in sandy soils, in which nematodes can move freely in the water film. Under these circumstances, it has been necessary to use soil sterilisation routinely to control nematodes.[38] Soil sterilants or fumigants formerly used included metam-sodium and 1,3-dichloropropene, and these had to be used at sufficient depth to control the target organisms – up to 40 cm for *Pratylenchus penetrans*.

Soil sterilisation in the UK

In the UK narcissus are usually grown on heavier soil than in the Netherlands, and therefore soil disinfestation is not routinely necessary for controlling nematodes. However, soil disinfestation may have value in specific, small-scale operations:

- It has been used to control virus-vector nematodes in the bulking and maintenance of virus tested stocks.
- It may have a role in managing 'soil sickness' in tazetta cultivars grown in the Isles of Scilly.
- It is known to control soil-borne fungal diseases such as white root rot[39] and 'base plate rot' (this is distinct from basal rot).[40]

It was formerly possible to use formaldehyde to treat stem nematode-infested patches in a crop, but no replacement material is available for this use.

Soil sterilants or fumigants

Methyl bromide, now phased-out, was much used for soil sterilisation because of its wide spectrum of activity and effectiveness under a wide variety of soil conditions. The products currently available for soil disinfestation in the UK are shown in Table 21.[41,42] All three active substances can be useful fungicides, and soil pests (including nematodes) and weeds can be targeted by using the appropriate material and rate. Some contractors offer combined treatments, with soil sterilants applied at different depths or at different times.

Soil sterilants/fumigants have many drawbacks to their use:

- They are highly toxic: chloropicrin is a Part 1 Poison, while dazomet and metam-sodium work by releasing methyl isothiocyanate on contact with moist soil.
- Chloropicrin and metam-sodium may only be applied by appropriate contractors, and dazomet requires the used of specialist applicator.
- All require sealing of the soil surface after use using polythene sheeting or smearing and repeated watering.

Further details of sterilants/fumigants and soil disinfestation are given in HDC Factsheet 09/07.[43]

Alternatives to soil sterilants

With the loss of soil sterilants, alternative techniques are being investigated, and these are also described in HDC Factsheet 09/07.

- Steam-sterilisation was the standard treatment before methyl bromide was adopted, and is now being 're-invented'. Suitable boilers and equipment are being developed in the UK for use under glass or other protected structures, and even in the field. Various forms of steaming are available: more details are given in the factsheet cited above.
- Trailed equipment, for directly heating soil and returning it as a bed, for burning and disinfesting the soil surface using propane, or for sterilising soil by hot air, have been developed in the UK, the Netherlands and elsewhere and have used commercially. Soil heating by radio frequency and microwave treatment is also being developed.

Table 21 Approved sterilants/fumigants for soil disinfestation

Active ingredient	Organisms controlled	Product names	Expiry date (for use)	Marketing company	Field of use
Metham-sodium	Controls fungi, nematodes and weeds at higher doses	'Discovery'	31/12/2014	United Phosphorus	For all except 'Metham Sodium 400': potting soil, other soil (indoor or outdoor) (before planting non-edible crop) For 'Metham Sodium 400', contact CRD for crop/use information
		'Fumetham'	31/12/2014	Chemical and Nutritional Supplies	
		'Metam 510'	31/12/2014	Taminco	
		'Metham Sodium 400'	31/12/2014	United Phosphorus	
		'Sistan'	31/12/2014	Universal Crop Protection	
		'Sistan 38'	31/12/2014	Universal Crop Protection	
		'Sistan 51'	31/12/2014	Universal Crop Protection	
		'Vapam'	31/12/2014	Willmot Pertwee	
Chloropicrin	Fungicide, higher doses control weeds and nematodes	'Custo-Fume'	Emergency 120 day authorisation beginning 1 Feb 2014	Custodian Computer Services	Ornamental plant production (outdoor and protected)
		'K&S Chlorofume'	Emergency 120 day authorisation beginning 1 Mar 2014	K&S Fumigation Services	Soil intended for growing ornamental plant production
Dazomet	Fungicide, also controls many soil pests, nematodes and weeds	'Assassin'	31/12/2021	AgriGuard	Soil (intended for cropping), soil for compost making
		'Basamid'	31/12/2021	Certis	
		'Basamid'	31/12/2021	Kanesho Soil Treatment	
		'Sterisoil'	31/12/2021	ChemSource Ltd	

- In the Netherlands flooding has been used successfully to control pests and pathogens, though it requires the availability of fields where the water table can be closely controlled.[44]
- In the Netherlands the cultivation of *Crocosmia* and especially *Tagetes*[45] has been tested and found to be an effective way of controlling nematodes (*Pratylenchus* species) and boosting yields when growing the disease-susceptible cultivar 'Tête-à-Tête'. Other species, notably *Brassica*, are also being tested as green manure biofumigants for controlling pests, diseases and weeds.
- Beneficial fungi (such as *Trichoderma* species) and organic soil amendments (such as composted green waste) are being investigated for their suppressive effects on soil-borne plant pathogens, though it is likely that a good deal of research will be needed before effective, practical techniques are available.

Management of 'soil sickness' on the Isles of Scilly

In HDC Projects BOF 50 and 50a the control of 'soil sickness' in tazetta cultivars was investigated on the Isles of Scilly at using 'problem' sites at which root lesion nematode (*Pratylenchus penetrans*) and the pathogenic fungus *Cylindrocarpon destructans* were present.[46,47] The treatments were growing *Tagetes* pre-planting, standard soil sterilisation using 1,3-dichloropropene (as 'Telone II'), and a combined treatment. Bulbs of tazetta cultivars 'Royal Connection' were then planted. After two growing seasons, the combined treatment gave the highest crop vigour and lowest *Pratylenchus* levels, while the single treatments (*Tagetes* alone and 1,3-dichloropropene alone) also produced measurable improvements. After a third season, improved plant vigour was still evident on only one of the two trial sites (where it continued to be so for the total of five years that the site was monitored), though effects on nematode numbers were no longer apparent. The reason for the discrepancy in results between the two sites is not known, but nematode levels fluctuated considerably over the five-year trial period. Although 1,3-dichloropropene was withdrawn in 2008, it is possible that one of the remaining sterilants/fumigants (Table 21) might be substituted.

Using Tagetes

In the 'soil sickness' projects, *Tagetes patula* 'Ground Cover' was sown 1.5 to 2 cm deep in late-June at a seed rate of 5 kg/ha.[48] For good germination, the soil should be moist during the first few days after sowing. The crop is rotovated in after growing for three months and is an effective green manure, contributing some 20 t/ha (dry matter) and 50 to 100 kg of N/ha.

6.4 References

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7.0 Bulb handling up to hot-water treatment

7.1 Handling and hygiene

Handling

As with any fresh produce, careful handling of bulbs is important, though largely a matter of common sense. The precautions taken should include reducing and cushioning drops during bulb handling, so reducing bruising and other physical damage that not only detract from visual quality, but can also provide entry points for infection.

UK and Dutch research has shown that, although viruses are not likely to be spread by bulb-to-bulb contact or by alternately handling infested and non-infested bulbs, transmission of some narcissus viruses - narcissus mosaic virus, narcissus latent virus and narcissus yellow stripe virus - via sap is possible.[1] Damage that might allow sap to be transferred between bulbs should be avoided.

Hygiene in general

Soil and other debris are sources of possible contamination with stem nematode, bulb-scale mite, fungal propagules, etc. Hygiene must be considered not only for the bulbs themselves, but also in respect of containers, working surfaces, equipment, implements, vehicles, buildings and roadways – anything that could come into direct or indirect contact with bulbs and potentially spread pests or disease. Bulb stores, drying walls, grading lines and similar areas should be deep-cleaned in advance of the season, physically removing dust before using a disinfectant (biocide). During the season, the floors of critical areas – such as around HWT tanks - should be regularly cleaned, preferably by vacuuming.

Grading lines are a major site for dust. They should be cleaned of accumulated soil and debris on a daily basis, and disinfected, daily, and particularly after dealing with any diseased stock. Under COSHH, the limit for exposure to dust is 10 mg/m^3 on a time-weighted average for an 8 hour shift.

Where practical to arrange, staff should not carry out dirty jobs before moving on to deal with cleaned or dipped bulbs. Where there is opportunity to design the layout of a facility, dirty or dusty areas (bulb grading areas) should be sited away from, or down-wind of, clean stores.

To stress the importance of hygiene:

- Bulb skins and other trash from a stock that had 11% of bulbs infested with stem nematode yielded 210,000 nematodes per 1,000 bulbs.[2]
- Nematode wool is known to survive in its dry state for 10 years in the absence of a host.[3]
- Chlamydospores of the basal rot fungus can remain viable for up to 10 years under some conditions.[4]

Disinfectants should be made up fresh for each use, following the manufacturers' advice. Where disinfectant boot-dips or wheel-washes are used, they should be topped-up or replaced with fresh disinfectant regularly. Disinfectants may become rapidly inactivated as they are contaminated with soil and other matter; 'dip-sticks' for testing the strength of solutions may be available.[5]

Choice of a general disinfectant for use in narcissus production

As well as physical cleaning – sweeping, vacuuming and washing down – bulb producers should choose a suitable disinfectant (biocide) for general use. Ideally, it should also be suitable for use in HWT, as well as for general cleaning and disinfecting. The disinfectant should have most or all of the following qualities:

- Non-phytotoxic.
- Wide spectrum of activity, but particularly against *Fusarium*, *Botrytis, Penicillium*, other fungi and stem nematode.
- Activity both at ambient and HWT temperatures.
- Compatibility with other chemicals used in HWT.
- Not rapidly inactivated in the presence of organic matter, such as soil.
- Non-corrosive where in contact with metal parts.
- Non-hazardous to operators, and not unpleasant to use.
- Inexpensiveness.

Use of 'commodity substances' and disinfectants

Some disinfectants have been recognised as 'commodity substances'. These are substances that have a variety of non-pesticidal uses in a variety of industries, but also have minor uses in agriculture, horticulture or animal husbandry. Their approval, under The Control of Pesticide Regulations, was on the basis of the active ingredient rather than the product: there was no approval holder or pesticide product label, and approval was required for use only (not for sale, supply, storage or advertisement). Both formaldehyde (as commercial formalin) and peroxyacetic acid/peracetic acid disinfectant (including 'Jet 5') were formerly approved as commodity substances.

Although subject to the EU Biocidal Products Directive, disinfectants fall outside the Plant Protection Product Regulations (PPPR) - provided that no pesticide activity is claimed; if such activity is claimed, the disinfectant would be treated as a pesticide. If no pesticide activity is claimed, a disinfectant may be used in agriculture and horticulture without reference to PPPR, provided it is not (at some later date) revoked through the EU review of biocides.

Classes of disinfectants

Many types of disinfectant are available, often with a wide choice of product within each type. A classification of disinfectants, with examples and some general characteristics, is given in Table 22, adapted from HDC Factsheet 15/05[6] and HDC Project CP 4,[7] which should be consulted for further details of usage, disposal, etc. The list of available disinfectant products changes rapidly: some products listed may no longer be available, while others may have become available, so the latest information should always be sought. 'Natural disinfectants' (such as 'Sporekill'[8]) are likely to become more common.

Formaldehyde (formalin)

Formaldehyde (as 'commercial formalin') was the disinfectant of choice in narcissus production for many years, and was used in bulb dips, including HWT, and as a general disinfectant. This use was withdrawn in 2008. Formaldehyde, when correctly used, complied with most of the requirements set out above (except for being non-hazardous and not unpleasant in use), and was regarded as a crucial element in bulb production. Following reconsideration by the EU of the hazards involved in using formaldehyde, its 'Essential Use' approval expired in 2008. At that point no practical alternative disinfectant or pesticide had been identified for use in narcissus production and, pending the results of further trials, no firm recommendation can yet be given.

Iodophor disinfectants

From the trial results mentioned below, iodophor disinfectants would appear to be effective for general use in bulb growing. The manufacturer's or supplier's recommendations for specific products should be followed carefully. Recently, an iodophor disinfectant ('FAM 30') has been tested for use in HWT.

Phenolic (cresylic acid) disinfectants

Although slightly less effective than iodophore disinfectants in the trial described above, cresylic acid disinfectants have long been recommended for general use around bulb husbandry. The older literature may contain specific recommendations,[9] but the manufacturer's or supplier's current recommendations for specific products should be checked and followed carefully.

Trial of disinfectants for general use

Most disinfectants are active against fungi, but few against nematodes. In HDC Project BOF 49 several disinfectants were tested for their potential use in disinfecting bulb equipment and working surface. The tests were carried out by immersion in standard concentrations of disinfectants at ambient temperatures, and with and without soil contamination, against free-swimming and wool-stage stem nematode.[10,11] The results were:

- An iodophor disinfectant was most effective against active nematodes, giving 100% mortality in less than five minutes.
- Benzoic acid and high boiling point tar acid (HBTA) disinfectants were somewhat less effective against active nematodes, with 100% mortality in under 20 minutes.
- The other disinfectants tested - peroxygen compounds, peroxyacetic acid, formaldehyde and quaternary ammonium compounds (QACs) - failed to give 100% mortality of active nematodes in less than one hour.
- When soil contamination was present, the disinfectants were less effective against active nematodes than when in clean water, with the time to 100% mortality increased by two- to five-fold.
- None of the materials tested controlled wool-stage nematodes within 10 minutes.

Preliminary cleaning

Disinfectant compounds may be absorbed or inactivated by soil, other debris, oil, grease and some metallic surfaces. Before spraying, dipping or fogging surfaces, stores and equipment, these should be cleaned using an industrial vacuum cleaner, steam cleaner or power-washer. A suitable disinfectant can be added to the water used in pre-cleaning, with the addition of a non-ionic wetter if recommended.[12]

Disinfection of surfaces, stores, storage areas and large equipment

The exact recommendations will depend on the manufacturer's guidance.

- For this purpose the disinfectant should be applied through a coarse spray to thoroughly wet the surfaces. Some disinfectants should be left after application to work for one hour. If the surfaces treated are liable to corrosion, they should be rinsed with water after an appropriate interval.
- Buildings can be fogged with commercial, fixed-position equipment, using suitable disinfectants. The building should be left sealed for an appropriate interval before ventilating.

Disinfection of bulk bins, containers and implements

- Containers and some small items can be cleaned and then sterilised in HWT tanks. A treatment of 50°C for 10 minutes is considered sufficient to kill stem nematode. Another recommendation is for a 'dip' at 85°C.[13]
- Though standard HWT should kill stem nematode by heat alone, a suitable disinfectant is often added to the tank to augment this effect and control other organisms.
- It is not unusual to find small bulbs and other debris jammed between the slats of washed or treated bulk bins, so physical cleaning is also needed.
- After a pre-wash (if needed), suitable implements can be immersed for a short time in a suitable disinfectant, afterwards leaving the equipment to stand for a suitable time before use.

Disinfection of vehicles

Vehicles and large machinery are among the most difficult items to clean effectively, though with the large numbers of bulb movements between South-West and Eastern England, this should probably be considered as quite important. Wash-down facilities should be provided at the entrance to main bulb-handling areas. Vehicular access around the bulb-handling facilities should be restricted to necessary movements, and sufficiently large wheel dips should be constructed, or a vehicle-sized disinfectant mat used.

Fumigation of bulbs in store

Fumigation with methyl bromide was formerly used to control bulb-scale mite in stored bulbs.[14,15,16] However, this is no longer possible as the remaining 'critical' exemptions for using methyl bromide expired on 18 March 2010. Other options for in-store fumigation to control bulb-scale mites were considered in HDC Project BOF 63, but it was concluded that no suitable fumigants were available at this time for use in stores containing produce.[17]

Fumigation by methyl bromide has also been used to control large narcissus fly larvae (and possibly other pest insects), for example, when required for exported bulbs.

Table 22 Examples of disinfectants that have in the past, or could potentially be used in horticultural crops

Class	Active ingredient	Product examples	Comments on class
Alkali	Sodium hydroxide	(various)	Commodity chemicals, broad spectrum, too caustic for general use.
	Calcium oxide	(various)	
Biguanide/ biguanidine	Chlorhexidine	Nolvasan	Mainly for bacteria and therefore unsuitable for most horticultural applications; also inactivated by organic contamination.
		Virosan	
Cationic surfactant (quaternary ammonium compounds, QACs)	Benzalkonium chloride	Antec Ambicide	Non-corrosive, non-irritating, penetrative (when combined with a wetting agent), varied and selective effects on micro-organisms, less active if organic contamination, oils or waxes present, some expensive, some cause foaming or leave residues.
		Antec HD3	
		Hortisept	
		Menno Ter Forte	
		Vitafect	
		Quatchem BC50	
	Combined types with QACs		
	QAC + biguanidine	GPS 8	
		Vitafect	
	QAC + inorganic acids	Hortisept	
		Horticide	
	QAC + aldehyde	Unifect G	
		Vitafect PepMV	
Halogens and halogen-releasing compounds (chlorine-based)	Sodium hypochlorite (bleach)	(various)	Bleach is a commodity chemical. Release chlorine when activated; broad spectrum but slow for spores, work at cool temperatures, unaffected by lime scale, short residual effect, may be corrosive, precipitate in iron-rich water.
	Sodium dichloroisocyanurate	-	
Halogens and halogen-releasing compounds (iodophor)	Iodine/phosphoric acid	Antec Virudine	Iodine in a phosphoric acid base, usually with surfactants. Broad spectrum except for bacterial spores, work at ambient temperatures, may stain metals or plastics, may corrode aluminium, may be expensive.
		FAM 30	
		Deosan Iodel FD	
Halogenated tertiary amine	Halogenated tertiary amines	Avisafe	Broad spectrum, benign (use in bird houses), stable in solution for a long time, non-corrosive, biodegradable.
		Trigene	
Organic acids (aliphatic acids)	Citric acid	(various)	Commodity chemical, inexpensive, some biocidal activity.

Table 22 Examples of disinfectants that have in the past, or could potentially be used in horticultural crops continued

Class	Active ingredient	Product examples	Comments on class
Organic acids (aromatic acids)	Benzoic acid	-	Good activity except against algae.
Oxidising agents (peroxides)	Hydrogen peroxide	Antec Hyperox	Broad spectrum (including spores), effective in cold, effective with organic contamination, hydrogen peroxide and peroxyacetic acid products are environmentally benign.
	Peroxyacetic acid	Jet 5	
		Sanpox P	
Oxidising agents (peroxygen compounds)	Peroxygen compounds	Jet 5	As above but generally safer to handle.
		Sanpox P	
	Combined types with peroxygens		
	Hydrogen peroxide + formic acid	Reciclean	
	Hydrogen peroxide + silver	Sanosil	
	Hydrogen peroxide + peroxyacetic acid	Sorgene 5	
	Peroxygen compounds + organic acids	Virkon S	
Phenols (high boiling point tar acids, HBTAs)	Carbolic acid	Farm Fluid S	Broad spectrum, potent, acidic, may be corrosive, effective in cold and with organic contamination, strong odour, may be corrosive.
	Cresylic acid	Longlife 250S	
		Jeyes Fluid	
Phenols (synthetic and chlorophenol)	Hexachlorophene	-	Neutral and lack the odour and staining properties of HBTAs; less broad spectrum than HBTAs, and some question of environmental safety.
	Troclosan	-	
	Dichlorophen	Panacide M	
		Enforcer	
Reducing agents	Glutaraldehyde	Horticide	Wide spectrum, slow acting, hazardous to operators, temperature-dependent.
	(formaldehyde)	Unifect G	
Plant extracts	Essential oils	-	Harmless to users and environment, expensive, some anti-bacterial and anti-fungal effects, expensive, efficacy equivalent to synthetics remains to be proven.
	Citrus extracts	Citrox P	

7.2 Bulb storage up to HWT

General storage conditions

Correct bulb storage conditions are always important, and this includes any holding period before HWT and planting.

- Bulbs can be stored in loose bulk, bulk bins (wooden or plastic, half- or one-tonne capacity), net bags (holding 25 kg bulbs), bulb trays, or a variety of other containers.
- Ideally, storage should be at 17-18°C in a controlled-temperature store with good air movement, some exchange of fresh air, and a relative humidity below 75%.
- Using a controlled temperature store will greatly improve the health of the stock by avoiding exposure to the higher temperatures (>20°C) that favour basal rot development and the multiplication of stem nematode and bulb-scale mite. Lower temperatures (<17°C) slow shoot development, which may be a problem in some cases. Low humidity desiccates bulbs excessively, while a relative humidity >75% encourages fungal growth and the premature emergence of roots (which will then be damaged in handling).
- If stored in loose bulk or bulk bins, air movement through the bulbs should be maintained through a drying floor, letter box wall, or some form of fan over or attached to the bin. If stored in bulb trays with adequate ‘upstands’ (corner posts projecting above the bin sides) in a suitable location, passive air circulation may be adequate.

- Where damp air is being drawn into the store, condensation on the bulbs can be a problem. This might be eliminated through dehumidification, but this has rarely been used in bulb stores and there are no data to support it. Alternatively, an intake of fresh air might be used only when conditions outside are appropriate.
- In practice, bulbs are often stored at ambient temperatures in a variety of buildings or even outside. If this is unavoidable, containers should at least be protected from sun, rain and contamination with plant or soil debris. This should apply even when 'parking' bulbs temporarily whilst moving around the farm.

Narcissus roots

The roots of narcissus bulbs form over a short time and emerge simultaneously. They are limited in number and in their ability to re-grow once damaged. When, in experiments, the roots were repeatedly excised, new roots developed from the base plate, but their number was progressively reduced and plants failed to flower.[18]

If roots sprout from the base plate under damp conditions and continue to grow in storage, they are liable to become damaged before or at planting, sometimes significantly so.[19] Any emerged roots in bulbs for HWT will be seriously damaged by the treatment, resulting in seriously stunted plants.

7.3 Treatments to reduce damage due to HWT

HWT damage and the basis of pre-warming

Even properly done, HWT reduces crop vigour and may damage the flower bud within the bulb, though such damage is far outweighed by the benefits of controlling stem nematode. In any case, the loss of bulb yield is insignificant over a two-year growing period.

In the South-West the first-year flower crop has always been the more important part of the industry. Treatments have, therefore, been developed that reduce flower damage and yield loss caused by HWT in the year following treatment, based on pre-warming (warm storage of bulbs before HWT). The elevated temperatures of pre-warming appear to slow the development of the shoot initials and make them less sensitive to disruption by high temperatures. The value of pre-warming Lincolnshire-grown bulbs was investigated in HDC Project BOF 12.[20] Warm storage also extends the window in which HWT can be carried out safely.[21]

Like HWT, pre-warming itself can decrease the subsequent vigour of the bulbs, though this should be more than balanced by the beneficial effects on the first-year flower crop.[22,23] Pre-warming also makes stem nematode more resistant to control: this, in turn, needs to be countered by soaking the bulbs at ambient temperatures before HWT ('pre-soaking') and using a higher HWT temperature (usually 46°C).

The following sections are based on UK research. There are significant differences between UK and Dutch advice and practice on this subject, and it is important to understand these differences.

Pre-warming and pre-soaking

Pre-warming partly desiccates the bulbs, which may induce any stem nematode present to migrate to the outside of the bulbs, usually near the base plate, where they exude as blobs of 'nematode wool'. The wool easily scatters in draughts, disperses in the dip during HWT, and is resistant to desiccation and relatively resistant to high temperatures. The formation of nematode wool can be combated by pre-soaking before HWT, since that re-hydrates the wool and makes it susceptible to HWT-temperatures, and by using a higher HWT temperature (46.0°C).

The following is the recommended procedure to be used for bulb stocks in which there is no suspicion of a stem nematode infestation:

- Bulbs should be completely dry when pre-warming is started. If they are not, the raised temperature will increase the relative humidity and could lead to a potentially serious development of soft rot (*Rhizopus*).
- Store bulbs for one week at 30°C before HWT. This is the traditional procedure regularly used in the South-West to reduce damage to the flowers caused by HWT.[24,25,26]
- The exact pre-warming treatment is not critical: regimes of three to eight days at 30 to 35°C are successful.[27,28]
- Pre-warming should always be used with HWT-sensitive narcissus such as poeticus cultivars and 'Tête-à-Tête'.[29]
- When pre-warming has been used, the bulbs are pre-soaked before HWT, by immersing the bulbs at ambient temperatures for three to four hours (or overnight) immediately before HWT. Normally a suitable disinfectant is added to the pre-soaking tank to control the spread of pests and pathogens.
- After pre-warming and pre-soaking the HWT temperature is increased, usually to 46.0°C, the duration of HWT remaining at three hours.

If the bulbs to be treated are known to be (or are suspected of being) infested with stem nematode, the above routine should not result in any nematode problem, provided that a suitable disinfectant is available for use in the pre-soaking and HWT tanks and the correct duration and temperature are used for HWT. However, following the withdrawal of formaldehyde, until a suitable replacement disinfectant is available, pre-soaking should be avoided.

Storage at 18°C (sometimes called 'partial pre-warming')

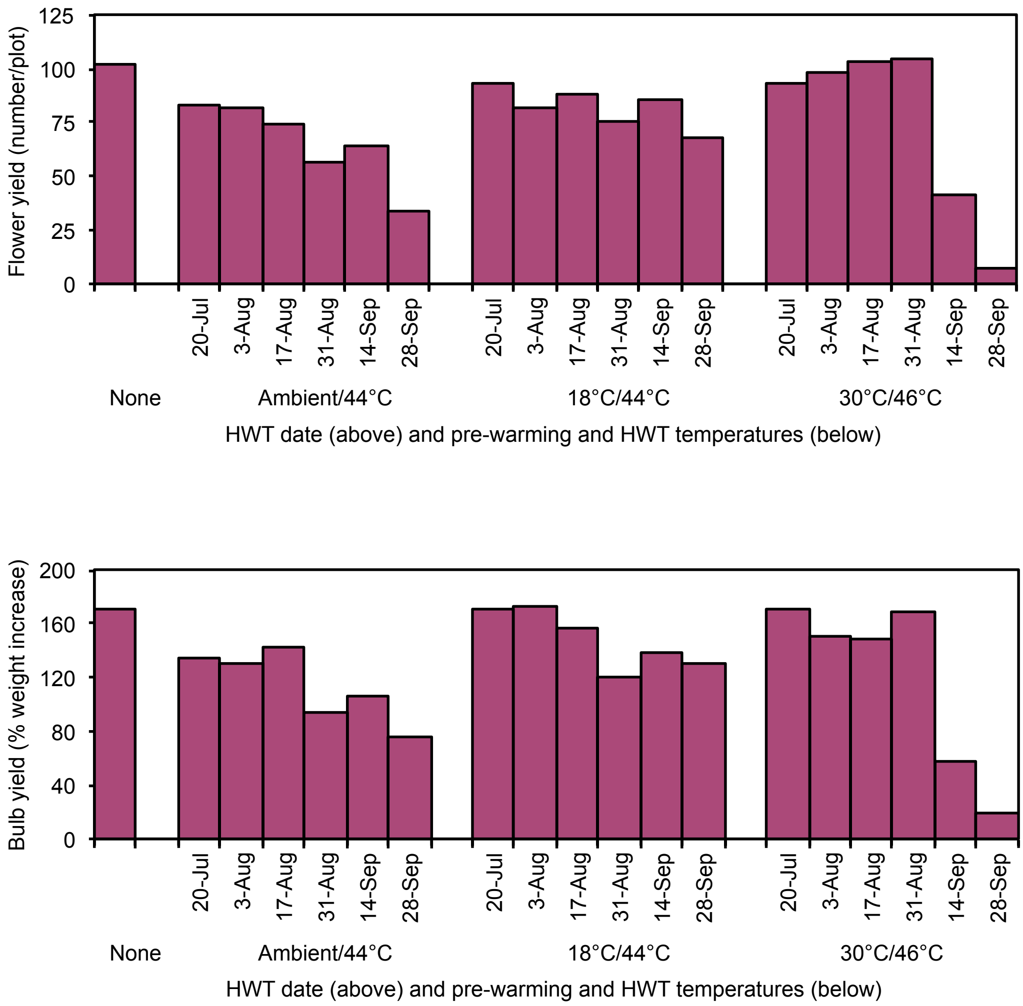
The lower limit of the warm-storage effect is about 18°C. If bulbs are stored for two weeks at 18°C before HWT - where the summer weather might otherwise mean storage would have been at lower temperatures - HWT damage can also be prevented.

Unlike pre-warming (say, one week at 30°C), a treatment of two weeks at 18°C does not require bulbs to be pre-soaked, nor is a higher HWT temperature needed – the usual three hours at 44.4°C is sufficient. Assuming that the temperature of HWT alone will control stem nematodes, an 18°C treatment offers a way around the loss of formalin in the pre-soak tank.

Pre-warming (seven days at 30°C), partial pre-warming (14 days at 18°C) and storage at ambient temperatures of 'Carlton' bulbs in Lincolnshire were compared at Kirton in the late-1980s, when flower cropping was becoming more usual in Eastern England (HDC Project BOF 12).[20] Bulbs were lifted on 15 or 29 June and 13 July and HWT was given on 20 July, 3, 17 or 31 August, or 14 or 28 September. Pre-warmed bulbs were also pre-soaked and HWT was at 46.0°C; bulbs treated at 18°C or stored at ambient temperatures were not pre-soaked and HWT was at 44.4°C. The main findings were as shown here:

- In the first crop year, flower yields were much reduced if HWT was given after 17 August following ambient storage or after 31 August following pre-warming, but were only slightly reduced following partial pre-warming even following HWT on 28 September. The poor plots were associated with stunted growth and flower damage.
- In the second crop year flower yield was much more consistent: only those treatments that were worst affected in the previous year showed reduced flower numbers and stunting.
- Bulb yields were much reduced after late HWT, especially if pre-warming had been used, while partial pre-warming reduced the effects of late HWT to a large extent. In the poorest treatments, a high proportion of the lift was in the smaller bulb grades.
- In this case the untreated controls (no HWT) gave good yields: this illustrates the unavoidable detrimental effects of pre-warming and HWT on vigour, which has to be accepted in order to control any stem nematode infestation.
- In broad terms, these results were little affected by varying the lifting date.
- Figure 10 exemplifies this information, using data for the middle lifting date: flower and bulb yields are relatively unaffected by late HWT where bulbs have been pre-treated at 18°C, whereas late HWT progressively reduces yields following ambient or 30°C pre-treatments.

Figure 10 Second-year flower yields and bulb yields for 'Carlton' lifted on 29 June and given different pre-warming and HWT



Cultivars susceptible to HWT damage

'Carlton' is one mainstream cultivar that is regarded as being relatively sensitive to HWT damage, so it often used in trials for this reason. Dwarf cultivars, such as 'Tête-à-Tête', are also susceptible to HWT damage. In trials at Kirton with 'Tête-à-Tête', pre-warming (one week at 30°C), pre-soaking and HWT at 46°C prevented HWT damage, but storage for two weeks at 18°C before HWT (at 44.4°C) did not; however, bulb production after two-year-down growing was not reduced by omitting pre-warming.[31]

Implications of the withdrawal of formalin

Adding the disinfectant formalin to cold dips and HWT tanks had been considered essential for the control of stem nematode and basal rot since the 1930s. Following the withdrawal of formalin for agricultural and horticultural uses in 2008, attempts have been made to find a replacement disinfectant. The iodophore disinfectant 'FAM 30' showed promise for bulb dip and HWT use.

- Until there is a definite replacement for formalin, when there is any doubt that a bulb stock is free of stem nematode bulbs should not be 'pre-soaked' (cold dipped prior to HWT to re-activate nematode wool) because of the likelihood of spreading pests and diseases in the absence of a disinfectant. This also means that neither 'pre-warming' (say for one week at 30°C) nor a higher-than-usual HWT temperature should be used, as these procedures depend on pre-soaking.
- Only stocks known to be free of stem nematode should be pre-warmed at 30°C (and should then be pre-soaked and treated at the higher HWT temperature of 46°C).
- However, bulbs could still be 'partially pre-warmed' (that is stored at 18°C for two weeks before HWT) as this does not require pre-soaking; following 18°C storage HWT is at the usual temperature of 44.4°C. This will still give protection from HWT damage (including late HWT).

UK and Dutch advice on pre-warming

Pre-HWT storage for one week at 20°C is recommended in some Dutch advisory material,[32] which conflicts with UK advice. Dutch advice on the warm-storage of early-lifted bulbs infected with stem nematode also differs. This states that warm storage for at least one week at 30°C should be used after lifting. UK advisors would strongly recommend against this practice because of the danger of nematode wool formation. These differences are probably connected with different climatic and husbandry factors in the two countries.

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8.0 Hot-water treatment

8.1 Overview of HWT and the HWT plant

Why HWT?

Much of the information in this section has been derived from the MAFF/ADAS Books Hot-water treatment of plant material [1] and Hot water treatment of narcissus bulbs,[2] augmented with information from the sources cited at the start of previous sections and other worldwide research.

Although HWT can be used to control pests and diseases in a variety of plant materials, such as chrysanthemum stools and strawberry runners, its main use is for narcissus bulbs. HWT is sometimes carried out under contract, though in the UK it is usual for bulb growers to have their own HWT plant. It is likely to be one of their main facilities dedicated to narcissus growing. However, HWT tanks can also be used for sterilising containers and equipment and for treating other produce that requires dipping at ambient or elevated temperatures, and developing alternative uses for them could offset some of the cost.

It is essential that all bulbs receive HWT before re-planting.

- All planting stocks should receive HWT to control stem nematode.
- Having no history of stem nematode in a stock does not mean HWT is unnecessary. HWT should still be given. An infestation of a very few nematodes can result in the destruction of a bulb within a year.
- HWT incidentally kills other pests and pathogens which have similar or lower tolerances to high temperature.
- When bulbs are being grown for more than one- or two-years-down, it is even more important to carry out HWT thoroughly.

There is no doubt that HWT is an energy-expensive, time-consuming and inconvenient procedure. At present, however, there is no practical alternative,[3] though some possibilities have been considered.

Types of HWT tanks

Three main types of tank are in use:

Front-loading tank

The most usual tank design in the UK, in which bulk bins are loaded and unloaded using a fork-lift truck through the front door in the tank, the dip solution having meanwhile been pumped to a holding tank (slave tank) (Image 48). When the tank holds more than a single stack of bins, one behind the other, it may be referred to as a 'drive in' tank.

Through-loading tank

Similar to the front-loader, but the bins are loaded by fork-lift truck through a door in one end and unloaded through another door at the other end. This allows untreated and treated bulbs to be segregated into 'dirty' and 'clean' areas of the bulb-handling facility, potentially reducing the risk of re-contamination. Some of these processes have the potential to be automated.

Top-loading tank

In the UK this is generally an older design of smaller tank with a hinged or removable lid, through which bulbs are loaded and unloaded using either an overhead hoist or a fork-lift truck with specially designed tines that hold the bins below them for insertion into the tank. Top-loading tanks of all sizes, loaded from an overhead gantry, are common in the USA, and they include both concrete tanks set into the ground and above-ground steel tanks (Image 49).

48 Typical front-loading HWT equipment with common holding tank above

Photo: Secker Welding

49 A top-loading HWT tank in the USA

Photo: Gordon Hanks

Alternatives to HWT

At present, no practical alternative to HWT is available for controlling stem nematode. As HWT is so critical an operation but has several disadvantages – it is slow, expensive on energy and labour, and creates problems with disposal – this is an area for potential technical developments. However, as HWT is generally acceptable and successful despite its disadvantages, there is little incentive to look for substitutes.

'Vapour heat' and vacuum infiltration

In the 1940s, a steam (or 'vapour heat') treatment was investigated. However, the regime necessary to control stem nematodes, eight hours at 47.7°C, had adverse effects on the crop.[4] It has been claimed that chemicals used in HWT do not penetrate below the outer bulb scales when bulbs are dipped at ambient temperatures unless a vacuum treatment is applied,[5] though it is not clear whether or not this has been assessed critically.

Nematicides

Nematicides have been previously tested as cold soaks, but were either ineffective or suitable chemicals are no longer available.[6,7,8] Currently there is no option for using a nematicide in HWT, as the materials formerly used have been withdrawn or are either toxic, ineffective or unreliable. [9,10,11,12,13,14,15,16] Of these, thionazin, pirimiphos-methyl, phoxim and carbofuran had the best effects, some preventing the multiplication of surviving nematodes for some time, until nematicide concentration in the bulb had declined.[6,7,17]

For soil incorporation and field applications the situation in the UK is similar – appropriate pesticides are either untested, unavailable or known to be ineffective.[6,7,8] However, field applications of nematicides have been used successfully in the USA.

Microwave and other technologies

In theory, a number of technologies might substitute for HWT. Small-scale tests of microwave treatments have been carried out, and, though the method showed promise, the cost of developing an on-line prototype plant that would heat bulbs without hot-spots was thought likely to be prohibitive.[18]

HWT tank capacity

HWT is a slow process, the 'rate-limiting step' in handling bulbs between lifting and re-planting, so it is important to have adequate HWT capacity. To carry out HWT within the safe window of three to four weeks, a grower's HWT capacity should take account of:

- The tonnage of bulbs treated annually.
- The number of tank-loads practical in a three to four-week period.

HWT tanks are usually built with capacities between 0.5 t and 10 t. Three loads should be possible over an extended working day, but '24/7' operation may need to be considered on larger enterprises. A worked example for determining the HWT capacity required is shown in Table 23.

Table 23 Calculation of HWT tank capacity

Parameter	Requirement
Bulbs to HWT for re-planting	650 t
Overall period for HWT	3 weeks
Number of HWT runs per week	18 (3 per day over a 6-day week)
HWT capacity required	650/(3x18) = 12 t (say 2 x 6 t tanks)

The HWT facility and location

The site for the HWT facility should fulfil a number of criteria:

- The HWT plant (tanks plus post-HWT ventilation/cooling/drying equipment) may be sited outdoors, in an open-sided shed, or inside a specific building that is adequately ventilated.
- The site should take account of the need for safe vehicular movements, sources of infection and the predominant wind direction (so that potential sources of infection are less likely to reach the site), and the need to avoid re-contaminating bulbs once treated.
- 'Clean' and 'dirty' areas should be separated, and the only exchange between them should be sterilised bulbs moving directly from the tank to the clean area. The 'clean' area should be upwind of the 'dirty' area.
- Roadways that are easily washed down are preferred, and a wash-down area should be provided for cleaning and disinfecting vehicles and equipment, with drainage away from the clean area. A wheel dip should be considered, large enough to cope with the largest tyres in use.
- The buildings and surrounds should be cleaned using an industrial vacuum cleaner rather than brushes, and debris should be buried or burnt off-site in a down-wind direction.
- Good air extraction should be provided in HWT buildings so that any fumes from the tanks and treated bulbs are removed. Fumes around HWT tanks, from disinfectants or pesticides or the formulations in which they are made up, should be treated as a source of concern: exposure will need to be minimised and monitored, if appropriate taking account of any maximum exposure levels (MEL).

HWT tank design

A well-designed HWT tank should have the features listed here.

Operator-friendliness

The design should take into account both the health and safety of operators and its convenience in use.

Adequate size

A water-to-bulb ratio of 3:1 (say, 3000 L/tonne of bulbs) provides an adequate 'buffer' against temperature fluctuations and provides good transfer to the bulbs. The bulbs at the top of the tanks should be covered by at least 2.5 cm of water.

Accurate and precise temperature control

Tanks need to operate over the range 40 to 50°C and with an accuracy of ±0.1°C. A precision of 0.1°C may seem demanding, but is the recommended standard. There should be reliable and easy-to-read temperature monitoring and recording equipment as this will encourage careful working and provides traceability.

Thermal efficiency

The heating system should be capable of providing both rapid initial heating and fine control of temperatures during treatment. There should be good insulation, allowing a stable temperature to be maintained and reducing heating costs.

High rate of water circulation

The pump, circulation and associated components should be designed to ensure an adequate flow of water at the correct temperature through the treatment tank and the heat exchanger. The pump should be capable of delivering five tank-volumes/hour in a free-flowing system (bulbs in nets or open cages; a minimum capacity of 15,000 L/hour for one tonne of bulbs) or eight to ten tank-volumes/hour with a vertical circulation directed through the bulk bins. The pump should be capable of handling some solids, this being preferable to fitting an inferior pump that needs integral filters that may clog and reduce water flow and should have sufficient head of pressure to cope with blockages. The pump and pipe-work should be designed to achieve adequate circulation without cavitation, since the latter leads to additional wear and tear and to foaming (stem nematode can survive on foam since it will have a slightly lower temperature than the water itself).

Construction using suitable materials

HWT tanks are usually constructed in mild steel. Although rust-inhibiting treatments such as galvanising are not generally used, the interior of tanks should be painted with an anti-corrosion paint (e.g. a zinc-based paint) as part of regular maintenance. Such paints are said not to interfere with the action of the chemicals used in the tanks, though following the withdrawal of formalin this will need to be verified with any new disinfectant adopted. It is possible that using acidic soaks or adding acidifiers could cause significant corrosion of the tanks and pipe-work over prolonged (several years) use. Stainless steel or Teflon surfaces would be inert, but probably prohibitively expensive. Pumps and plumbing too must be constructed from suitable materials in order to cope with the temperatures and chemicals in the HWT environment. If stones are not separated from bulbs before HWT, they can cause significant damage to components.

Bulb containment

HWT tanks are usually designed around handling bulbs in a suitable style of bulk bin. There should be some means of covering the open tops of bins with mesh to prevent the escape of bulbs, such as a wind-down mesh framework for the top bins and individual mesh covers for the lower bins.

Tank maintenance

Tanks should be serviced each year a few weeks in advance of the HWT season, remembering that they may be needed before the main season for treating contaminated stocks, early-lifted or reclaimed bulbs, or bulb boxes or trays. There is little scope for delay once the season has started.

- As well as checking the general operation of the tanks and associated equipment, it is important to test and validate temperature control and monitoring before use. However, the final settings should be checked in working tanks under a normal load of bulbs.
- For the manual checking of temperatures by the operator, a mercury-in-glass thermometer or temperature probe, supplied with a calibration certificate and having a range of at least 20 to 50°C marked in 0.1°C intervals, should be used. If practical, temperatures should be checked at the same point where temperatures are normally monitored. Any chart recorders should also be checked for accuracy. During the HWT season it is useful to have a robust digital thermometer handy to encourage regular checks to be carried out.
- At the end of the season the tanks should be thoroughly washed down and flushed out with clean water. Routine maintenance should be carried out then, and the tanks painted with a suitable anti-corrosion paint.

8.2 Hot-water treatment regimes

Timing of regular HWT

Routine HWT should be completed within the three- to four-week window when the bulbs are at the stage in which HWT will cause least damage to the bulbs. The timing of HWT is important for several reasons:

- To minimise flower and other crop damage, bulbs should be treated once the flower initials have been formed (‘stage Pc’) but before the root initials have developed too far (shown by the roots becoming obvious in the base plate).
- Though the stage of flower development used to be determined by dissection of the flower buds (the ‘internal stage of development’), it is now carried out by date. In the UK ‘stage Pc’ is reached in mid- to late-July in the South-West and in late-July to early-August in Eastern England, meaning that bulbs should receive HWT from late-July onwards, aiming to complete HWT no later than the end of August.[19] After that, the risks of damage increases with time, as roots and shoots prepare to emerge, and ambient temperatures fall.
- Cultivars that produce fine or early roots (poeticus, cyclamineus and jonquilla cultivars) should be treated first.[20] For standard cultivars the accepted order of treatments is small-cups, large-cups, and then trumpets.
- Dutch work has shown that recent offset removal increases the likelihood of infection, especially in some dwarf cultivars.[21] If offsets are removed, there

should be an interval of at least a week, to allow any wounds to seal before HWT is started.

- In certain cases HWT should (or could) be carried out earlier or later than normal.

Early HWT

Early HWT is used where the need to control a pest or disease outweighs the need to minimise flower and crop damage.

- Bulbs re-claimed from forcing may be given HWT early, in May or June.[22]
- Where there is a known (or suspected) nematode problem in a stock, the current UK advice is to lift bulbs early (in June) and clean, grade and carry out HWT promptly. Affected bulbs should be treated as soon as practical after lifting, in order to minimise storage time (when the stem nematode can multiply rapidly). In this case warm storage must be avoided as it leads to the formation of nematode wool.[19,23]
- If basal rot is a problem, then earlier HWT – say in mid-July rather than August - is more effective, though it will cause some damage to shoots and flowers.[24,25,26]
- Where flower quality is not important, an earlier start to HWT may be acceptable for logistical reasons. It is unclear *how* early a start may be acceptable, as the critical stage for avoiding damage to the leaf initials does not appear to have been documented.

Late HWT (and 'partial pre-warming')

Late HWT is more harmful than early HWT because it can lead to extensive damage to the leaves and roots, from which it may be difficult to recover. If late HWT is necessary for logistical reasons (there is no other reason to carry out HWT late), then the adverse effects can be mitigated to an extent by storing bulbs at 18°C for two weeks prior to HWT (sometimes called 'partial pre-warming').

The 18°C treatment extends the window during which HWT may be carried out safely, and was investigated in HDC Project BOF 15.[27] In a trial at Kirton, bulbs received standard HWT at weekly intervals from 27 July to 28 September, following storage at ambient temperatures or storage with a two week-period at 18°C interposed between ambient storage and HWT. The main results were:

- Without an 18°C treatment, the highest first-year flower yields were obtained following HWT on 27 July for 'Barrett Browning', 10 August for 'Carlton' and 24 August for 'Golden Harvest'. Yields fell rapidly following later HWT, and in these treatments flower size and stem length were also reduced. When an 18°C treatment was used, flower losses due to later HWT were reduced in 'Carlton' and 'Golden Harvest' but not in 'Barrett Browning'. Treatment at 18°C did not prevent damage to flowers by HWT.
- After two years, bulb yields in 'Carlton' and 'Golden Harvest' were greatest following earlier HWT, but the detrimental effects of later HWT were much reduced by giving an 18°C treatment. An 18°C treatment did not prevent yield reductions through late HWT in 'Barrett Browning'.

These effects may operate through a mild retardation of shoot growth. Floral development of 'Barrett Browning' was about two weeks in advance of the other cultivars, which may indicate why an 18°C treatment was ineffective in this cultivar.

Internal stage of development (ISD)

The ISD is determined in order to assess the progress of floral development within the bulb. This is useful in deciding whether it is the right time to carry out HWT or to cold-store bulbs for forcing. HWT and cold storage can be carried out safely after 'complete flower differentiation' ('stage Pc') has been reached. This is the stage at which the trumpet or cup (corona), the last formed part of the flower bud, can be clearly seen with a hand lens. The petals, then stamens, then carpels are formed before the corona.

To determine the ISD the bulb is cut down to reveal the flower bud, which is then carefully dissected. Detailed instructions with illustrations of ISDs are available in various texts.[61,62,63] Briefly:

- Carry out the procedure at intervals from mid-June to late-August.
- The top half of the bulb is cut off and discarded.
- To begin with, it may be helpful to cut off progressively (a few millimetres at a time) the top layer of the bottom half of the bulb, until the centrally placed, yellow-coloured flower bud is reached: you will now be clear as to the size and location of the bud you are looking for
- Using a fresh bulb, remove and discard the top half, and, starting at the outside and working progressively from the outside, remove the bulb scales on the bottom half by cutting downwards through one scale at a time and carefully pulling it away from the base plate.
- Reaching the young bud in the centre of the bulb, trim away any excess bulb tissue to leave the bud in place on a small cube of base plate (about 1cm^3) by which the bud can conveniently be held.
- Possibly helped by a x10 hand-lens, remove the layers around the bud – first the new leaves, and then the spathe (the thin sheath surrounding the perianth segments) – to expose the bud itself.
- The outer layers of the bud should by now consist of the six petals, which can carefully be bent back and removed to reveal – assuming development has continued so far - the stamens and other flower parts within.
- Once developed, the ring of six chunky stamens is the most obvious of the floral parts (as they develop, the stamens become obviously two-lobed and full of yellow pollen) (Figure a).

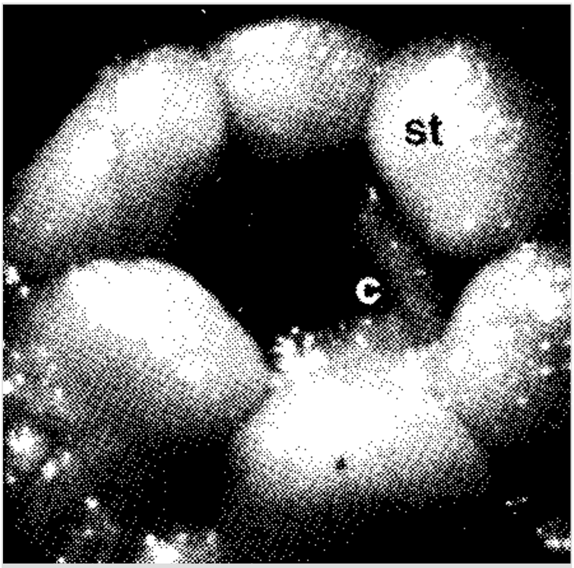
Internal stage of development (ISD) continued

- In the middle of the stamens, once developed, the three carpels will be found (Figure b); as they grow they are often described as looking like a Y-shaped structure.
- Once developed, the corona can be seen as a wavy margin, circling the stamens, and projecting from near where the petals were previously attached (Figure c).
- This process is easier to follow once the fully developed bud has been seen: Figure d shows a very well developed bud dissected.
- The early stages of development can be found by dissecting bulbs earlier, though this is not necessary for practical purposes, and it will probably involve the use of a low-power (x25) dissecting microscope.

The stages of development are abbreviated to:

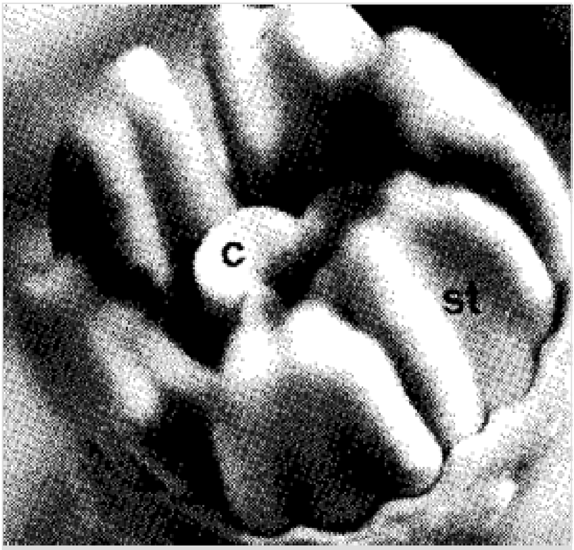
I	Foliage leaf and bulb scale initiation; apex flat.
II	Apex broadened, thickened and dome-shaped.
Sp	Spathe initial visible.
P1	Outer perianth segment initials visible.
P2	Inner perianth segment initials visible.
A1	Outer stamen initials of andrœcium visible.
A2	Inner stamen initials of andrœcium visible.
G	Gynœcium (three carpel) initials visible.
G+	Gynœcium well formed (distinct Y-shape).
Pc	Paracorolla (corona) initials visible.

50 Internal stages of bud development



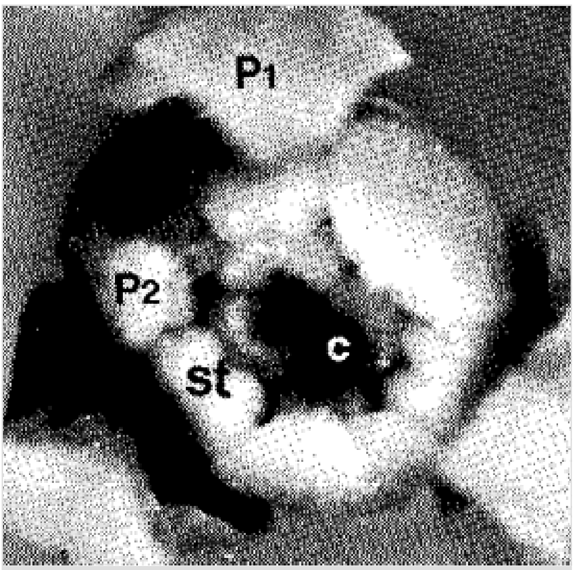
a Stage A2: Dissected bud with petals removed, showing six stamens (st) and (barely visible) the carpels (c)

Photo: MAFF[45]



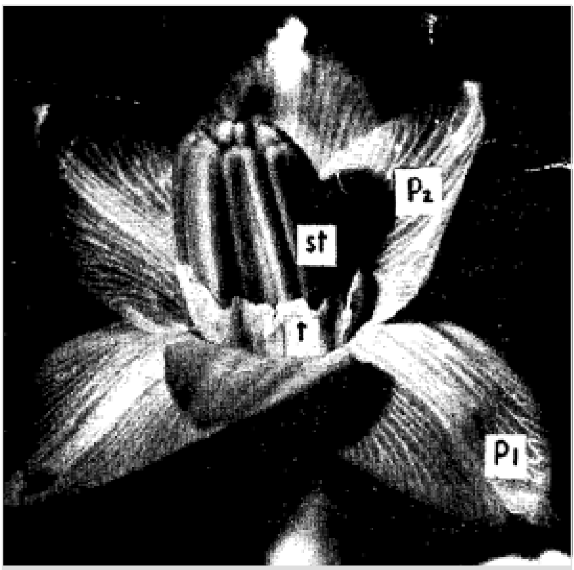
c Stage Pc: Dissected bud with petals cut away, showing stamens (st), carpels (c) and (wavy margin around stamens) the corona

Photo: MAFF[45]



b Stage G: Dissected bud with petals (P1, P2) pulled back, showing six stamens (st) and three carpels (c)

Photo: MAFF[45]



d Well-developed stage Pc: Dissected bud with petals (P1, P2) pulled outwards, showing stamens (st) and corona (t)

Photo: Plant Pathology[43]

UK and Dutch HWT practice

There are some important differences between HWT recommendations in the two countries.

- In the UK, where narcissus are grown for at least two-years-down, all planting stocks should be treated using a three-hour period at 44.4°C, even in stocks that have neither symptoms nor history of stem nematode.
- In the Netherlands, where narcissus crops are often grown one-year-down and soil sterilisation is used to control nematodes, HWT for two hours at 43°C is considered adequate for controlling mites and narcissus fly larvae, in the absence of stem nematode. When a nematode problem is suspected, and when using two-year-down growing, a longer, hotter regime (four hours at 47°C) is used.[64] For ex-forced (reclaimed) bulbs, the recommended HWT in the Netherlands is four hours at 48°C.

Temperature and duration of HWT

The temperature and duration of HWT needed to kill stem nematode are close to those which can be lethal to the bulbs themselves, meaning that the recommendations are a compromise between an effective kill of nematodes and the avoidance of unnecessary bulb damage. Using a lower temperature than recommended has been reported to cause temporary inactivation of stem nematodes, from which they can revive.[28,29]

Over time it has become technically possible to measure and control temperatures with a greater degree of precision, so it is not surprising that both temperatures and durations of HWT recommended have increased over the years, becoming even more critical.

- In the early years of the 20th century experimenters used treatments of one to six hours at 48.9°C. Equipment was, of course, quite crude, and this treatment was mostly lethal to the bulbs.[30]
- Work from the 1910s to the 1930s resulted in a long-standing recommendation to treat for three hours at 43.5°C.[31,32,33,34,35,36,37]
- In the 1930s and 1940s, in order to improve control, the treatment was increased to three hours at 44.4°C, or four hours at 43.5°C.[38,39,40] ('44.4°C' is the conversion of the former recommendation, 112°F.)
- Since the 1970s, a treatment of three hours at 44.4°C has remained standard UK advice.
- Where bulbs are pre-warmed at 30 to 35°C to reduce HWT damage to flowers, as is common in the South-West, additional treatments are needed to combat the nematode wool that is formed under these conditions. After pre-warming, the bulbs are pre-soaked before HWT, and the HWT temperature is increased to 46°C. However, pre-soaking and higher-temperature HWT are not required where an 18°C 'partial pre-warming' treatment has been used.
- Anecdotally, growers in the UK and the Netherlands are currently treating bulbs at up to 49°C. Pre-warming and pre-soaking are necessary prior to such extreme treatments. Such a regime cannot be recommended until it has been tested critically.

HWT at temperatures higher than 44.4°C should always be preceded by pre-warming, to reduce HWT damage.

The steady increase over time in the temperature used to control stem nematode suggests the nematode may be capable of acclimatising to higher temperatures. In experiments, however, nematode isolates from both clover and narcissus were equally killed by HWT, so this explanation seems unlikely.[41] Other experiments, in which warm storage was used to acclimatise stem nematodes to HWT, gave contradictory results.[17,42,43,44,45] The fact that problems with stem nematode still occur, despite the careful use of HWT and better HWT tank design, suggests a better understanding of stem nematode kill is needed.

Safe, effective HWT is a balance between time and duration, as the following examples show:[46]

- A treatment at 43.5°C can safely be extended to six and a half hours.
- Using a three-hour treatment the temperature can be safely raised from 44.4 to 46.1°C.
- Increasing the temperature of a three-hour HWT to 47.2°C impairs crop vigour.
- At 54.4°C, even a 45-minute treatment is lethal.

There are important differences in the HWT regimes advised in the UK and in the Netherlands. In the Netherlands, recommendations depend upon the health of the bulb stock. In the USA, a three- or four-hour treatment at 43 to 44°C is often used.[47]

More on the duration of HWT

It is usual to time the three-hour HWT period from when the dip regains the target temperature (usually 44.4°C) after the cooling effect of loading the bulbs into the tank. With experience the tank temperature can be 'surcharged', that is raised to a higher temperature before the bulbs are loaded, and this way the target temperature is re-gained more quickly once the bulbs are in the tank. The surcharge temperature needed will vary for different HWT systems, but should never exceed 49°C.

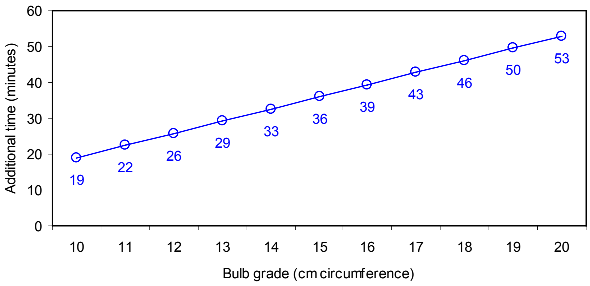
HWT recommendations were derived from measurements of the temperature in the centre of the bulb, and the recommended treatments are long enough to kill stem nematodes there. However, bulbs of different sizes naturally take different times to reach the desired core temperature, a factor not normally taken into account. Using water bath experiments and 'Fortune' bulbs from six to 20 cm-circumference, into which a temperature probe had been inserted, researchers in California recommended that the time for the centres of bulbs to attain the target temperature after placing in hot water should be added to the basic treatment time.[48] Using linear regression analysis, the additional treatment times required (in minutes) could be calculated from the following equations in Table 24, where X is the bulb circumference (cm).

Table 24 Additional treatment times taking into account bulb circumference

Target temperature (°C)	Equation
44	Additional treatment required time (minutes) = -15 + 3.4 X
48	Additional treatment required time (minutes) = -10 + 2.7 X
50	Additional treatment required time (minutes) = -14 + 3.3 X

For example, a 16 cm bulb to be treated at 44°C would require the additional treatment time of [–15 + (3.4 x 16)] = [-15 + 54.4] = 39.4 minutes. The resultant HWT times for different grades of bulbs are shown in Figure 11. However, varying HWT regime by grade is not normal, and would call for the reorganisation of how stocks are graded, handled and stored. The cost-effectiveness of such a change would need to be evaluated.

Figure 11 The additional time (in minutes) required for the centre of narcissus bulbs of different sizes to reach a target HWT temperature of 44°C



Variant regimes for specific pest and disease management

Bulb-scale mite

Milder HWT regimes and ‘dry heat’ treatments were tested at Central Science Laboratory in HDC Project BOF 25a to see if they might be used to control bulb-scale mite in bulbs intended for forcing, without damaging the flowers.[49] Both treatments were shown to have potential for controlling bulb-scale mites adequately without damaging the flower crop, though the latter aspect was not trialled comprehensively. In this study a short HWT (one hour at 44.4°C, with formalin, no pre-warming or pre-soaking) appeared enough to kill adults and eggs, and similar treatments are becoming more widely used in the UK prior to forcing bulbs.[50] Only stocks infested, or suspected of being infested, with bulb-scale mite need be treated. Alternatively, for ‘dry heat’ treatment, a three-hour period at 42°C was sufficient to kill all adults and eggs, with no significant effects on bulb vigour or flower quality.

Aphelenchoides subtenuis

Short, hot regimes (45 minutes at 50°C or 25 minutes at 55°C) have been reported suitable for controlling this nematode without damage to bulbs.[51]

Nematode-associated base plate rot

Note that this condition is distinct from basal rot. HWT for four hours at 45°C or two hours at 48°C was effective, while late HWT, in September, was more effective than HWT in August.[52,53]

Black slime disease

In the Netherlands, black slime disease in ‘Tête-à-Tête’ has been controlled using procymidone added to cold soaks or HWT, though this causes some loss of yield.[54] (Procymidone is not available in the UK.)

The end of HWT and post-HWT treatment up to planting

At the end of the HWT period bulbs should be unloaded from the tank promptly, and an effective alarm or other warning system may be needed to ensure this happens. If foam or scum is visible on the surface of the dip, it should be skimmed off before draining down the tank (in side-entry systems) or lifting out the bulbs (in top-loading tanks) to prevent this potentially infected material being deposited on the bulbs. Once the tank has drained down, loose bulbs may be found on the floor of the tank or lodged elsewhere, and these should be removed and disposed of and not put back into the bins – they may have remained in the tank from a previous run.

Immediately after HWT, bulbs should be allowed to drain and should then be blown using some form of forced ventilation system capable of producing rapid cooling to near-ambient temperatures, removal of fumes, and surface-drying (if the bulbs are to be stored for planting later, they should be fully dried). There is no evidence from trials that extra-rapid cooling after HWT is beneficial,[55] though it seems sensible. Delayed or slow cooling can result in bulb damage, in effect, ‘over-cooking’ (narcissus bulbs hold heat well). It has been reported that storage at sub-lethal temperatures after HWT increased the kill of stem nematodes.[56]

Drying, cooling and ventilating after HWT can utilise some form of drying wall, or fixed or mobile fans fitted over or onto bins and using either positive or negative air pressure. Whatever form of ventilation system is used, it should be sited in a clean area, away from un-sterilised bulbs. Subsequent storage up to planting should also be in an area that poses minimal risk of contamination from un-sterilised bulbs.

For operator safety, the ventilation of bulb-handling areas is critical, especially when bulbs are being removed from the HWT tanks.

There are opposing views on when the bulbs should be replanted.

Traditional practice

The traditional view of planting – and one still recommended on plant health grounds – is that bulbs should be fully surface-dried after HWT and then stored until replanting in September, by which time soil temperatures are lower and therefore less favourable to basal rot. As always with wet bulbs, prompt drying is important to control basal rot,[57 58] and storage should be under appropriate conditions and preferably at 17°C. This regime also gives an opportunity for further bulb treatments before planting.

Contemporary practice

In modern practice, however, bulbs are generally planted as soon as practical after HWT, after cooling and ventilation but not necessarily full drying. This has the practical advantage of avoiding the need for re-drying and storage before planting, reducing the cost of handling. However, it does means that bulbs are planted into relatively warm soil in August, which will encourage basal rot.

Damage due to HWT

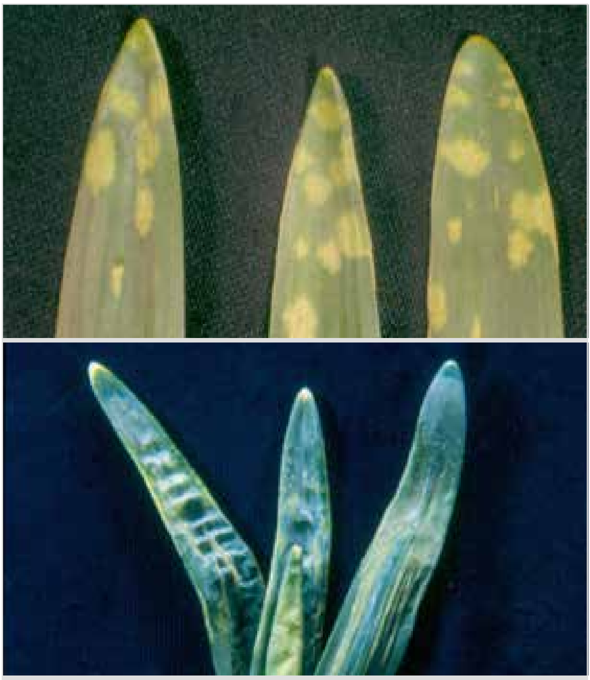
If HWT is carried out too early or too late, for too long a time or at too high a temperature, or following the storage of bulbs at low temperatures, various types of damage will occur in the first year of the crop:

- Mild flower damage (cause - early HWT).
- Mild leaf damage - mottling and roughening of the leaf tips (cause - early HWT).
- Damaged flowers – small and 'starry', indented ('notched') perianth segments, 'frayed' corona (cause - early HWT).
- Aborted flowers (cause - early HWT).
- Dead buds (cause - late HWT).
- Severe leaf damage, with severe distortion or stunting and resultant yield loss (cause - late HWT, bulbs too cool before HWT, or excessive HWT treatment).
- Gray rings or spots developing in scales (cause - excessive HWT treatment).
- Root damage, leading to severe yield loss (cause - late HWT).
- Death of stem apex and abnormal production of extra bulb units[59,60] (cause - excessive HWT temperature).

These symptoms are illustrated in Figures 51 to 55.

51 Notching of petals is common in 'Carlton' as a result of HWT damage

Photo: Warwick HRI and predecessors



52 Examples of leaf-tip mottling and roughening in response to early HWT

Photo: Warwick HRI and predecessors

53 Small, star-shaped flowers, a result of early HWT

Photo: Warwick HRI and predecessors

54 Damage damage to base plate (bulb on right) as a result of HWT/formalin

Photo: Warwick HRI and predecessors

55 Empty spathes ('flags') due to HWT damage

Photo: Gordon Hanks

8.3 HWT chemicals

Chemicals in HWT

HWT is used to kill stem nematode and basal rot propagules, and incidentally other pests and diseases, but its prime use is to control stem nematodes. The HWT regime is designed to kill stem nematodes through the effects of heat alone, so theoretically no chemical additives are necessary. However, it appears that stem nematodes in the 'wool' or 'free-swimming' stages (as opposed to stem nematodes living within the bulb) are more resilient to high temperatures, and so for this reason it has long been standard practice to add a disinfectant – formaldehyde (as 'commercial formalin') - to the tank, to ensure that all stages of the nematode are controlled. Until 2008, when it was banned for agricultural and horticultural use, formaldehyde was almost universally used for this purpose: at the time of its banning, no ready alternative was available, so alternatives are now being urgently sought.

HWT also provides a useful delivery system for fungicides, primarily to improve kill of basal rot, but also to control other pathogens such as *Penicillium* and *Botrytis*. Where large narcissus fly is a problem, an insecticide may also be added. Other substances – such as non-ionic wetters and an anti-foam preparation - may be added to augment the effects of the pesticides and disinfectant.

Pesticide Usage Surveys: HWT

The *Pesticide Usage Surveys* provide useful guidance about the disinfectants and pesticides that have been used in HWT. Although the survey data are bulked to cover all flower-bulbs, it is only narcissus that will receive HWT. Data from the last three surveys – conducted in 1997, 2001 and 2005 – are summarised in Table 25. For HWT, usage is expressed in the number of 'planted-hectares' treated. The table includes the total area planted, so the percentage of the whole crop being treated with a chemical can be determined. Here are the main findings, with notes on those pesticides currently available.

- Over the period 1997 to 2005, formaldehyde was used almost universally in HWT, with a small area being treated with peroxyacetic acid disinfectant. In general terms, disinfectants do not fall under Plant Protection Products Regulations (PPPR) when they are used as biocides and not for the control of specific pests and diseases.
- Although thiabendazole is generally advised as the fungicide of choice for controlling basal rot, the surveys show that large volumes of bulbs were also treated with other MBC fungicides and prochloraz; captan was also popular until its withdrawal. Only thiabendazole- and chlorothalonil-based fungicides are now approved for this use.
- Significant amounts of bulbs were also treated with chlorpyrifos for the control of large narcissus fly, especially in 2005; a small volume was treated with dimethoate. Chlorpyrifos-based insecticides are currently approved for use in bulb soaks (including HWT).

Table 25 Amounts of field-grown flower-bulbs in Great Britain treated with disinfectants and pesticides in HWT, taken from the Pesticide Usage Surveys*

Pesticide type and active ingredient	Planted-ha treated (with total area grown)		
	1997 (4,751 ha)	2001 (5,237ha)	2005 (4,916ha)
Disinfectants			
Formaldehyde	1985	2203	1555
Peroxyacetic acid	0	59	25
Total	1985	2262	1580
Fungicides			
Benomyl	169	121	0
Captan	261	0	0
Carbendazim	596	574	390
Cyproconazole + prochloraz	0	37	0
Mancozeb	11	7	11
Prochloraz	874	1342	422
Thiabendazole	543	448	480
Vinclozolin	11	7	11
Others**	4	25	59
Total	2469	2561	1373
Insecticides			
Chlorpyrifos	79	64	244
Dimethoate	11	7	11
Total	90	71	255

* Figures exclude some 'unspecified' 'seed treatments' or HWT applications.

**'Others' means active substances used on <0.1% of the total area treated with pesticides, or 'unspecified'.

Disinfectants – the quest for an alternative to formalin

It has long been known that formaldehyde, the active substance of formalin, was effective in controlling all stages of the stem nematode in bulb dips.[65,66,67] The use of formalin in HWT tanks was almost universal, and in the UK and the Netherlands its use was considered essential for the control of stem nematode, though in the USA it was regarded as more important for the control of basal rot. Formalin was effective, cheap, controlled other pests and pathogens too, and its use was familiar to bulb growers and validated by long practice.

Formalin has been under scrutiny since at least the 1980s, because of concerns about its effect on human health.[68] In 2006 these concerns were revived by legislators, despite what many regarded as weak evidence for only a slight health risk, and that not even in the horticultural industry.[69] The speed of formalin's withdrawal (at the end of 2008) did not allow the industry to develop an alternative, though the issue had been raised for many years and sporadic attempts had sometimes been made to find one.

Formalin had a number of disadvantages for HWT, and any alternatives identified would need to avoid or minimise these issues:

- Formalin had to be used in a well ventilated space and while wearing appropriate Personal Protective Equipment (PPE), and the concentration of formaldehyde in the air needed to be regularly monitored.
- At low temperatures formaldehyde polymerises and loses activity, necessitating the addition of methanol ('winterised formalin') and storage under frost-free conditions.
- Commercial formalin had a shelf-life of one year from manufacture.
- Increasing formalin concentrations had little benefit on fungicidal activity but could result in crop toxicity, with fewer and deformed flowers.[70,71]
- Higher rates of formalin could damage the base plate, producing cork-like areas when HWT is done early or soon after lifting.[72]
- Formalin could be damaging to the roots of dwarf and early-rooting or fine-rooted cultivars.[73]

HDC Project BOF 61 was set up with ADAS in 2006 to find an alternative to HWT with formalin. Alternative technologies were rejected as likely alternatives to HWT, either because they were considered too expensive to develop or they were untested, so efforts were concentrated on finding alternative chemicals. From small-scale laboratory studies, an iodophor disinfectant, 'FAM 30', was identified as having potential to control stem nematode (including the wool stage) and basal rot spores without obvious toxicity to the crop. At the same time the fungicide chlorothalonil (tested as 'Bravo 500') was identified as a possible alternative to thiabendazole for the control of basal rot.

The following disinfectants and fungicides were rejected as possible candidates as they were found to be ineffective or to have phytotoxic effects:

- Ascorbinic acid (laboratory reagent, 99% l-ascorbinic acid).
- Chlorine dioxide (as 'Harvest Wash').
- Citric acid (a commodity product).
- Hydrogen cyanamide (as 'Cultamide').
- Silwet L-77 (a silicone wetter).
- 'Sporekill' (a natural product).

HDC Projects BOF 61a and 61b comprised two-year-down field trials, set up in 2008 and 2009, to evaluate the iodophor disinfectant and the fungicide chlorothalonil on a field-scale.[74,75]

- In the first trial (starting 2008) 'Golden Harvest' bulbs from a stock with significant basal rot levels, augmented with 'inoculator bulbs' infested with stem nematode, were given HWT in plain water (control), the standard concentration of formalin (5 L 'commercial formalin'/1,000 L water), 'FAM 30' (either 4 L or 8 L product/1,000 L water) or 'Bravo 500' (either 0.5 or 1.0 L product/1,000 L water). As expected because of the high initial levels of basal rot, many bulbs in the control set rotted and failed to emerge. However, during the first spring and summer bulbs from all other treatments grew and flowered normally, with no indication of phytotoxic effects (stunting, loss of flower yield, flower distortions, etc.), showing that, in this case, HWT with either 'FAM 30' or 'Bravo 500' had been at least as successful as HWT with formalin. Regrettably the bulb stock largely failed to survive into the second year due to basal rot, always a risk in working with infested stocks.
- In the second trial (starting 2009) normal commercial stocks of eight cultivars were HWT with plain water (control) or 'FAM 30' or 'Bravo 500' (same concentration as before) or 'FAM 30' plus 'Bravo 500' (each at its lower rate). In the first spring, all cultivars in all treatments grew and flowered normally, with no symptoms of phytotoxicity, with the sole exception that flower yields were reduced in the control lots.

Apart from some minor yield reductions when 'FAM 30' was used at the higher rate (8 L product/1000 L water), no adverse effects due to using either 'FAM 30' or 'Bravo 500' in standard HWT have been identified, performance being at least comparable to performance following the use of formalin.

Iodophor and other alternative disinfectants

Iodophore disinfectants

The results described above suggest that 'FAM 30' (or other iodophore products) may have a place in HWT after further testing. However, several other disinfectants have been tested for use in HWT from time to time. It is likely that growers will need information on disinfectants that might improve on iodophor-type materials, or at least provide alternatives against future chemical losses.

Peroxyacetic acid (peracetic acid)

A commercial preparation of hydrogen peroxide–peroxyacetic acid acid was tested at Wellesbourne for killing basal rot chlamydospores under HWT conditions, and found to be highly effective and without damage to the crop.[71] 'Jet 5' was further evaluated for use in HWT in 1997. In work at HRI, rates of 0.5 to 1.5% of 'Jet 5' were shown to be effective against stem nematode, including the wool stage and free-swimming nematodes, and against the chlamydospores of the basal rot pathogen.[76,77] Peroxyacetic acid killed the spores of the fungus within one hour, whereas total kill was not achieved with the standard concentration of formaldehyde, 0.5% of 'commercial formalin' (containing 38 to 40% formaldehyde), even after four hours. At these concentrations 'Jet 5' caused no subsequent crop damage.

Following these tests, 'Jet 5' was used by some bulb growers, though anecdotal information suggested the active substance may have been rapidly broken down in practical use. No definitive information on this point appears to have been made known, so there remained insufficient information to recommend its use. Peroxyacetic acid (including 'Jet 5') is no longer authorised for use in horticulture.

The Pesticide Usage Surveys

Pesticide Usage Surveys for Great Britain are published at intervals (now by Fera), providing considerable insights into the pesticides actually used on crops. The reports include surveys of field-grown bulbous flower crops and field-grown (non-bulbous) flowers and foliage for cutting, conducted in 1993,[116] 1997,[117] 2001[118] and 2005.[119] All data are anonymised.

The 'bulb and flower' surveys were based on data collected from about 29, 47 and 37% of the crop area for the 1997, 2001 and 2005 surveys, respectively, scaled up to the total areas grown (obtained from Defra statistics). Separate figures are provided for the two sub-sectors (outdoor bulbs and flowers and foliage), but are not generally split to species. Thus the bulb data include the small areas of other flower-bulbs grown in Great Britain, for example in the 2005 survey, narcissus, gladiolus and lily made up 88, 7 and 3% of the total area, respectively, while in 1997 and 2001 narcissus made up 98 and 96% of the total bulbs area, with other bulbous species contributing at most 1% each. As some treatments are applied only to particular species, the amounts used solely on narcissus, say, can be ascertained by various means, and in any case the predominance of narcissus weights the results. The narcissus data were derived from about equal areas of first-year, second-year and older crops in 2005, and from about equal areas of first- and second-year crops and a minor area of older crops in 1997 and 2001.

Table 26 shows the average number of sprays, products and active substances applied to these crops in the survey years. Table 27 shows the percentage of the planted area that received pesticide sprays in the field, and the average numbers of sprays applied.

The reports also present usage as the weights of active ingredients used. Since some substances are used at a high rate or are intrinsically heavy, e.g. glyphosate or sulphuric acid, this can greatly exaggerate the industry's apparent usage; care should be taken in how these data are expressed.

As well as the amounts of pesticides used, data are also collected on the rate of application and the perceived reasons for their application, providing a guide to how important growers and farmers view their pest and disease problems. The reports state that the "reason for application… is the grower's stated reason for use of that particular pesticide and may not always seem entirely appropriate"; for the field-applied fungicides, herbicides and insecticides, the percentage incidence of the various reasons are summarised in Table 28.

The above reports are applicable to Great Britain as a whole; specific reports or information are also available for Scotland[120] and Northern Ireland.[121]

Table 26 The average number of sprays, products and active ingredients applied to bulb and flower crops (primarily narcissus) in Great Britain in 1997, 2001 and 2005

Survey year	Sprays/year*	Products/year	Active ingredients/year
1997	5	8	9
2001	9	15	16
2005	5	9	9

* All counts include any repeat applications of the same material.

Table 27 The percentage of the planted area receiving pesticide sprays and the average number of sprays applied for bulb and flower crops (primarily narcissus) in Great Britain in 1997, 2001 and 2005

Survey year	Fungicides	Herbicides	Insecticides
1997	88%; 4 sprays	92%; 3 sprays	26%; 1 spray
2001	90%; 3 sprays	92%; 2 sprays	24%; <1 spray
2005	89%; 3 sprays	87%; 2 sprays	17%; 1 spray

Numbers of sprays in the two tables will not necessarily agree due to rounding.

Table 28 Reasons given for applications of pesticides (as percentages) to bulb and flower crops (primarily narcissus) in Great Britain in 1997, 2001 and 2005

Reason stated	Fungicides			Herbicides			Insecticides		
	1997	2001	2005	1997	2001	2005	1997	2001	2005
Basal rot	<1	0	0						
Botrytis	<1	0	0						
Botrytis or general disease	<1	6	9						
Smoulder	2	6	<1						
General disease	33	52	36						
Desiccation				<1	<1	<1			
Broad-leaved weeds				6	4	7			
Grass weeds				<1	<1	2			
General weeds				37	62	38			
Aphid/caterpillar							2	7	8
Large narcissus fly							41	2	28
General pests							<1	78	19
Unspecified	64	37	54	56	34	52	57	14	45

Chlorine dioxide

Chlorine dioxide is widely used in the fruit and vegetable industries as a substitute for chlorine, and its effect against basal rot chlamydospores has been thoroughly investigated in the USA.[78,79] Chlorine dioxide is less inactivated than chlorine by the presence of organic matter, and is a more effective biocide against several microorganisms than sodium hypochlorite, iodine, QACs, glutaraldehyde and phenol. In experiments, no viable inoculum was detected five minutes after inoculum was added to a tank containing 2.5% chlorine dioxide. In HWT tests with narcissus bulbs having high levels of basal rot, basal rot levels were reduced and bulb yields increased when either chlorine dioxide (5 or 10 ppm) or formalin (0.5% commercial formalin) were added to the HWT tank. Commercial equipment is available for chlorine dioxide generation on-site, and further trials would be valuable. Unfortunately, the effect of chlorine dioxide on stem nematode does not appear to have been studied, though at least one USA grower has routinely used chlorine dioxide for over five years with apparent success.[80] Currently, the possibility of using chlorine dioxide in HWT is being investigated in HDC Project BOF 70.

Glutaraldehyde

Glutaraldehyde is used as a disinfectant in hospitals and has been shown to be effective against stem nematodes at HWT temperatures.[81] A commercial preparation of glutaraldehyde was tested at HRI for killing basal rot chlamydospores under HWT conditions, and was found to be highly effective and non-phytotoxic.[71] However, glutaraldehyde is relatively expensive, may have human health concerns of its own, and functions best in an alkaline solution.

Thiabendazole

Although not a disinfectant, thiabendazole is listed here as it has been shown to have activity against stem nematodes in its own right used in HWT,[77] and it has a mild effect on stem nematode even at room temperatures.[82] It was originally introduced as an anthelminthic (for intestinal parasitic worms),[83] but whether this confers any practical degree of nematode suppression when used on narcissus in HWT is not known; this property of thiabendazole should be investigated, to see how it could be better exploited in bulb growing.

Quaternary ammonium compounds

In the USA, a product consisting of quaternary ammonium compounds, 'Physan 20', has been used as a fungicide, bactericide and algaecide and is approved for use on various crops including ornamentals. The sales literature includes 'Fusarium basal rot' amongst the pathogens controlled; earlier literature recommended its use on bulbs, including narcissus, using a ten-minute dip immediately after cleaning and again immediately before planting. Possibly this indicates that this type of disinfectant may have some potential for use.[84]

Can HWT be used without formalin or any other disinfectant?

Researchers in California, where the standard HWT regime was four hours at 44°C, showed that this treatment was sufficient to control stem nematode without adding formalin to the tank.[85] Using formalin, a two and a half-hour treatment was sufficient for control, and caused no crop damage. Using formalin and elevated temperatures, nematode control was achieved by one and a half, three quarter and half-hour treatments at 46, 48 and 50°C, respectively, but these treatments caused crop damage. HWT for four hours at 44°C reduced the number of fungal colonies of *Penicillium* species, *Fusarium oxysporum* f.sp. *narcissi* and *Mucor plumbeus* recovered from bulbs, though the effects of formalin, glutaraldehyde and sodium hypochlorite in controlling these fungi were variable.

In the USA, where the agricultural use of formalin has been controlled for some years, it has been considered more important for the control of basal rot than stem nematode. Without it "…the temperature of the water (43-44°C for four hours) is not high enough to prevent the spread of basal rot inoculum from diseased to healthy bulbs during HWT". Although US growers can currently use nematicides to control nematode, they have "very few alternatives to formalin to prevent the spread of *Fusarium* inoculum during HWT…"[14]

In the light of the loss of formalin in the UK, researchers in ADAS and WHRI have studied changes to the current HWT regime (including longer HWT but without formalin or any alternative) as well as alternatives such as warm-storage treatments, field-applied nematicides, or a plant breeding solution (HDC Project BOF 61).[86] These alternatives were rejected as likely to be either ineffective, impractical or very long-term; however, the initial findings showed that standard HWT (44.4°C for three hours) was sufficient to kill nematodes without the addition of formalin, although this conclusion will continue to attract debate.

Fungicides available for use in bulb soaks or HWT

HWT provides a useful delivery for fungicides against basal rot as well as other fungal pathogens such as *Penicillium* and *Botrytis*. No fungicide currently has full approval for use as a bulb soak (a bulb soak is construed to cover both cold soaks and HWT), but there are relevant EAMUs for fungicides based on chlorothalonil (as 'Bravo 500'), 'Life Scientific Chlorothalonil' and 'LS Chlorothalonil' and thiabendazole (as 'Storite Clear Liquid' and 'Tezate 220 SL'). Some approval details are given in Table 30. Under current UK approvals, the use of thiabendazole fungicides on narcissus bulbs is restricted to one application per year (so the active ingredient cannot be used as a post-lifting treatment and in HWT), and its use in the Isles of Scilly is prohibited.

Properties of thiabendazole

The effectiveness of thiabendazole in killing basal rot chlamydospores under HWT conditions was confirmed at Wellesbourne and elsewhere,[71] and thiabendazole was considered the basal rot fungicide of choice in the UK for many years, usually as 'Storite Clear Liquid' (though data from the *Pesticide Usage Surveys* indicate that it was by no means the most used, probably on the grounds of its high cost).

For several years, anecdotal information had circulated within the UK bulb industry that the control of basal rot by thiabendazole was enhanced by acidification of bulb dips with SBS (sodium bisulphate, also called sodium hydrogen sulphate),[88] though no definitive information on this point was obtained from the licence holders or distributors. Around 2000, some growers were reportedly adding from 0.9 to 1.2 kg of SBS/1,000 L of dip.[24] The suggestion appears to have originated in research to improve the control by benzimidazole fungicides of *Verticillium* wilt in cotton[89] and of Dutch elm disease.[90]

Some key-facts about thiabendazole are listed here:

- In ‘Storite Clear Liquid’ (and presumably ‘Tezate 220 SL’) a soluble concentrate formulation, thiabendazole is formulated as the acidic thiabendazole hypophosphite. Thiabendazole (and other MBC fungicides) are broken down by alkaline hydrolysis and have limited solubility in water at other than acidic pH values. The maximum concentration of thiabendazole occurs at pH 2.2, 38,400 ppm. Its solubility falls to only 50 ppm at pH 5.0.
- The outcome of these properties of thiabendazole is that it exists both in solution and in suspension in HWT tanks and elsewhere. Both dissolved and suspended thiabendazole may be assumed to be active in controlling fungi in the HWT situation. The amount of dissolved thiabendazole will be largely dependent on the pH of the dip, while the amount of suspended thiabendazole will be largely dependent on its rate of settling-out. An acidic environment and good circulation are assumed to be necessary to maintain the full availability of thiabendazole in HWT tanks.
- In practice, observations show that the amount of material (presumably consisting at least partly of fungicide) settling-out on the tank floor can be considerable, though it may be bulked through mixture with soil and other debris.
- As a result of these considerations, on an earlier label the approval holders of ‘Storite Clear Liquid’ gave clear instruction for replenishment on the label as follows: “The tank should be topped-up to the original level after each batch of bulbs has been removed and 1.5 L of Storite Clear Liquid should be added for each tonne of bulbs removed in order to keep the concentration stable”.[91] However, the recommendation to add an additional 1.5 L of Storite Clear Liquid for each tonne of bulbs treated does not appear on the current EAMU, so the dip may only be topped-up at the current rate, 1.25 L product/1000 L water.
- Thiabendazole also has activity against stem nematodes under HWT conditions in its own right, having been originally introduced into agriculture as an anthelminthic.[13]

Cumulative fungicide treatments and basal rot management through correct bulb handling

In the 1980s trials at Kirton showed that the use of thiabendazole (or other fungicide) to manage basal rot should be integrated with ‘physical’ methods of control, i.e. correct bulb handling, drying, storage and HWT, to improve results. To achieve a consistent improvement of the health of bulb stocks, this practice should be continued over a number of years.[92,93,94]

- Single treatments with thiabendazole were highly effective against basal rot, but it was the cumulative effect of treatment over three or four years that most effectively reduced the incidence of the disease.
- Where basal rot was severe, a double thiabendazole treatment was formerly advised, with a post-lifting treatment (on-line bulb spray or a cold soak) and application in HWT (this double treatment is no longer permitted). However, the repeated use of a benzimidazole fungicide could result in the pathogen developing fungicide resistance. The double treatment also had a slight phytotoxic effect, with earlier die-down and slightly reduced yields that year, though there was compensatory growth in the next year. If a double treatment were required, it would be better to alternate thiabendazole and a fungicide from another mode-of-action group, such as chlorothalonil.
- The correct physical handling of bulbs – prompt, high-temperature drying, controlled-temperature storage at 17°C, and correct application of HWT (even without a fungicide added) – in itself reduced levels of basal rot, and combining this with an effective fungicide treatment was even more effective.

In HDC Project BOF 42, these findings were applied to commercial Lincolnshire ‘Golden Harvest’ and ‘Carlton’ stocks with a history of basal rot problems.[95] The bulb stocks were sub-divided and six treatments were applied so that the different elements of physical handling, mentioned above, could be tested (see Table 29).

Following treatment, the bulb lots were sub-divided further and grown-on either at the farm of origin or in replicated plots at Kirton. The bulb lots were inspected and the numbers of rotted bulbs recorded at each stage of the trial. The main findings are listed here.

- There were high initial infestations of basal rot in the stocks. The incidence of soft-rot (due to *Rhizopus*) and damage due to large narcissus fly larvae and mechanical damage to the base plate, was also high.
- Sorting bulbs prior to HWT, there were markedly reduced numbers of rotted bulbs in treatments 1 and 4, which had 17°C storage in common. Ambient temperatures during that period had been about 22°C.
- This difference was largely maintained following growing-on, with bulbs from treatments 1 and 4 giving better yields and more marketable bulbs.
- In terms of improving stock health, storage at 17°C was more effective than the other measures (a post-lifting fungicide spray, rapid high-temperature drying, or using ‘Storite Clear Liquid’ in HWT). Since basal rot development is highly temperature-dependent, a small increase in the ambient temperatures over 17°C, as observed here, can be understood as very likely to increase the incidence of basal rot.
- Eventual bulb yields and disease status were largely dependent on bulb health at planting. Since it is difficult to provide adequate labour to sort bulbs on the inspection line, there is a need to develop automated methods of bulb sorting.

Acidity and the concentrations of thiabendazole in HWT tanks

The apparent loss of thiabendazole in HWT tanks, and how to combat it, were investigated with stocks of ‘Golden Harvest’ and ‘Carlton’ at Kirton and Wellesbourne in HDC Projects BOF 43[96] and 43a.[97] The main findings were as follows:

- From an initial concentration of thiabendazole of 1,100 ppm (then the current recommendation by the approval holder, i.e. 5 L of ‘Storite Clear Liquid’/1,000 L of dip tank solution), the concentration typically fell to around 200 ppm by the end of a routine three-hour HWT. Over a five-day test period the pH of this dip was between 3.9 and 4.2.

Table 29 Treatments applied as part of HDC Project BOF 42

Treatment	Post-lifting spray	First-stage drying	Second-stage drying and storage	HWT
1	'Storite Clear Liquid'	3 days 35°C	17°C	With 'Storite Clear Liquid'
2	'Storite Clear Liquid'	Ambient temperatures	Ambient temperatures	No 'Storite Clear Liquid'
3	None	3 days 35°C	Ambient temperatures	No 'Storite Clear Liquid'
4	None	Ambient temperatures	17°C	No 'Storite Clear Liquid'
5	None	Ambient temperatures	Ambient temperatures	With 'Storite Clear Liquid'
6	None	Ambient temperatures	Ambient temperatures	No 'Storite Clear Liquid'

- When an acidifier, SBS, was added to the HWT tank at a rate of 1.38 kg/1,000 L, giving an initial dip pH of about 2.5, a near-target concentration of thiabendazole could be maintained in the tank over the three-hour treatment. The tank was topped-up with fungicide and SBS after each use. The dip pH was broadly maintained, drifted up to only 3.3 by the end of the five-day test period. At the end of the five-day period, the thiabendazole concentration in the dip had fallen to 72% of the target concentration.
- Alternatively, an increasing amount of SBS was added to the tank daily, but it was difficult to control pH this way (pH varied from 1.9 to 3.4 over the period). At the end of the five-day period, the thiabendazole concentration in the dip had fallen to 71% of the target concentration.
- SBS was used as a technical-grade chemical, easily obtained from suppliers. A commercial SBS product designed for controlling pH in swimming pools, 'Briswim Dry Acid', was also used effectively.
- Increasing acidity by means of adding a commercial acidifier, 'Croptex ZIP', resulted in dip pH varying from 3.5 to 4.1, and by the end of the 5-day period, the thiabendazole concentration had fallen to 29% of the target concentration.
- Subsequent crop growth was normal, though there was a slight reduction in flower yield where SBS had been used. After two years' growth, bulb yield and the percentage of bulbs with rots were the same in control plots as where the standard rate of SBS had been used. Using the highest rates of SBS, however, led to a reduction in bulb yield and an increase in the number of bulbs with rots.

Due to the reduced losses of active ingredient when SBS acidifier was added, it seemed possible that a lower rate of 'Storite Clear Liquid', acidified, might still be effective against basal rot. The effects of full-, half- and quarter-rates, all with SBS to maintain a pH between 2.5 and 3.0, were assessed. This meant the half- and quarter-rates were 2.5 or 1.25 L 'Storite Clear Liquid'/1,000 L dip, topped up with 0.750 L or 0.375 L 'Storite Clear Liquid' /1 tonne of bulbs dipped, respectively. Higher rates of SBS (lower pH values) were also tested. The half- and quarter-rate treatments were effective in controlling basal rot and did not cause phytotoxic effects over a two-year field trial.

Shortly after the addition of chemicals to the HWT tank, and after a three-hour soak, the measured concentration of thiabendazole were:

- Control (no acidification, target 1,100 ppm): 290 falling to 260 ppm.
- Full-rate (acidified, target 1,100 ppm): 1,102 falling to 963 ppm.
- Half-rate (acidified, target 550 ppm): 341 initially, 392 ppm at the end.
- Quarter-rate (acidified, target 275 ppm): 314 initially, 289 ppm at end. (The slightly higher-than-expected concentrations for the reduced-rate treatments were probably within the limits of normal experimental errors of the bioassay used in this project to measure thiabendazole concentrations).

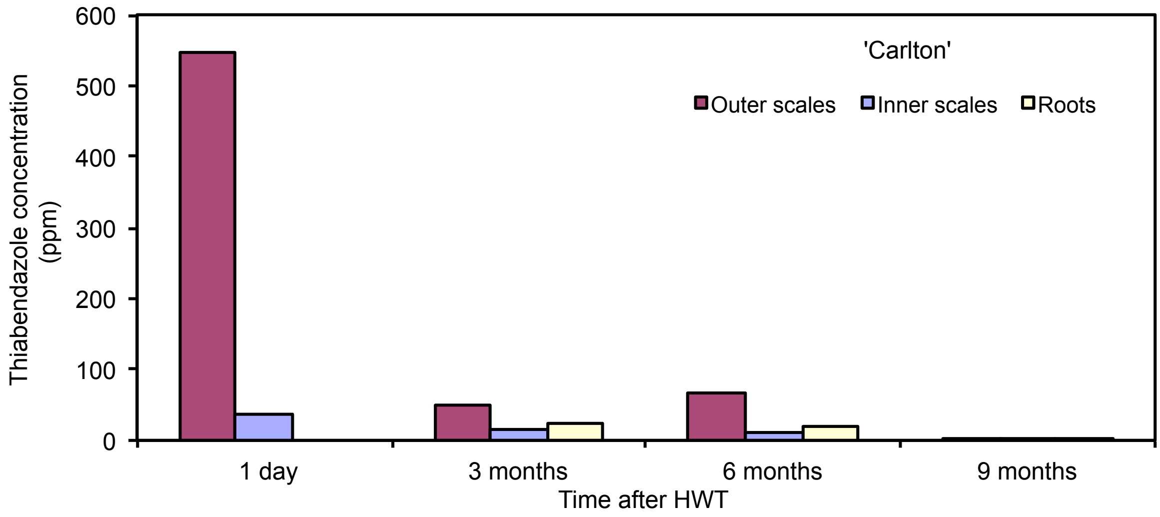
As well as the full-rate treatment, the half- and quarter-rate treatments were also effective in controlling basal rot over a two-year field trial, gave higher flower and bulb yields than control lots without 'Storite' or SBS; no other phytotoxic effects were seen.

Adding a greater rate of SBS to give a pH value <2.5 resulted in yield loss, as in the previous study.

These projects included determining the concentrations of thiabendazole in bulbs as well as in the tank. However, most of the thiabendazole 'taken up' by the bulb during dipping appeared to remain on or in the outer layers of the bulb, and was not translocated to the centre of the bulb where new growth occurs and basal rot begins (Figure 12). When the roots had emerged, low concentrations of thiabendazole were found here, but none was detected in the emerging shoots. The thiabendazole initially detected was metabolised in the first few months after planting, so could not provide protection throughout the first year of the crop, even using the full-rate treatment. Figure 13 shows that, with acidification, using half- or quarter-rate 'Storite' results in adequate concentrations of thiabendazole in the outer scales for the fungicide to act as a 'surface fungicide', reducing the likelihood of spread while handling bulbs or in storage. These results suggest it is important not to overestimate the effect of thiabendazole in longer-term basal rot control.

In HDC Project BOF 64[98] the levels of thiabendazole were determined in bulbs before and after HWT (with acidified, quarter-rate 'Storite Clear Liquid'), after drying (representing the amount of thiabendazole potentially added to the environment through planting the bulbs), and after drying and washing (to estimate the amount of thiabendazole potentially leached from the bulb into the soil after planting). The results are shown in Figure 14. This information was utilised by the licence holder and the HDC in formulating new recommendations acceptable to Pesticide Safety Directorate in terms of fungicide residues.

Figure 12 Thiabendazole concentrations in outer and inner scales and roots at various intervals after HWT with full-rate 'Storite Clear Liquid' with 'Carlton' and 'Golden Harvest'



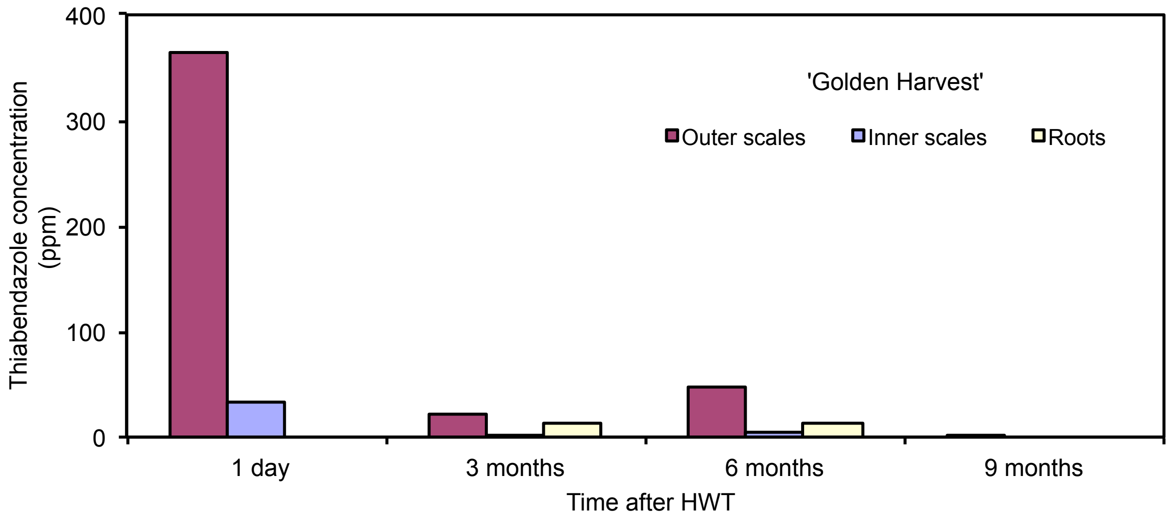


Figure 13 Thiabendazole concentrations in outer and inner scales 1 day after HWT with acidified dips of full-, half- and quarter-rate 'Storite Clear Liquid'

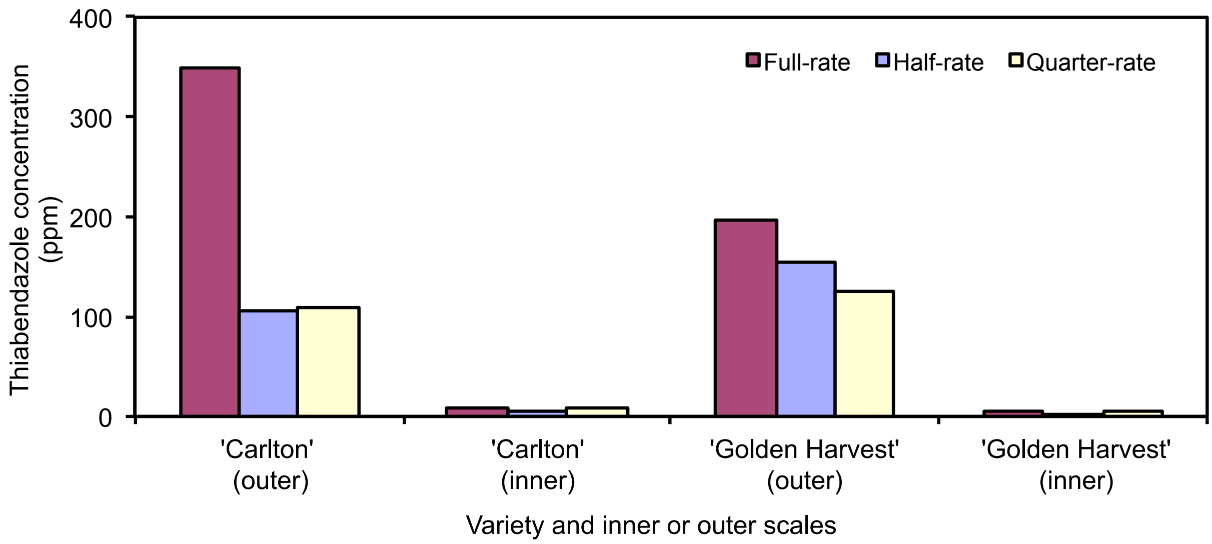
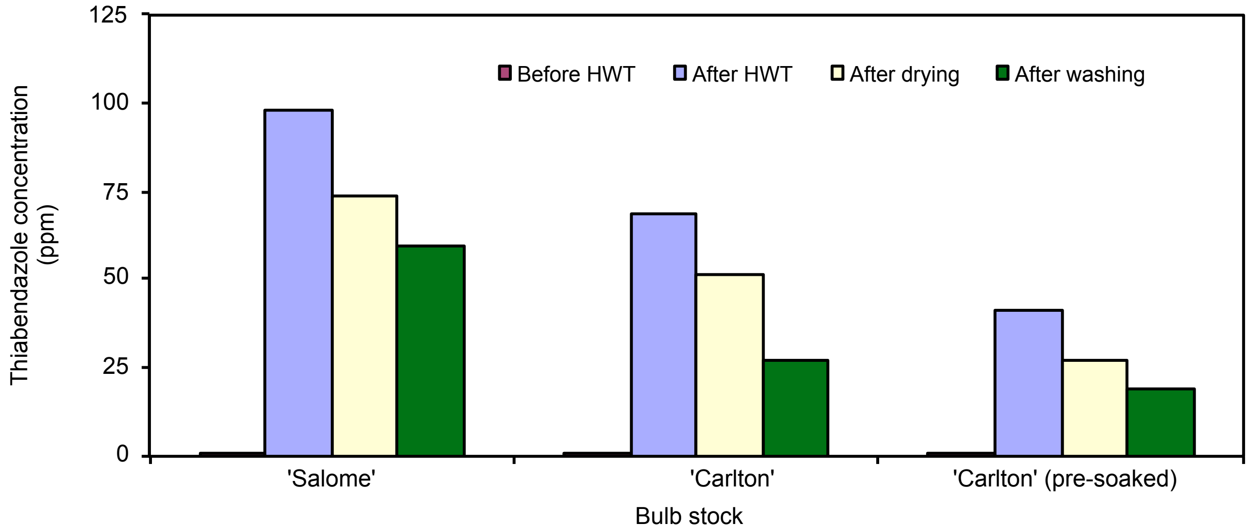


Figure 14 Thiabendazole concentrations in bulbs before and after HWT and following bulb drying and washing



Current use of 'Storite Clear Liquid' and 'Tezate 220 SL'

The following points about using 'Storite Clear Liquid' (or 'Tezate 220 SL') should be noted:

- For narcissus stocks severely affected by basal rot, thiabendazole was sometimes formerly used in HWT when it had already been applied post-lifting. This 'double treatment' provided the greatest initial reduction in the number of diseased bulbs, though some early foliage senescence and consequent yield loss were sometimes seen in the first crop year.[99]
- The current EAMU for 'Storite Clear Liquid' used as a dip for narcissus, and the full approval for the same product used as a post-lifting bulb spray, limit its use to once per year, so a double treatment is no longer possible.
- The conditions attached to approval of the post-lifting spray are the same as previously, that is using 1 L of product/1 t of bulbs.
- Each of these uses of 'Storite Clear Liquid' is specifically prohibited in the Isles of Scilly.
- As a bulb dip (either a cold dip or in HWT), usage is now limited to a maximum of 1.25 L product/1,000 L dip. It is assumed that the former, on-label top-up rates should be reduced proportionally.
- Advisory information on the EAMU refers growers to HDC Project BOF 43a regarding the use of acidifiers. The use of an acidifier (such as SBS) falls outside the PPPR regime, but clearly it should be used with care and following a COSHH assessment. The use of an acidifier is not obligatory.
- In the studies described, the pH of the mains water used (at Kirton) was between 7.3 and 7.8, so growers in areas using water of a different pH value may need to adjust their procedures.
- It is possible that, following prolonged use, there may be increased likelihood of corrosion to tanks where an acidifier is regularly used. The opinions of users within the industry, based on long experience, differ. Specific corrosion tests do not appear to have been carried out.
- In the HDC trials referred to, these treatments were tested only in standard HWT using formalin, wetter and anti-foam product, so the results should not be extrapolated to other HWT regimes or bulb dipping procedures or when other tank additives are being used.
- The bulbs used in these tests were reasonably clean, and the presence of excessive amounts of soil might cause further loss of fungicide.

Based on the above findings, detailed methods for using quarter-rate 'Storite Clear Liquid' or 'Tezate 220 SL' with SBS in HWT are given below (adopted from HDC Factsheet 13/04).[100]

How to use quarter-rate 'Storite Clear Liquid' or 'Tezate 220 SL' in HWT

Start-up for first dip, with plain, pre-heated water in HWT tank

- Gradually and allowing time for solution, add SBS to the tank first, at 1.38 kg/1,000 L.
- Add 1.25 L 'Storite Clear Liquid' (or 'Tezate 220 SL') /1,000 L.
- Add a disinfectant, non-ionic wetter and (if necessary) anti-foam preparation at the standard concentrations.
- Check dip pH is between 2.5 and 3.0 using a pH meter (the exact pH is not crucial within this range) and continue to check at intervals until familiar with dynamics of the tank.

Top-up (ideally after every HWT)

- Top-up tank with water to original mark and note the volume added (to the nearest 100 L).
- Add 0.138 kg SBS for each 100 L water added.
- Add 0.375 L 'Storite Clear Liquid' (or 'Tezate 220 SL')

for each tonne of bulbs just treated in the tank.

- Also add 0.25 L of 'Storite Clear Liquid' (or 'Tezate 220 SL') for every 100L of water top-up.
- Add a disinfectant, non-ionic wetter and (if necessary) anti-foam preparation at the standard concentrations for each 100 L water added.

At the start of each further day's dipping (in addition to the normal top-up)

- Add an additional 0.25 kg SBS/1,000 L dip in the tank; this amount may have to be adjusted by trial and error to obtain the correct pH reading (2.5 – 3.0).

Other fungicides

Despite the generally good results of using 'Storite Clear Liquid' in HWT for basal rot control, alternative fungicides are needed - to reduce costs, provide alternatives or choice, and reduce the likelihood of fungi developing resistance. Also, no pesticide can be guaranteed to remain on the market.

In HDC Project BOF 31a[101] a range of fungicides was tested *in vitro* against the basal rot fungus and other fungi implicated in neck rot (*Botrytis narcissicola* and *Penicillium hirsutum*). Captan, prochloraz, imazalil and thiabendazole were effective against all three pathogens, whereas fludioxonil, guazatine and quintozene were not. Captan, prochloraz, imazalil and thiabendazole, along with chlorothalonil and iprodione, were applied to healthy and basal rot-infested stocks of various cultivars as post-lifting sprays or by addition (with formalin) to the HWT tank. Although most of these fungicides are not currently approved for bulb use in the UK, the results can indicate the types of treatments for which approvals might need to be sought at a later date. The main conclusions were as follows:

- Thiabendazole and some other fungicides resulted in mild phytotoxic effects in the first year, with slight loss of yield and quality, but this was evident only in healthy stocks where control of basal rot was not applicable. The crops recovered fully from these mild adverse effects in the second year.
- Apart from iprodione, which was relatively ineffective, the other fungicides tested as post-lifting sprays produced clear benefits in diseased stocks, increasing bulb and flower yields and reducing storage rots.
- Apart from iprodione and imazalil, which were relatively ineffective, the other fungicides tested in HWT with formalin tended to increase yields and reduce storage rots, with benefits increasing in the most disease-prone stocks.
- These results suggested that the most effective fungicides do not need to be used at every HWT, or as a double treatment (post-lifting plus HWT), in mildly diseased stocks; increasingly serious infestations warrant increasingly stronger fungicide treatments.
- A fungicide cocktail, consisting of prochloraz and formalin with reduced-rate captan and thiabendazole, was also tested in HWT.[102] This severely reduced crop vigour in both crop years. In a follow-up trial, the same mixture was not harmful when used in a Dutch HWT regime of two hours at 43.5°C, suggesting that care should be taken in tank-mixing fungicides for HWT under UK conditions.

Several other fungicides have been tested as HWT additives against basal rot, and others will have, no doubt, been resorted to. This information is summarised here as it may provide guidance for future research.

- Fungicides recommended in the Netherlands at various times have included benomyl, captan, carbendazim, maneb, thiophanate-methyl and zineb, none of which are now available for use on bulbs in the UK. Lower concentrations of fungicides are advised for reclaimed bulbs, because the drier bulbs take up more dip.[38]
- In the Netherlands fungicides have often been used in mixtures, especially for dwarf cultivars.[103] Relatively recent recommendations were for a combination of formaldehyde, captan, carbendazim and prochloraz.
- Other fungicides found in trials in the UK, the Netherlands and the USA, to be effective in controlling the spread of basal rot during HWT included chlorothalonil and thiram.[104,105,106]

Anti-resistance strategy for basal rot and thiabendazole

UK growers may have become over-dependant on 'Storite Clear Liquid' because few alternatives were available. Over-reliance on one active ingredient, as well as possibly leading to resistance development by the pathogen, is inadvisable, since market and other forces may result in it being withdrawn.

Although there have been no obvious indications of a loss of effectiveness of thiabendazole against basal rot as a result of many years of exposure, there is evidence for the development of thiabendazole-resistant isolates of the pathogen from Defra-funded research at Wellesbourne.[107] In 1999, 75 isolates from three cultivars and eight sources from East and South-West England were tested, and in 2002 a further 76 isolates from minor cultivars. All but two of the isolates were pathogenic to narcissus bulbs. Of isolates collected in 1999, 5% could tolerate concentrations of thiabendazole above 4 ppm, while, of those collected in 2002, 25% could. All isolates remained sensitive to prochloraz. While *Fusarium oxysporum* is the main pathogen targeted, thiabendazole also controls *Penicillium* species, though there are also reported instances of the ineffectiveness of the fungicide against this pathogen, possibly an indication of resistance.[108]

An anti-resistance strategy would involve:

- Growing basal rot-resistant cultivars where possible.
- Using fungicide treatments when necessary, not as a matter of routine.
- Using fungicides from two or more mode-of-action groups, e.g. thiabendazole as a spray into store and an alternative (such as chlorothalonil) if necessary in HWT.
- Using effective rates of fungicides.
- Developing tank-mixes of fungicides from different mode-of-action groups.
- Making use of other methods to manage basal rot, not relying on fungicides alone, including prompt drying, use of correct bulb storage conditions, delaying planting when soil temperatures are high.

Insecticides for large narcissus fly control

Until the withdrawal of aldrin, formerly used as an in-furrow application at planting to control the large narcissus fly, including an insecticide in HWT tanks was unnecessary. In the South-West chlorpyrifos is now used when required in HWT, and prevents the subsequent infection of bulbs by the larvae, though for one year only.[109] With the subsequent increased incidence of large narcissus fly in Eastern England, the treatment was investigated in trials in Eastern England (at Kirton and in Norfolk) in HDC Project BOF 24.[110] Application in HWT was the most effective method for controlling large narcissus fly, irrespective of whether the bulbs were stored at ambient temperatures beforehand, or were pre-warmed at 18 or 30°C. Used without pre-warming, chlorpyrifos treatment resulted in some loss of yield and other detrimental effects (fewer and smaller flowers and shorter stems), though bulb yield and crop quality two years later were unaffected.

The *Pesticides Usage Surveys* showed that chlorpyrifos has been used on a variable but modest proportion of UK crops in the years examined. Until withdrawal, dimethoate-based insecticides were used to a lesser extent. Over many years, numerous other insecticides have been tested in bulb soaks and HWT and have been found to be ineffective in controlling the large narcissus fly larvae.

Only chlorpyrifos-based insecticides currently have approval for this use, and some approval details are given in Table 30. Some points to note about chlorpyrifos are:

- Added to the HWT tank, chlorpyrifos has some phytotoxic effects on narcissus, reducing flower yields in most cultivars unless the bulbs have been pre-warmed.
- HWT is the preferred method of application, as post-HWT cold soaks and application at planting, though generally crop-safe, are less effective.
- Three chlorpyrifos insecticides, 'Alpha Chlorpyrifos 48 EC, 'Cyren' and 'Pyrinex 48 EC' currently have EAMUs for use as a 15-minute pre-planting cold soak (as 1.0 L product/100 L water) and as a three-hour HWT (as 0.5 L product/100 L water).

Other substances used in HWT

Wetters

A non-ionic wetter (spreader or surfactant) is considered essential in HWT to enhance pesticide action. Only a non-ionic wetter should be used, since cationic and anionic wetters can cause damage to the crop.[111,112] It should be appreciated that wetters can have far-reaching effects on cell chemistry, so it is important to use them at the recommended rates.

Anti-foam preparation

The use of anti-foam materials is essential in some HWT systems for reducing foaming, since nematodes can survive in foam which is cooler than the dip itself. If no standard rate is provided on the label, add enough to prevent foaming. Anti-foam preparations have no adverse effect on the crop.[113]

Anti-dust preparation

In the Netherlands an anti-dust 'sticker' may be added to the HWT tank to reduce problems in handling treated bulbs.[114] This would appear to be a potentially very useful treatment, though no information on the materials has been located.

Acidifier

As mentioned previously, fungicides such as thiabendazole are more soluble if the solution is acidified. Current experience is based only on using SBS with 'Storite Clear Liquid'.

Other chemicals tested in HWT

Some other compounds have been reported to enhance fungicide action in HWT. However, when dimethyl sulphoxide, indolylacetic acid and hydrochloric acid were tested, they showed no benefits in UK trials.[115]

Table 30 Fungicides and insecticides with Extensions of Authorisation for Minor Use (EAMUs) for use in bulb dips

Active ingredient	Product	Approval number and expiry date	Marketing company	Approved crop(s)	Disease(s) or pest(s) treated
Fungicides					
Chlorothalonil	Bravo 500	2011/0943 03/03/2015	Syngenta Crop Protection UK	Narcissus bulbs (dip)	Basal/neck rot (*Fusarium oxysporum*)
	Life Scientific Chlorothalonil	2012/0379 28/02/2016	Life Scientific Limited		
	LS Chlorothalonil	2011/1881 31/05/2015	Kilcullen Kapital Partners		
Thiabendazole	Storite Clear Liquid	2007/0924 31/12/2015	Syngenta Crop Protection UK	Narcissus bulb (dip)	Basal/neck rot (*Fusarium oxysporum*)
	Tezate 220 SL	2009/1180 31/12/2015	Agrichem		
Insecticides					
Chlorpyrifos	Alpha Chlorpyrifos 48 EC	2009/1085 31/12/2021	Makhteshim-Agan (UK)	Non-edible ornamental bulbs	Narcissus bulb fly [i.e. large narcissus fly]
	Cyren	2005/0236 31/12/2021	Headland Agrochemicals		
	Pyrinex 48 EC	2010/0043 31/12/2021	Makhteshim-Agan (UK)		

8.4 HWT dip management

Making up dips and topping-up

This is an area convenient to gloss over, but it is crucial to achieving good results.

- Some pesticide labels state that bulb dip solutions should be freshly made up for each soak. This would, of course, be entirely uneconomic in commercial bulb production. In practice it is normal to re-use HWT dips for as long as practical, providing gross contamination with debris (bulb skins, soil, etc.) can be minimised.
- For topping-up, the manufacturer's recommendations should be consulted, though these are often non-specific. After dipping, tanks should be topped up with water to the original mark, and appropriate amounts of disinfectant, pesticide, etc., added such that the top-up is given at the original strength. Unless specified differently, this should be the normal routine.
- 'Storite Clear Liquid' was an exception, as definite top-up procedures are provided on label.
- Dutch recommendations[122] suggest using slightly higher top-up rates for prochloraz, but using other pesticides at the original strength.

Monitoring chemical concentrations and pH in dips

Little published guidance exists on the stability of the pesticides used in bulb dips. As active ingredients can be lost in use by precipitation, hydrolysis, etc., it is advisable to have the concentration of disinfectants and pesticides determined for some samples, at least until experience of their dynamics in the user's HWT system has been gained.

Thiabendazole and other fungicides

No convenient on-farm method is available, and samples would be sent to an analytical laboratory for testing.

pH value

When pH is being monitored for acidified thiabendazole in HWT, the pH of dips is best measured using a portable, temperature-compensated pH meter. Although the electrodes need careful handling and maintenance, a pH meter is more reliable than using dip-stick testing. Cheaper digital pH meters are also available.

Running-down tanks

Growers need to minimise the amounts of spent dip to be disposed of at the end of the HWT season. It is usual to treat HWT basal rot-susceptible cultivars first, because these are more likely to need the addition of a fungicide; the residual fungicide is thereby 'used up' in the subsequent HWT of non-basal rot-susceptible cultivars where no further fungicide is added. At the end of the HWT season, topping-up should be no more than necessary to cover all bulbs being treated, in order to reduce the amount for disposal, and, if the HWT system is capable of working on half-capacity, the amount of dip could be reduced further for the last few dips.

Disposal of spent dips

Dilute pesticide waste should be disposed of according to Section 5 of the *Code of Practice for using Plant Protection Products*. Briefly, this may be by application to a crop or area within the terms of the product approval, through a waste-disposal contractor, by disposal onto soil or grass under the terms of an authorisation under the Groundwater Regulations, by processing the waste or disposing to a lined biobed under the terms of an appropriate waste-management licence, or by disposal into a sewer under a trade effluent consent.

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9.0 Other pre-planting treatments

9.1. Insecticide treatments

As an alternative to adding an insecticide for controlling large narcissus fly to the HWT tank, separate post-HWT, pre-planting cold soaks (usually for 15 minutes) were investigated in MAFF-funded trials[1,2] at Starcross and Rosewarne and in HDC Project BOF 24 at Kirton and in Norfolk.[3] Cold soaking with chlorpyrifos was found to be less effective than using it in HWT, though the cold soak had no adverse effect on the bulbs, as was the case with application in HWT (unless pre-warming treatments were given). In some of these trials, the cold soak was applied immediately after HWT. Should bulbs receive a further soak treatment after HWT, some of the HWT-applied pesticides may be washed out. Some chlorpyrifos-based products currently have EAMUs for bulb dip treatment.

Similar treatments have been investigated in the Netherlands, with chlorpyrifos applied as a pre-planting cold soak, as a drench in spring, or as regular crop sprays.[4] In these cases it was found that chlorpyrifos soaks and drenches were less effective than regular crop sprays of omethoate, though the latter is not available in the UK.

Other trials of pre-planting cold insecticide soaks have been reported, and, although most of the pesticides tested are no longer available in the UK, they provide guidance about potentially useful bulb treatments should alternative materials become available in the future.

- In earlier trials in the UK insecticides investigated or used for this purpose included aldrin, chlordane, dieldrin and gamma-HCH.[5,6,7]
- In trials in Poland, cold soaks shown to be effective against large narcissus fly larvae included carbofuran, diazonin, isofenphos and metylopirimiphos.[8,9] A one-hour soak was most effective.

9.2. Fungicide treatments

In trials at Rosewarne, a cold soak in a copper fungicide after HWT showed promise for basal rot control.[10] This treatment does not seem to have been further tested, though some copper fungicides are available.

In the Pacific Northwest, concerns about neck rot caused by *Botrytis narcissicola* led to trials of 20-minute, pre-planting cold dips in a range of fungicides.[11] An infested stock of 'Dutch Master' was treated, air-dried overnight, and grown on in a glasshouse at 15°C/10°C (day/night temperatures):

- Neck rot and leaf necrosis were significantly reduced by using products with the following active ingredients: boscalid + pyraclostrobin, fludioxonil, and tank-mix of thiabendazole + captan.
- Axoxystrobin and trifloxystrobin were less effective.
- Pyraclostrobin was ineffective.
- Although these materials are available in the UK there are currently no approvals for their use as dips or generally in ornamental plant production.

9.3. Storage treatments to manipulate flowering and growth

Advancing flowering ('forwarding')

In South-West England a major part of farm income is derived from early flowers from field-grown daffodils. Even earlier flowers can be cropped in the field if a pre-planting cold treatment ('pre-cooling') is used, a form of 'outdoor forcing' that is, however, dependent on ambient temperatures in the spring. The advent of newer, earlier flowering cultivars has obviated the need for forwarding to some extent.

'Pre-cooling' bulbs for two to six weeks at 9°C before planting results in earlier flowers and allows picking over a longer period, though the flowers may be of poorer quality and subsequent bulb yield is reduced.[12,13] In trials at Rosewarne and Kirton it was shown that the optimum treatment for advancing flowering was six weeks at 9°C, with no advantage of using either longer or colder treatments, or of augmenting the treatment by covering the growing crops with polythene film.[14,15] These procedures gave flowering dates between eight and 28 days earlier than from untreated controls.

Some variations on the pre-cooling technique have been reported.

- From trials in France it was reported that flowers could be obtained, 30 to 45 days earlier than from untreated bulbs, by warm storage (seven days at 34°C) followed by cooling (eight weeks at 9°C) and covering the rows with a narrow polythene tunnel.[16]
- Similarly, in Italy, pre-cooling was investigated prior to planting bulbs outside, successfully using a treatment at 3°C for up to six weeks.[17]

A schedule for forwarding

The following is an outline of forwarding for South-West England:

- Most cultivars respond to advancing, but those chosen should be the ones that respond best and which are in plentiful supply, since pre-warming will reduce bulb yields: 'Golden Harvest', 'Hollywood' and 'Fortune' were most used.
- Bulbs around 12 or 13 cm grade are suitable.
- Stocks with any suspicion of nematode infestation should not be used, as the warm storage treatments used would favour nematode development.
- Bulbs intended for earliest flower production should be lifted in June.
- Soon after lifting, bulbs should receive a warm storage of 5 days at 35°C. This treatment can double as 'high temperature drying', or, for forwarding, can be replaced by the normal pre-HWT pre-warming; alternatively, both pre-warming treatments can be used.
- Bulbs of most cultivars are best stored at 17°C until 'stage Pc' before HWT is given. However, bulbs of 'Golden Harvest' and 'Hollywood' can proceed to treatment before stage Pc, at any time in July. Bulb cleaning and grading can take place during this time.
- HWT is essential for the control of stem nematode, so the bulbs are pre-warmed for one week at 30°C, pre-soaked at ambient temperatures for three hours or overnight, and given HWT for three hours at 46°C. Any delay between pre-warming and HWT should not exceed one day. The normal HWT additives should be used. The pre-warming periods, and HWT itself, give an advancing effect provided they are completed before late-July.
- After drying at 17°C for two to three days, the bulbs should be cooled by storing for in appropriate conditions for four to six weeks at 9°C and 75% relative humidity. If treated for the full six weeks, there is a danger that cultivars like 'Hollywood' and 'Fortune' may grow too early and be damaged by winter weather, so a four- to five-week period is used. A four-week period also reduces yield loss in the subsequent year, at the expense of losing some earliness. To spread picking dates, bulbs may be planted in two batches, say after four and six weeks of cold storage.
- Bulbs should be planted in September under normal conditions and at a planting density of about 20 t/ha, avoiding cold sites (such as north-facing slopes or frost pockets). They should be grown for two- or three-years down.
- In some cases irrigation may be useful to assist establishment.
- Other aspects of growing forwarded crops are as for normal growing.

Delaying flowering

If the warm-storage treatments used above are delayed until August, some varieties may respond by later flowering. In some cases late flowers may be required, for example to meet the demand for flowers at a late-Easter. Trials at Rosewarne showed that bulb storage at between 20 and 26°C from August to October could delay flowering, but by less than a week.[18]

Manipulation of plant growth generally

Other than for extending the flowering season, there appears to be scope to use pre-planting temperature control to manipulate growth more generally to suit the requirements of the producer.

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10.0 Bulb planting

10.1 Crop duration

Traditionally, bulbs were planted in one year and lifted in the next. In the UK, growing 'two-year-down' narcissus was adopted in the 1970s. The two-year-down system was developed for economic reasons, in response to low returns for bulbs. In two-year growing, only half of the bulb stock needs to be lifted, treated and re-planted each year. In practice, many crops are now planted and left down for three years.

From trials of one-, two- and three-year-down growing at Rosewarne and Kirton, it was concluded that costs were, at that time, too high for an annual system to be economic;[1] a similar conclusion was drawn from trials in Norway.[2] Figure 15 is a typical example of percentage bulb weight increase for one- and two-year growing at Rosewarne. Two-year growing gives a similar or slightly greater increase than one-year growing, density for density. In Figure 16 the same results are expressed as disposable yield, that is the saleable yield after taking out stock for re-planting (at the same rate as before): disposable yield is very similar for all treatments – but consider the potential savings in land use and labour. To achieve gross margins from two, one-year cycles in excess of that for one, two-year cycle (with 150% weight increase), annual weight increases of 70 to 100% would be needed from plantings of 25 t/ha; this is achievable, but probably difficult to achieve consistently.[3]

Figure 15 Percentage bulb weight increase in two-year growing and in each year of one-year growing; 11-13 cm 'Golden Harvest' planted at Rosewarne (Note that the lowest planting rate was not tested in one-year growing, nor the highest planting rate in two-year growing)

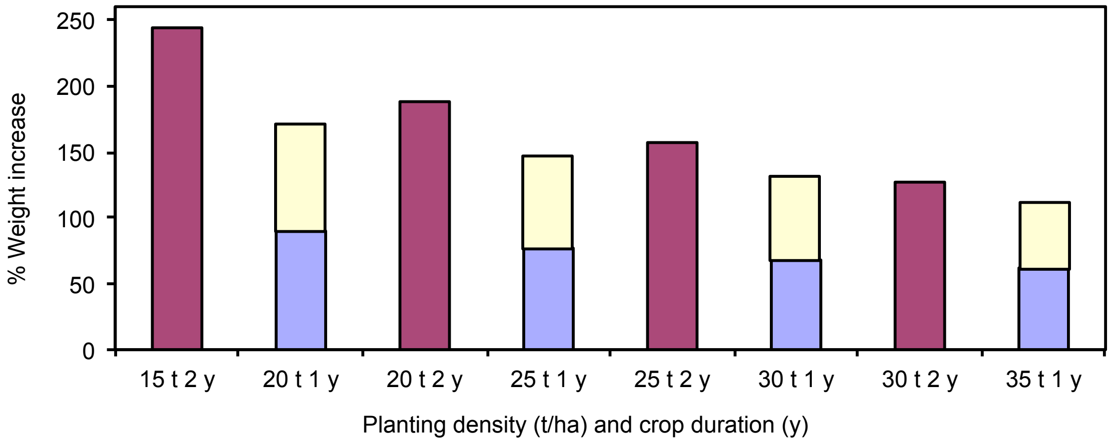


Figure 16 Disposable bulb yield in two-year growing and in each year of one-year growing; 11-13 cm 'Golden Harvest' planted at Rosewarne

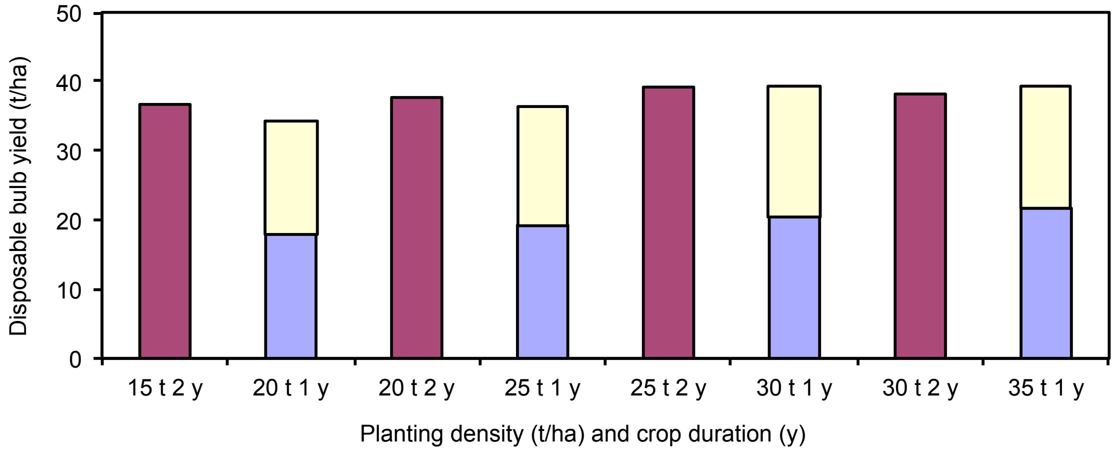
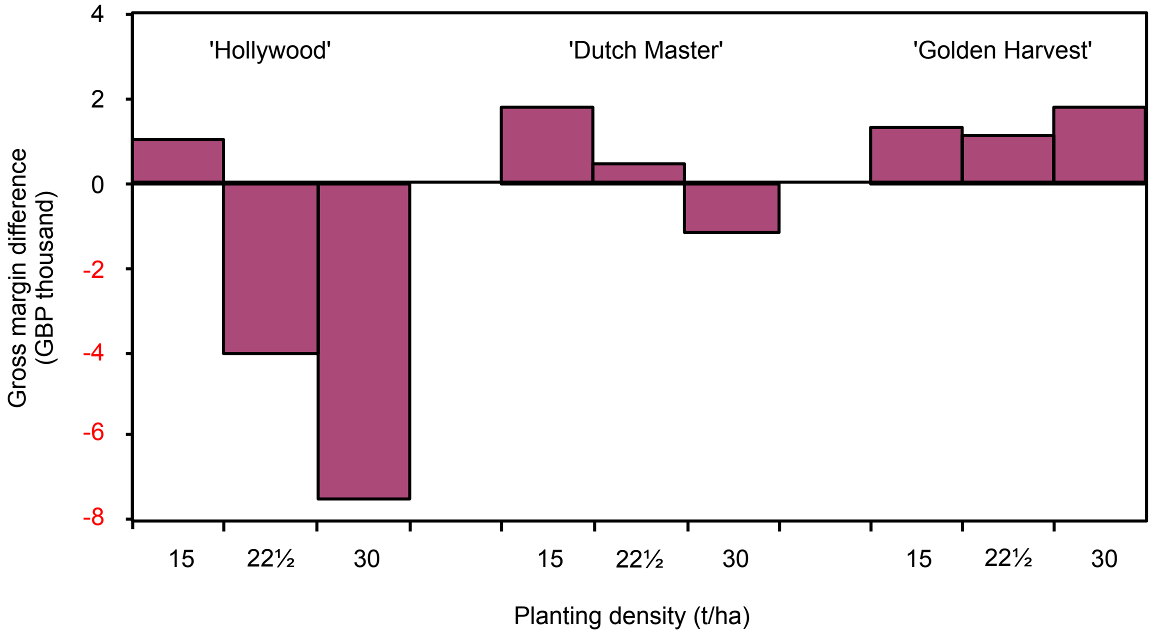


Figure 17 The gross margin (for flowers plus bulbs) resulting from a three-year crop, relative to two-year production. (Note that the gross margins are values from about 1990 in £k)



In two-year growing, treatments such as HWT, post-lifting fungicide treatment or high-temperature drying can be carried out only in alternate years, so there is increased risk due to stem nematode and fungal diseases. Fungal pathogens and stem nematodes can build to serious levels over a two-year period, whereas they are not normally a problem in one-year growing. On husbandry grounds alone, leaving bulb crops down for more than a single year is inadvisable, because of the potential for the build-up of pests and diseases with the extended interval between HWT; economically, however, the traditional, one-year system was untenable.

From the 1980s cut-flowers from field-grown crops became critical to the bulb industry throughout the UK, and growing narcissus for longer durations benefited flower yields at a time when bulb prices had fallen. Relatively few agronomic trials have been carried out on crops grown for three-year or longer cycles, but Figure 17 illustrates the effect on gross margins of growing for three, rather than two, years. The data, including costings, are from Rosewarne around 1990, so the gross margins should be used as relative values only. The figures show that 'Dutch Master' and 'Hollywood' need to be planted at 15 t/ha to gain benefit from a three-year system; however, 'Golden Harvest' could benefit from using higher planting densities but only with a vigorous stock treated with an effective fungicide regime to manage basal rot.[3]

Using longer crop durations enabled UK growers to become more efficient by reducing their annual demands for labour, land and storage, while producing not only good flower yields and but yields of bulbs that were still acceptable. In the 1990s more UK growers left narcissus crops down for three or more years, as their returns for bulbs fell. Table 31 gives an indication of the 'age distribution' of crops in 1997, 2001 and 2005, using the samplings in the *Pesticide Usage Surveys*: it demonstrates the developing trend for leaving narcissus down for more than two years. The benefits of three- or four-year growing cycles have been widely demonstrated in other countries.[4,5]

Table 31 The percentage of first, second and older crops from Pesticide Usage Survey samples

Crop year	Survey year		
	1997	2001	2005
1	43	43	39
2	53	47	39
>2	4	10	22

Advantages and disadvantages of growing for two or more years-down

The characteristics of two- (or more) year growing are summarised here:

- Compared with one-year-down growing there is some loss of yield because an optimum planting density obviously cannot be achieved in both years. Too low a bulb density in the planting year is uneconomic, while too high a density produces overcrowding in the lifting year, so a compromise density should be used.
- Using a low planting density, say 10 t/ha, about half the bulb weight increase occurs in each year of a two-year cycle. At high densities, say 20 t/ha, virtually all the increase in bulb weight occurs in the first year.
- Where flower production is more important than bulb production, two-year-down growing is beneficial, since more flowers are obtained in year two. After the first year the flowers are no longer affected by previous HWT, so quality is high and, unless it is wished to crop flowers in the first year, there is no need for using pre-warming or other techniques for reducing HWT-damage.
- Using two-year-down growing there is a higher yield of the smaller grades of saleable bulbs that are in demand for pre-packs.
- There is a compensating effect on bulb yield in year two if poor growth has occurred in year one (as a result of to early senescence or mild fungicide damage for example).

Besides the greater vigilance against pests and diseases that is needed when growing on longer crop cycles, some other disadvantages include:

- In the summer between growing periods the bulbs remain in the soil, when temperatures are high and liable to encourage basal rot.
- The benefits of early bulb lifting - avoidance of narcissus fly and aphid-borne viruses - are lost.
- When narcissus are left in the ground, they begin growing earlier, and earlier rooting allows more effective infection by soil-borne pathogens while soil temperatures are still high.
- Second-year bulbs sprout earlier than first-year bulbs, and may be susceptible to frost damage.
- If significant pest and disease problems arise, a temporary return to one-year-down growing might be considered, but probably only in the case of an elite stock.

10.2 Planting in ridges or beds

Traditionally, bulbs were grown in flat beds and planted and lifted annually by hand. Planting and lifting are now mechanised, and in the UK growing in ridges was adopted in the 1970s for practical reasons. Ridges are also used in the Netherlands where bulbs are grown on heavier soils. When growing in ridges smaller volumes of soil need to be moved, and the equipment used for potato growing can be shared.

Growing in ridges utilises planting machines that feed bulbs from a hopper into furrows which are then ridged-up, planting two ridges at a time (except in the case of older one-row lifters that may still be useful in specific cases). The planting rate should be calibrated by adjusting the hopper aperture and/or the speed of the delivery belt. Constant attention by an operator is useful as blockages can occur, and correct planting depth can easily be lost in undulating fields. The current high planting rates may be difficult to achieve with some older bulb planters. Planting in ridges may be assisted at some sites by first using a de-stoner or bed former. When planting in beds, small, uniform bulbs may be planted several rows at a time using a row planter. Larger bulbs are planted using bed digging and filling machines that lift the soil and transfer it to the adjacent planting bed.

When crops are grown in beds rather than ridges, the utilisation of land would be expected to be better, producing a higher bulb yield/m^2. Trials were set up at Rosewarne in the 1960s to compare the two systems. Offsets and double-nosed bulbs were planted at densities from 54 to 216 bulbs/m^2 (*ca* 5 to 22 t/ha for 10 g offsets, 32 to 130 t/ha for 60 g double-nosed bulbs), and grown for one, two or three years.[6,7]

- Flower yield in the first year was directly related to density, thereafter declining with higher densities and with larger bulbs.
- Ridges were out-yielded by beds by 26-29%, except at the lowest density where the difference was only 15%.
- Planting at 20 to 30 t/ha gave the highest combined financial returns for bulbs and flowers.
- Two- and three-year growing were more efficient than growing for one-year, especially at medium densities.

10.3 Planting density

When bulbs were planted by hand in beds, they were “traditionally spaced one and a half to two bulb diameters apart in rows eight to 12 inches [20 to 30 cm] apart [giving] populations ranging from 200,000 down to 120,000/ acre [494,000 down to 296,000/ha], depending upon the size of bulb planted”.[8] Today, the rate of planting depends on the vigour of the cultivar, bulb prices, the percentage bulb weight increase expected, the size of bulbs required and the growing system adopted.

In the UK, narcissus bulbs (for two-year growing or longer) are now planted at densities between 12.5 and 25 t/ha, with a norm of about 17 t/ha.[9] The higher planting rates now used, say above 20 t/ha, are much greater than those being used at the time higher rates were recommended following detailed trials work.[8] In the Netherlands, planting rates for one-year-down narcissus vary from 14 t/ha for small offsets, to 35 t/ha for large ‘mother bulbs’, in which the high rates encourage splitting to smaller, saleable bulbs.

Low or high planting densities?

The planting density will depend on a number of factors:

- Low planting densities are used where vigorous bulbs are being planted, where a high rate of increase is required (such as when bulking an expensive cultivar), or where large bulbs are required.
- High planting densities are used when growing a commonplace cultivar, where the requirements are a reasonable rate of increase coupled with reduced land and labour requirements, or where a good yield of smaller grade bulbs is needed.
- The preferred planting rate is that which gives the best financial returns, not the greatest yields.[10,11]

When high planting densities are used it may result in:

- Accentuation of pest and disease problems.
- Creation of handling problems at planting and lifting.
- Changed irrigation and fertiliser needs.

Planting density trials in the 1960s

The early planting density trials used bed-grown crops. In the 1960s, two-year crops of ‘King Alfred’ were investigated at Rosewarne.[8] Small bulbs (<10 cm grade) were planted at densities equivalent to 2.4 to 15.9 t/ha. The main findings were:

- Flower numbers (in the second year) increased from around 215,000 to 2,316,000/ha as the density was increased, falling off only at the highest density.
- Over the same densities, stem length increased from 29 to 35 cm.
- Over the same densities, bulb yield increased from around 18.4 to 74.9 t/ha. Unlike flower yield, bulb yield did not peak within the range of densities used, but, even so, yields were considered more than adequate even at the highest planting density.
- Planting density did not affect flowering date.
- The yield of larger bulbs reached a maximum above 10.8 t/ha.

The effects of planting density and grade planted were investigated in three successive one-year-down trials at Kirton in the late-1960s. The main findings were:

- For smaller grades of bulbs, the optimum economic planting densities were greater than the highest rates used in the trial, which were 38 t/ha for 6-8 cm bulbs and 48t/ha for 8-10 cm bulbs.
- For larger grades (10-12 and 12-14 cm) there were large differences in optimum densities and financial returns between years, so it was difficult to draw any general conclusions.
- Over the three years the mean optimum densities were 42 t/ha for 10/12 cm grade and 27 t/ha for 12/14 cm bulbs.

These and similar trials indicated that planting rates up to 22.5 t/ha, considerably higher than were used at the time, could be profitable where a high volume of saleable bulbs was required. Since higher planting densities led to longer stems, the increased crop support created on windy sites was also useful where the flower crop was important.

Planting density trials in the 1980s

Further planting density trials were carried out at Kirton and Rosewarne in the 1980s.[12] Bulb yields from a two-year 'Golden Harvest' crop grown at Rosewarne at planting densities between 7.5 and 22.5 t/ha are shown in Table 32. Although the percentage weight increase is reduced by 57% when planted at 22.5 rather than at 7.5 t/ha, higher planting rates give relatively more income and more bulbs in the saleable, middle grades. The lowest planting rate gives one-third of the lift in the >16 cm grades that were becoming less in demand with an increase in the 'pre-pack' trade.

The effect of planting grade and planting density on grade-out are shown in more detail in Figure 18, taken from a similar trial with 'Carlton' at Kirton. This and other trials confirmed the reduction in the proportion of the yield in the larger grades, and an optimum economic planting density of 20 to 25 t/ha.

Planting density and basal rot

Planting density has a major effect on the spread of basal rot (and presumably of other diseases and pests). The following findings have come from UK trials at various locations:

- Healthy bulbs were placed 0, 10 or 20 cm laterally from 'inoculator bulbs' (bulbs infected with basal rot). After one growing season 60, 27 and 6% of the healthy bulbs were affected, respectively.[13]
- In the soil the basal rot fungus can infect bulbs 30 cm away.[14]
- For all bulbs in the ridge to be at risk of infection when grown on ridges at 76 cm centres requires 10% infected bulbs at a density of 10 t/ha, but of only 5% at 20 t/ha.[15] With ridges at 90 cm centres the percentages would be lower (because the bulbs are more densely crowded within the ridges).

Planting density and dwarf cultivars

In the Netherlands, dwarf cultivars are usually planted at about half the density of standard cultivars. In HDC project BOF 23[16] planting <8 or 8-10 cm-grade bulbs of 'Tête-à-Tête' at 5 or 10 t/ha and growing for two-years-down gave disposable yields of 6 to 7 t/ha. There were no benefits of using either higher planting densities or one-year-down growing.

Figure 18 Distribution of bulb yield (by weight) to grades in two-year growing of 8-10 and 10-12 cm grade 'Carlton' bulbs planted at Kirton

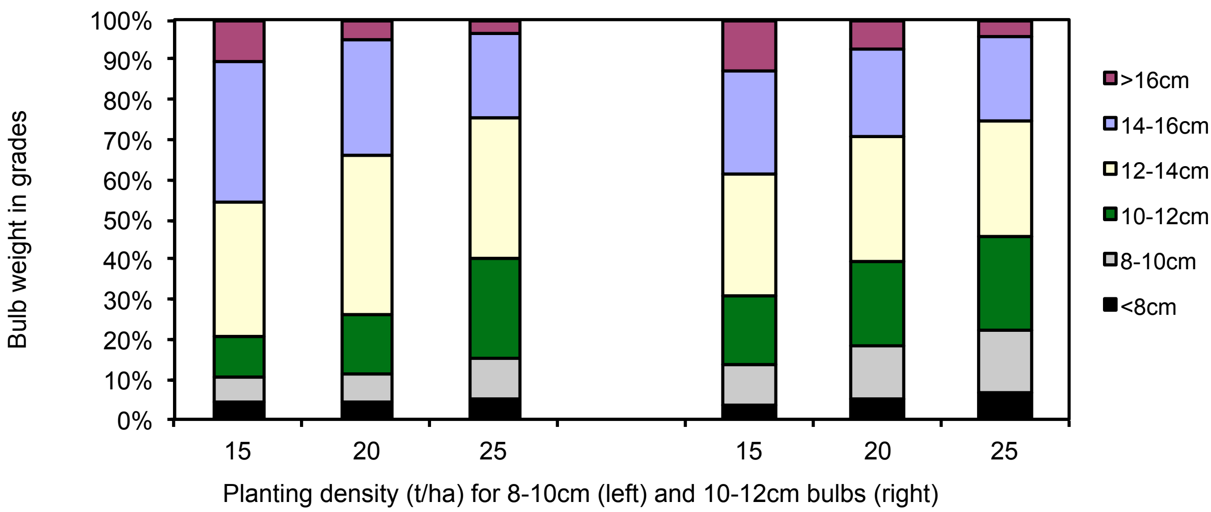


Table 32 Effect of planting density on bulb yield of 10-12 cm grade 'Golden Harvest' grown at Rosewarne for two years

Planting rate (t/ha)	% of yield in grades (by weight)			% weight increase	Total weight lifted (t/ha)	Disposable yield (t/ha)	Additional income over 7.5 t/ha (£/ha)
	<10 cm	10-12 to 14-16 cm	>16 cm				
7.5	6	61	33	224	24.3	16.8	-
15.0	12	68	20	140	36.0	21.0	945
22.5	17	75	8	97	44.3	21.8	1125

10.4 Planting geometry

Planting geometry includes such factors as the dimensions of the ridge and planting band, row direction, the rectangularity of planting, and bulb orientation.

Ridge width and planting bands

In the UK ridges are now almost invariably arranged at 90 cm centre-to-centre, though some small traditional farms may ridge at 76 cm centres.[17] Planting machinery is often set to plant bulbs in a 20 to 25 cm-wide band within the ridge, so the actual planting density within the planted band may be three to four times that in the overall area of the field (the latter being the way densities are conventionally expressed). In trials at Kirton, using overall planting densities between 20 and 30 t/ha, it was found that the width of the planting band, over the range 20 to 35 cm, had little effect on either percentage bulb weight increase or bulb grade-out.[18,19]

The effect of similar changes in bed planting was studied in trials in the Netherlands.[20] Changing from 95 cm-wide planting bands in 140 cm-wide beds to 105 cm-wide planting bands in 150 cm-wide beds, was said to be easier in practical terms, and it also allowed 2% more bulbs to be planted in the same overall area without significant impact on labour requirements.

Rectangularity and row orientation

Trials of bed-grown crops at Rosewarne in the 1960s also investigated the effects of rectangularity, the ratio between in-row spacing and between-row spacing. Bulb yield declined with increasing rectangularity in East-West rows, but was unaffected by rectangularity in North-South rows. This was interpreted as an effect of wind, shelter or light interception.[21]

The effect of row orientation was investigated in the same project. The main finding was that plants in North-South rows had longer stems than those in East-West rows. Longer stems are also produced in more densely planted crops, an effect of shading. In perennialisation trials in Oklahoma, USA, bulbs of two cultivars ('Music Hall' and 'Tahiti') were planted in raised field beds and covered with shade cloth to give 0, 30 or 60% shade.[22] Increasing shade increased stem length, but did not affect the percentage of bulbs flowering.

Bulb orientation

When bulbs were planted by hand in beds, they were placed upright and about equal distances apart. Now, planting machines tumble the bulbs into a furrow so they are more-or-less randomly orientated within the ridges. This results in less uniform growth and shape. At about the time planting machines were introduced, the effect of bulb orientation was investigated at Rosewarne.[23,24] This showed that:

- Random orientation produced bulbs with bent necks.
- Vertical, inverted, diagonal or horizontal bulb orientation did not significantly affect bulb yields.
- Vertically planted bulbs gave slightly earlier crops.

10.5 Planting depth

In the UK using a planting depth that avoids frost damage is not usually a consideration, since soils here rarely freeze deep enough to cause injury. Narcissus bulbs are usually planted about 13 cm-deep (measured from the base of the bulb to the top of the ridge). This is considered sufficient to reduce basal rot problems due to higher temperatures near the surface. Taking care to adjust machinery to ensure an even planting depth, especially on undulating sites, produces a more uniform bulb environment and aids bulb lifting. Shallower planting may lead to damage from cultivation and herbicides, and the bulbs are in warmer soil that would encourage basal rot. Deeper planting (25 cm) may result in better growth and reduce attacks by large narcissus fly larvae, but the bulbs are more difficult to lift.

Narcissus bulbs have contractile roots. Trials in the UK showed that planting bulbs 20 cm deep resulted in a typical 'bulb-shaped bulb', whereas planting only 5 or 10 cm deep resulted in bulbs becoming elongated as the contractile roots pulled the bulb deeper.[25,26,27] By increasing the planting depth from 8 to 23 cm, it was found that emergence and flowering were progressively later, while bulb yields were greatest planting at intermediate depths.[28] Narcissus bulbs can probably be planted much deeper than this, although this would be suitable only for garden and landscape use, where it would avoid damage from surface cultivation and frost.

In trials of the perennialisation of spring bulbs in Oklahoma (USDA climatic zone 6b-7a), narcissus 'Music Hall' and

‘Tahiti’ were planted 15, 30 or 45 cm deep (measured from the base of the bulb to the soil surface in raised field beds).[29] The percentage of bulbs flowering was greatest in 15 cm-deep plantings and considerably reduced in 45 cm-deep plantings, deeper planting delayed flowering.

In experiments with tazetta cultivars in Israel, bulbs were planted at depths up to 90 cm.[30] It was shown that:

- Deeper planting delayed emergence.
- Planting deeper than 60 cm resulted in fewer leaves and a net loss of bulb yield.
- Some shoots emerged even from bulbs planted 90 cm deep.

10.6 Planting date

It used to be standard practice to plant narcissus in September, and this is still good practice on plant health grounds - by late-September soil temperatures will have fallen and infection by the basal rot fungus is therefore less likely. However, in the UK it is more practical and cost-effective to plant bulbs soon or immediately after HWT, in August or early-September. This avoids the costs of re-drying and storing bulbs after HWT, but means the bulbs are planted into relatively warm soil, increasing the likelihood of basal rot infection at the crucial stage when roots are erupting from the base plate.[31,32]

It is usual to plant cultivars in the same order in which they received HWT, with dwarf types being planted first, followed by small-cups, large-cups, and then trumpets.

There appear to be surprisingly few published data relating narcissus planting date to yield. UK data from the 1930s, for one-year-down crops, showed a steady decline in bulb yield when bulbs were planted later than September. One study showed yields of 120% from a September planting but of only 63% from a December planting.[33] In contradiction, another report stated that significant yield loss did not occur until planting was even later.[34]

For modern two-year-down growing, the lack of information may simply reflect the commercial impracticability of extending bulb storage to September or beyond. In any case, with two-year-down crops poor growth in the first year – for whatever reason - would be compensated for by better growth in the second year.

10.7 Pesticide application at planting

Insecticides

Bulb planting provides an opportunity to apply pesticides directly onto and around the bulbs, but presently cannot be done in the UK because suitable pesticides are not available. The main use would be for insecticides preventing the larvae of the large narcissus fly from entering bulbs. Until its withdrawal in 1989, aldrin was routinely used on Cornish crops as a band-spray at planting, and this treatment was credited with keeping the pest under control since aldrin provided a full two years’ protection.[35] Other insecticides, such as chlordane and dieldrin, which had been used earlier in UK trials, are also no longer available.[36,37,38,39]

Dutch trials showed that chlorpyrifos or isofenfos applied to bulbs at planting controlled large narcissus fly (and narcissus leaf miner, a pest not recorded in the UK).[40] However, in HDC Project BOF 24, chlorpyrifos, applied as a spray over bulbs at planting in trials at Kirton and in Norfolk, was generally ineffective in controlling large narcissus fly, compared with using it in the HWT tank.[41] Chlorpyrifos, though not isofenfos, is available in the UK, but its EAMU on narcissus limits its use to HWT or a pre-planting cold soak.

Nematicides

‘Soil sickness’ controls in the Netherlands have included a pre-planting soil application of a nematicide such as fenamiphos.[42] Bulb growers in the Pacific Northwest also apply a nematicide, usually fenamiphos, into the furrow at planting to control stem nematode.[43] However, fenamiphos is not available in the UK.

Possibilities for biological control

Following promising MAFF-funded research at Exeter University,[44] the biological control of basal rot by microorganisms antagonistic to the basal rot pathogen was field-trialled at Kirton in HDC Project BOF 6.[45] At planting, granular formulations of *Trichoderma* species*, Minimedusa polyspora, Streptomyces* species and *Penicillium rubrum* were sprinkled over ‘Golden Harvest’ bulbs that had previously been treated, or not, with thiabendazole fungicide in HWT, and the results were assessed two years later. Compared with untreated controls, some antagonist treatments resulted in a small reduction in the number of bulbs developing basal rot and an accompanying small increase in yield, with the combined treatment (antagonist plus thiabendazole) improving results further, but these effects were considered too insubstantial to warrant commercial development.[46]

At the present time HDC Project BOF 69 is examining the potential for biological control of basal rot in small scale systems. No further research on the biological control of narcissus pests and diseases appears to have been carried out. Should suitable biological agents become available, it could be envisaged that the most appropriate times for application would be pre-planting or at planting.

10.8 Crop covers (mulches) and cover crops

Mulches include any loose or sheet material used on the soil surface or over the crops to provide protection, and cover crops are crops sown for a similar purpose. In the UK mulches and cover crops are not used commercially on narcissus, though they have been tested on an experimental scale. Despite the possibility of damage by frost, in HDC Project BOF 23 it was shown that relatively frost-sensitive cultivars such as 'Tête-à-Tête' could be grown successfully without covers in Eastern England.[47]

However, suitable mulches can lower soil temperatures sufficiently to reduce basal rot development. In addition to offering some control of the basal rot fungus, mulches may also be a way of reducing herbicide use, conserving water, and modifying temperature-sensitive crop development. Cover crops may help control soil erosion and run-off. These techniques may deserve further investigation in the light of their possible environmental advantages.

Crop covers and cover crops in the Netherlands

In the Netherlands it is usual to protect bulb crops from low temperature, wind and blown-sand injury by covering the soil with straw or reeds or by sowing a cereal crop. Various methods are used:

- Bulbs planted in beds may be covered with straw (10 t/ha for standard cultivars or 15-20 t/ha for frost-sensitive cultivars). The straw is removed in February, either mechanically or by burning, though lower rates of up to 10 t/ha may be left in place.
- A lower rate of straw may be used in combination with sowing rye at 250 kg/ha. The rye is killed by spraying off with a contact herbicide before the bulb shoots emerge.
- Where narcissus are grown in ridges, rye or barley (250 kg/ha) is sown before planting. If sown after the ridges have been formed, much of the seed falls into the furrows.

Rusts from reeds used as a crop cover in the Netherlands may sometimes infect narcissus foliage.[48]

Other examples of crop covers

A straw cover is sometimes used for frost-protection on bulb crops in the Pacific Northwest,[49] while in the colder areas of Poland peat, straw, chaff and cow manure have been used as mulches on bulbs.[50]

Trials have been conducted in several countries to evaluate a variety of mulches and cover crops. In the Netherlands, plastic film and a covering of reeds were found to be much more effective than straw or rye in insulating bulbs from frost penetration.[51] In Danish trials, several covering materials were shown to increase soil temperatures by 1 to 2°C, only slightly hastening shoot emergence but significantly increasing bulb yields (by 2.7 t/ha compared with non-covered controls) such materials included:[52]

- Chopped straw (10 t/ha).
- Converted household refuse (100 t/ha).
- Sphagnum peat (130 m^3/ha).
- Bark (70 t/ha).
- Sawdust (70 t/ha).

As well as increasing soil temperatures in winter, if left in place crop covers reduce soil temperatures in summer, thereby reducing the likelihood of infection by the basal rot fungus.[53] However, in trials in the USA, late-season mulches of straw, foil, etc., were used in an unsuccessful attempt to reduce soil temperature for the same purpose.[54] These mulches achieved a soil temperature drop of only 2°C, whereas it was considered a 5°C reduction was required to achieve a useful effect.

In trials at Kirton with 'Tête-à-Tête', a crop cover of straw increased soil temperature at bulb depth by 2 to 3°C in winter, but there was no increase in bulb yields in trials over three years with quite different weather characteristics.[1] Using polythene covers was less effective in raising soil temperatures.

Netting barriers may be used on small areas of valuable stocks to protect them from large narcissus fly.[55]

Cover crops in the UK

On sloping sites, cover crops (either cereals, grass or oilseed rape) were shown in trials at Rosewarne to prevent soil erosion successfully, if sown immediately after bulb planting and killed before crop emergence, and provided the growing season was long enough.[56] This could also have a role in reducing run-off. Cereals are drilled in some UK narcissus crops to stabilise the soil in the first winter. Where this is the case a suitable herbicide will be needed to kill off the cereal before the narcissus emerge.

10.9 Planting in nets

The technique of planting bulbs in netting was developed in the Netherlands as an aid to the recovery of tulip bulbs grown in heavier soils.[57] A mechanical system of net planting and harvesting was developed at the Institute of Agricultural Engineering, Wageningen. It comprises a 400 or 500 mm-wide net fed by mechanical rollers through the planting machine into the furrows, scattering the bulbs in a 25 cm-wide band onto the net. A second net is then applied over the bulbs ahead of the discs that cover the net edge. On harvest, a modified lifting machine separates the nets, brushes off the bulbs, and re-winds the net for further use. With tulips, a 3 to 4% reduction in bulb yield was seen using netting, compared with conventional planting.

Planting in nets is not used in the UK, although a prototype, non-mechanised net-planting system was developed at Rosewarne.[58] In this system various small bulb species (not narcissus) were scattered by hand onto a single 500 mm-wide net lain in the furrow, the edges of which were then folded over. Mesh size was about 3 x 10 mm. At harvest the complete net with bulbs was dried in bulk bins and the dried bulbs removed later. For various small-bulbed species, the net system resulted in a yield loss of about 5%, but this compares with an about 5% loss in bulb recovery in conventional planting, so the system has potential for further development for the production of specialised bulbs. Trials at Kirton confirmed a similar technique did not significantly reduce bulb yields in 'Tête-à-Tête', compared with growing bulbs loose.[59] The method is often used in UK trials work where it is important to maintain plot-to-plot separation and ensure total recovery of bulbs at harvest. However, using too small a mesh can result in shoot damage reminiscent of that due to bulb-scale mite feeding marks. A mesh size of about 10 x 10 mm is used. For its strength, extruded, rather than knitted, netting is usually used.

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11.0 Growing season operations – weed, disease and pest management

11.1 Weed control

The aims of weed control

Bulb growers should aim for good weed control in order to:

- Remove weeds that are hosts of stem nematode.
- Prevent competition from weeds.
- Produce stronger stems through removing shading effects (though stems may be slightly shorter).
- Clean up crops between growing seasons.
- Assist harvesting and other operations (weeds can clog bulb lifters).

Competition from weeds

- The effects of weed competition on narcissus yield have been studied extensively in Scotland.[6,31,41,101,102]
- Even when weed cover was substantial, weeds had little effect on early spring growth and flowering in the first crop year.
- When weeds resulted in shading during the period of rapid bulb growth, leaves and stems grew longer at the expense of bulb yield, though shading from late-June had no such effect.
- Foliage senesced quicker on weedy plots, reducing bulb yields.
- If weeds were killed late in the season, the loss of support could lead narcissus foliage to lodge.
- Over-wintering weeds that grew up with the narcissus foliage were most damaging, producing a larger proportion of small, weak bulbs.

Conditions for pesticide applications

All pesticide applications in the field should have regard to the state of the soil and weather. Natural run-off can be exacerbated by ill-timed operations, leading to pesticides being concentrated in the sediments of surface pools.[1,2]

It can be difficult to define ideal application dates when different cultivars are growing in the same field, so, to improve spray timing, early- and late-emerging cultivars should be planted in separate fields or in separate areas of the field. In any case, there is always the possibility of unsuitable weather preventing pesticides application on target dates.

The Pesticide Usage Surveys - field applied herbicides

The *Pesticide Usage Surveys*, compiled by the Central Science Laboratory, provide useful information about the herbicides applied to bulb crops, and data from the last three surveys (1997, 2001 and 2005) are summarised in Table 33. The surveys recorded not only the volume of each pesticide used, but also how it was applied, and why. Some care is needed in interpreting the data, because 'other bulbs', principally gladiolus, are included in the aggregated figures: however, in 2005 narcissus accounted for 86% of the total outdoor flower-bulb area, so the bulk of the findings do relate to the narcissus crop.

Table 33 Amounts of field-grown flower-bulbs in Great Britain treated with herbicides in the field, taken from the Pesticide Usage Surveys. Listed in descending order of usage in 2005

Active ingredient	Planted-ha treated (with total area grown)		
	1997 (4,751ha)	2001 (5,237ha)	2005 (4,916ha)
Glyphosate	3,184	5,104	4,441
Cyanazine	2,820	2,275	2,058
Chlorpropham	373	1,604	1,913
Diuron	230	536	1,337
Linuron	828	2,680	1,309
Diquat + paraquat	2,077	2,043	1,087
Paraquat	1,772	916	972
Simazine	355	274	586
Pendimethalin	515	531	538
Lenacil	546	1,072	388
Metamitron	299	1,911	305
Bentazone	0	1,950	161
Metoxuron	0	0	131
Diquat	226	147	74
Metazachlor	110	0	60
Chlorpropham + linuron	309	179	0
Cycloxydim	114	0	0
Fluazifop-P-butyl	0	469	0
Glufosinate-ammonium	48	0	0
Isoxaben	456	157	0
MCPA	72	0	0
Others*	71	284	29
Total	14,405	22,132	15,389

* 'Others' means active substances used on <0.1% of the total area treated with pesticides.

The table includes the total area planted, so the percentage of the whole crop being treated (or how many times it was treated) can be determined. Usage is expressed as the number of 'spray-hectares' (e.g. a 'percentage of crop treated' of 200 could mean that the whole area received two herbicide applications during the year). The main findings were:

- Total herbicide usage was similar in 1997 and 2005 (about 15,000 spray-hectares) but was recorded at about 22,000 spray-hectares in 2001, a peak corresponding with increased use of bentazone, glyphosate, lenacil, linuron and metamitron in that season. The reason for this increase is not known.
- Glyphosate was the most used herbicide, and was probably used on virtually the whole bulb area.
- The table gives an indication of the number of active ingredients being lost, with several of those still available in 2005 no longer available now (cyanazine, diuron, metamitron, metoxuron, paraquat and simazine).
- In 2005, most herbicide applications were made at about three-quarter of the full label rate.

The four stages of herbicide application

There are four stages at which herbicides should be applied to narcissus crops.

- A non-selective, non-residual herbicide (contact or systemic) is used in autumn or winter, well before narcissus emergence. It could also be used to clean up the land before planting bulbs. In the subsequent years of the crop a further application can be made in the 'dormant' season, between the growing seasons.
- Pre-crop-emergence residual herbicides are used as late as possible before crop emergence.
- Post-crop-emergence residual and (or) contact herbicides are used to prolong weed control well into the growing season. As a result of the susceptibility of narcissus to herbicide damage during flower development, and so that herbicides do not need to be applied around flowering, this application is usually made at an 'early-post-crop-emergence' stage when the shoots are 5 to 10 cm tall.
- A late-season herbicide is often necessary after flowering, either because by then weed populations may have started to build up, or, when flowers have been picked, having pickers walking up and down the ridges destroys any existing herbicide 'seal'.

Herbicides currently available

The information below was extracted from the CRD databases, with checks made against the HDC LIAISON database. It was found that information from these two sources was in reasonable agreement: all active ingredients, and most products, occurred in both datasets. There were some minor differences in the product range (especially where there were many products based on a single active ingredients), and infrequent differences in crop qualifiers; where such differences were found, the CRD information was taken as definitive.

Herbicides available for use on narcissus or in ornamental plant production are listed in Tables 34 to 37 (to be found at the end of Section 11.1).

Non-selective contact or systemic herbicides with full approval or EAMUs for use in ornamental plant production, and therefore available for use on narcissus pre-planting, pre-emergence or between growing seasons are presented in Table 34.

Herbicides (other than those in Table 34) with full approval or EAMUs for use specifically on narcissus or in ornamental plant production where the active substance is known to have been used on narcissus are presented in Table 35.

Herbicides (other than those in Table 34) with full approval or EAMUs for use in ornamental plant production, but where their effects on narcissus are either unknown or are known to be detrimental are presented in Table 36.

In addition to the herbicides with full approvals or EAMUs and listed in Tables 34 to 36, others are currently permitted for use in ornamental plant production through the Long Term Arrangements for Extension of Use (LTAEU) on an 'at own risk' basis. The details of these products can easily be extracted from the HDC's LIAISON database; when checked, this listed 719 entries for narcissus (outdoor), comprising 338 herbicide products with full approvals or EAMUs and 381 that could (legally) be used under LTAEU as presented in Table 37.

The LTAEU products are listed on the basis of being legally usable on the crop concerned, and they are not necessarily suitable, relevant or even crop-safe: they should not be used on narcissus without due consideration of these factors. Nevertheless, these additional active substances provide a valuable source of alternative, possibly useful, products.

Trials of herbicides

Much information has been gathered about the suitability of herbicides for safe, effective use on narcissus, for example, many herbicide trials were conducted by ADAS at Kirton and Rosewarne, and in Scotland, in the 1970s,[3,4,5,6] and the findings were incorporated into the advisory literature of the time.[7] Reports of herbicide trials have also been published in several other countries, including Germany,[8] Ireland,[9] the Netherlands,[10] the USA[11,12,13,14,15,16,17,18,19] and the former USSR,[20,21] and, while some of this information may provide useful guidance on the suitability of herbicides, much of it will have derived from husbandry practice, soil, climate, etc., significantly different to those in the UK. Some of the products and active ingredient tested abroad will not be available for use in the UK, while many of those tested in the UK will have become unavailable since that time.

The ADAS testing referred to above was effectively a free testing service and ended with commercialisation in the 1980s. From about the same period, the agrochemicals industry has not been able to justify testing new products on minor crops because of the cost of going through an increasingly demanding pesticide registration system. This explains why some herbicides used on commercial crops may not have been tested independently, or why growers have relied on experience and extrapolation rather than trials.

Anticipating the loss of further herbicides, a series of trials was funded by the HDC, starting in 1994. These trials were fully randomised, replicated and had appropriate controls, and treated bulbs were subsequently grown-on to ensure there were no adverse after-effects of treatment.

HDC funded late-season herbicide trial

A particular concern was the lack, apart from bentazone-based herbicides, of safe, effective late-season (post-flowering) herbicides. In HDC Project BOF 35 cyanazine (as 'Fortrol'), diuron (as 'Unicrop Flowable Diuron'), metamitron (as 'Goltix WG') and metazachlor (as 'Butisan S') were tested in tank-mix with isoxaben (as 'Flexidor 125') at three crop stages, pre-crop-emergence, early post-crop-emergence, and post-flower-cropping.[22,23] A full herbicide programme was built up by interposing the standard herbicides then available for the other application dates ('Profalon' pre-emergence and 'Fortrol' early post-crop-emergence).

- A tank-mix of isoxaben + metazachlor was crop-safe and effective when applied at any of the stages tested: pre-crop-emergence, early post-crop-emergence and post-cropping. Isoxaben and metazachlor are still available for use in ornamental plant production and narcissus (Table 35).
- As there is a possibility of isoxaben residues affecting subsequent crops, when it is applied in the year the bulbs are lifted, after lifting the land should be deep-ploughed to a depth of 20-30 cm, depending on soil type.
- Cyanazine, diuron and metamitron tank-mixes with isoxaben were also effective and crop-safe at certain application stages; of these, only metamitron appears to be currently available, through LTAEU.

HDC trial to find a replacement for cyanazine

The loss of cyanazine in 2007 posed a problem for UK growers, as it was a safe, effective herbicide for pre- or early post-crop-emergence application. In HDC Project BOF 52 florasulam was evaluated as an alternative to cyanazine and in applications at different crop stages.[24] Various rates of florasulam (as 'Boxer') were applied at three crop stages, post-crop-emergence (with leaves 7 to 10 cm-long), just before rapid bud growth, and post-flowering. Unlike cyanazine, florasulam has the disadvantage of being foliar-acting only, with no residual action, and to correct this florasulam tank-mixes were also evaluated.

- Florasulam was crop-safe at all three crop stages tested, at up to the cereal dose (100 ml 'Boxer'/ha), and also when applied as a split-dose (at 7-10 cm leaf length and post-flowering). Applied post-flowering, it was more effective than tank-mix isoxaben + metazachlor.
- Florasulam was safe in tank-mix with pendimethalin (as 'Stomp 400 SC') applied when leaves were 7 to 10 cm long.
- On the basis of limited evidence, florasulam was also safe in tank-mix with chloridazon (as 'Pyramin DF') and with isoxaben + terbuthylazine (as 'Skirmish'), applied when leaves were 7 to 10 cm long.
- Florasulam was also safe in tank-mix with isoxaben + metazachlor (as 'Flexidor 125' + 'Butisan S') applied post-flowering.

Florasulam, isoxaben, metazachlor and pendimethalin are still currently approved for use in ornamental plant production and narcissus (Table 35). Several products based on chloridazon, approved for use on beet, onion, herbs and various other vegetables, could be used on narcissus under LTAEU.

Stage 1 herbicide application: non-selective contact or systemic herbicide pre-crop emergence (and between growing seasons)

Dying narcissus foliage very readily takes up non-selective herbicides such as diquat or glyphosate, resulting in long-term damage to the bulbs. However, these herbicides are known to be safe to use when no narcissus foliage is present, so they can be used to remove weeds before planting narcissus and can be applied before narcissus emergence in the first crop year. In the subsequent crop years, they can be used between growing seasons to clear the ground, but, before application, it is important to check that no residual bulb foliage (green, dying or dead) is present, and that there are no cracks in the soil surface. Cracks in the soil can allow the herbicide to seep onto the bulbs, causing damage, while the remains of foliage can act as a wick and have the same effect.[25,26] It is not sufficient to remove narcissus foliage mechanically before applying this type of herbicide.

The recommendations for using non-selective contact or systemic herbicides on narcissus have changed significantly in recent years, largely as a response to the withdrawal of paraquat. In the 1990s, the application of glyphosate was strongly discouraged on land planted with bulbs, though it was applied before planting bulbs to ensure the land was cleared of perennial weeds such as couch grass.[7] With the loss of paraquat, glyphosate became the herbicide of choice pre-crop-emergence, for application well before any narcissus shoots have appeared; being systemic, it kills weeds down to the roots. Several glyphosate-based products are available for this purpose, either with full approvals or EAMUs (Table 34).[27] Contact, non-systemic herbicides, such as diquat- and glufosinate-ammonium-based products, are not usually used since they are not totally effective on perennial weeds. Glufosinate-ammonium-based herbicide may only be used around ornamentals.

Stage 2 herbicide application: pre-crop-emergence residual (soil-acting) herbicides

The aim here is to apply a residual herbicide as late as possible before crop emergence, so prolonging its effect. However, it may be better to err on the side of earliness, as the onset of unsuitable weather for spraying might otherwise prevent application until this crop stage has passed.

While some formerly well-used bulb herbicides have been lost (e.g. those based on cyanazine, diphenamid, diuron, pentanochlor or simazine), others are still available with full approvals or EAMUs for use in ornamental plant production. The following herbicides have approvals and have been shown to be safe to use on narcissus through usage or trialling (Table 35):[27]

- Chlorpropham.
- Tank-mix chlorpropham + linuron (formerly available as 'Profalon'): not recommended on light soils.
- Lenacil : not recommended on organic, very light, very heavy or stony or gravelly soils.
- Linuron (as 'Afalon', 'Alpha Linuron 50 SC', 'Datura' or 'Linurex 50SC').
- Tank-mix isoxaben + metazachlor (as 'Flexidor 125' + 'Butisan S').

Stage 3 herbicide application: post-crop-emergence residual and (or) contact herbicides

The time of application of a post-crop-emergence herbicide is usually based on a maximum permitted or recommended shoot height, though this may vary between products based on the same active ingredient (e.g. "2.5 to 5 cm high", "up to 10 cm high" or "before buds show") and should be checked on the manufacturer's literature. A number of herbicides can be used (Table 35):

- Chlorpropham: residual action (see comments under 'Stage 2 herbicide application').
- Tank-mix chlorpropham + linuron: residual action (see comments under 'Stage 2 herbicide application').
- Lenacil: residual action (see comments under 'Stage 2 herbicide application').
- Tank-mix isoxaben + metazachlor (as 'Flexidor 125' + 'Butisan S'): residual action (possible residual effects).
- Florasulam (as 'Boxer'): contact action, applied when leaves are 7 to 10 cm long or later (but before stage of rapid bud growth), or split-dose with a second application at the post-flowering stage.
- Tank-mix florasulam + pendimethalin (as 'Boxer' + 'Stomp'): contact and residual action, applied when leaves 7 to 10 cm long.
- Tank-mix florasulam + chloridazon (as 'Boxer' + 'Pyramin DF'): contact and residual action applied when leaves 7 to 10 cm long (based on limited evidence from project BOF 52).
- Tank-mix pendimethalin + linuron is often used.[28]The above herbicides either have on label approvals for use in ornamental plant production an EAMU can be used via the LTAEU and have been shown to be safe to use on narcissus through usage or trialling (Table 35).

Where narcissus crops are grown on peaty soil, additional post-emergence applications are likely to be needed.[9] The number of herbicides available for use at this stage in the future may well be limited because of the risk to flower- pickers from dislodgeable residues following any application.

Stage 4 herbicide application: late-season (post-flowering) herbicides

Weed growth may require herbicide application at this stage, but in any case any previously established herbicide 'seal' is likely to have been damaged by flower-pickers working through the crop. On narcissus, a late-season or post-flowering application of herbicide is difficult for a number of reasons:

- Herbicides with labels for use at this stage are few.
- Application is difficult because the foliage has often lodged, shielding the soil from the spray.
- Within the bulb, new shoots and flower initials are being formed at this time: they may be sensitive to damage by herbicides.

The following herbicides might be used:

- Bentazone (several products available for ornamental plant production, including for narcissus): contact action, to be used at (or more usually after) flowering but not during "flower bud formation"; bentazone products should not be sprayed at temperatures above 20°C or in other adverse conditions.
- Tank-mix isoxaben + metazachlor (as 'Flexidor 125' + 'Butisan S'): residual action, post-flowering.
- Florasulam (as 'Boxer'): contact action, post-flowering, or as a split-dose application following application when leaves are 7 to 10 cm long.

The above herbicides either have approvals specifically for use on narcissus, or for use in ornamental plant production and have been shown to be safe to use on narcissus through usage or trialling (Table 35).

Herbicides for controlling problem weeds

Poor weed control often relates to failure to control a relatively few resistant species.[29,30] Some problem weeds and suggested active substances for use in narcissus crops are:[29]

- Thistles – clopyralid, glyphosate.
- Cleavers – glyphosate.
- Mayweed - metazachlor.
- Groundsel – metazachlor.
- Annual nettle – metazachlor, pendimethalin.
- *Polygonum* species – pendimethalin.

Controlling cereals from grain in straw mulch

Although it is unlikely at present to be an issue with cultural practices in the UK, cereal grain may be a problem where narcissus crops have been mulched with straw.[31,32,33] Dutch trials showed that control of the cereals may be safely achieved by using:

- Fluazifop-P-butyl (e.g. 'Fusilade' products, see Table 35; EAMUs for use in ornamental plant production).
- Cycloxydim (e.g. as 'Laser', see Table 35; full approval for use on narcissus bulbs).

Controlling volunteer potatoes in narcissus

HDC Project BOF 46 was an investigation into the control of volunteer potatoes in narcissus crops, carried out at ADAS Arthur Rickwood.[34] A narcissus crop was co-planted with potato 'volunteers' and then sprayed with various herbicides when potato growth was 1-10, 10-20 or 25-30 cm tall. The application of clopyralid (as 'Dow Shield') appeared to be successful in controlling potato growth without damaging narcissus, despite the fact that, when it has been used in narcissus as a spot-treatment against thistles, it has been known to cause damage.

Herbicide damage

Numerous types of herbicide damage have been recorded on narcissus, though many of these are no longer available.[35] Even some recommended herbicides can cause reduced growth and poorer flowers under inappropriate conditions (e.g. chlorpropham and linuron[36]). Examples of herbicide injury (in crops generally) are described in appropriate textbooks[37] and illustrated in Images 56 to 58.

Currently available herbicides which are known to be inimical to narcissus are listed here, but there may be other examples:

- MCPA - damage to the basal leaf meristem resulting in flaccidity.
- Clopyralid – can be used to control thistles and volunteer potatoes in narcissus but also has a weak effect on narcissus itself.
- Fluroxypyr – known to kill narcissus volunteers.
- Sulfonylurea herbicides (including metsulfuron-methyl, thifensulfuron-methyl) - known to kill narcissus volunteers; distorted flowers (appearing to have 'melted' and the petals fused) have been recorded due to soil residues or spray drift.[38]

56 Flower damage due to glyphosate

Photo: Warwick HRI and predecessors

57 Glyphosate damage to forced flower (right)

Photo: Warwick HRI and predecessors

58 Bulb damage due to diquat

Photo: Warwick HRI and predecessors

Alternative weed control strategies

Unlike the case in some field vegetable production, mechanical or manual weed removal is hardly practical in narcissus growing. The application of mulch, such as chopped straw, is known from trials to be effective in suppressing weeds and reducing herbicide use.[39] However, this practice is not used in the UK.

The application of good farming practices that reduce problems with perennial weeds, and some inter-row cultivation to control annual weeds, are the only options to using a full herbicide programme. But is total weed control necessary? Some authors have suggested that a high degree of weed control is not essential, though this has not been properly researched. Some weed cover may in fact be beneficial, though obviously this depends on the type and number of weeds.

Over-wintering weeds may help the crop by giving winter protection and conserving moisture.[40]Weeds can lower summer soil temperature at bulb depth by 4°C, compared with a weed-free plot, which may be sufficient to reduce the development of basal rot.[41]Weed cover reduces run-off, reduces rain-splash soiling of flower stems, and gives a better surface for flower pickers to walk on.

Table 34 Non-selective contact or systemic herbicides with full approval or EAMUs for use in outdoor ornamental plant production, and therefore available for use on narcissus pre-planting, pre-emergence or between growing seasons

Active ingredient	Action (with HRAC mode of action code) and target weeds	Product name (with MAPP no. if more than one product)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Diquat	Contact non-selective, non-residual herbicide and crop desiccant (D) for general weed control	A1412A2	Full	31/12/2015	Syngenta Crop Protection UK	All non edible crops. Ornamental plant production
		Balista	Full	30/06/2018	Novastar Link	All non edible crops. Ornamental plant production
		Barclay D Quat	Full	01/02/2014	Barclay Chemicals	Ornamental plant production
		Brogue (13328)	Full	31/12/2015	AgriGuard	All non edible crops. Ornamental plant production
		ChemSource Diquat	Full	31/12/2015	Chemsource	All non edible crops Ornamental plant production
		Clayton Diquat	Full	31/12/2015	Clayton Plant Protection (UK)	All non edible crops. Ornamental plant production
		Clayton Diquat 200	Full	31/12/2015	Clayton Plant Protection (UK)	All non edible crops. Ornamental plant production
		Clayton IQ	Full	31/12/2015	Clayton Plant Protection (UK)	All non edible crops. Ornamental plant production
		Cleancrop Flail	Full	31/12/2014	United Agri Products	All non edible crops. Ornamental plant production
		Dessicash 200	Full	31/12/2015	Sharda International	All non edible crops. Ornamental plant production
		Di Nova	Full	31/12/2015	Agroquimicos Genericos	All non edible crops. Ornamental plant production
		Diqua	Full	31/12/2015	Sharda Worldwide Exports	All non edible crops. Ornamental plant production
		Diquash 200 SL	Full	31/12/2015	Agrichem	All non edible crops. Ornamental plant production
		Dragoon	Full	31/12/2015	Hermoo Belgium	All non edible crops. Ornamental plant production
		Dragoon Gold (14053)	Full	30/06/2014	Hermoo Belgium	All non edible crops. Ornamental plant production
		Dragoon Gold (14973)	Full	30/06/2018	Belcrop	All non edible crops. Ornamental plant production
		I.T. Diquat	Full	31/12/2015	IT Agro	All non edible crops. Ornamental plant production
		Life Scientific Diquat	Full	31/12/2015	Life Scientific	All non edible crops. Ornamental plant production
		Mission	Full	31/12/2015	Agrichem	All non edible crops. Ornamental plant production
		Quad S	Full	31/12/2015	Q-Chem	All non edible crops. Ornamental plant production
		Quad 200	Full	31/12/2015	Euro Chemicals	All non edible crops. Ornamental plant production
		Reglone	Full	31/12/2015	Syngenta Crop Protection UK	All non edible crops. Ornamental plant production
		Retro	Full	31/12/2015	Syngenta Crop Protection UK	All non edible crops. Ornamental plant production

Table 34 Non-selective contact or systemic herbicides with full approval or EAMUs for use in outdoor ornamental plant production, and therefore available for use on narcissus pre-planting, pre-emergence or between growing seasons continued

Active ingredient	Action (with HRAC mode of action code) and target weeds	Product name (with MAPP no. if more than one product)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Diquat (continued)	Contact non-selective, non-residual herbicide and crop desiccant (D) for general weed control	Standon Googly (12995)	Full	31/12/2015	Standon Chemicals	All non edible crops. Ornamental plant production
		Standon Googly (13281)	Full	31/12/2015	Standon Chemicals	All non edible crops. Ornamental plant production
		Standon Yorker	Full	31/12/2015	Standon Chemicals	All non edible crops. Ornamental plant production
		UPL Diquat	Full	31/12/2015	United Phosphorus	All non edible crops. Ornamental plant production
		Woomera (14009)	Full	30/06/2014	Hermoo Belgium	All non edible crops. Ornamental plant production
		Woomera (14972)	Full	31/12/2015	Belcrop NV	All non edible crops. Ornamental plant production
Glufosinate-ammonium	Contact non-selective, non-residual herbicide (H) for general weed control	Challenge	Full	31/12/2021	Bayer CropScience	All non-edible crops
		Finale 150	Full	31/12/2021	Bayer Environmental Science	All non-edible crops
		Harvest	Full	31/12/2021	Bayer CropScience	All non-edible crops
		Kaspar	Full	31/12/2021	Certis	All non-edible crops
		KurTail	Full	31/12/2021	Progreen Weed Control Solutions	All non-edible crops
		Marengo	Full	31/12/2021	Pan Agriculture	All non-edible crops
		Weedex	Full	31/12/2021	Novastar Link	All non-edible crops
Glyphosate	Systemic non-selective, non-residual herbicide (G) for general weed control	Glymark	Full	30/06/2018	Nomix Enviro	Ornamental plant production
		Hammer	Full	30/06/2018	Everris	Ornamental plant production
		Hilite	Full	30/06/2018	Nomix Enviro	Ornamental plant production
		Nomix Conqueror	Full	30/06/2018	Nomix Enviro	Ornamental plant production
		Nomix Frontclear	Full	01/12/2014	Nomix Enviro	Ornamental plant production
		Nomix G	Full	30/06/2018	Nomix Enviro	Ornamental plant production
		Nomix Revenge	Full	30/06/2018	Nomix Enviro	Ornamental plant production
		Stirrup	Full	30/06/2018	Nomix Enviro	Ornamental plant production

Table 35 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use on narcissus or in outdoor ornamental plant production where the active ingredient has been used on narcissus

Active ingredient (and application stage for narcissus)	Action (with HRAC mode of action code) and target weeds	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Bentazone (post-flowering)	Post-emergence contact herbicide (C3) for annual dicotyledons	Basagran	Full	31/12/2015	BASF	Ornamental plant production (narcissi)
		Basagran SG	Full	31/12/2015	BASF	Ornamental plant production (narcissi)
		Benta 480 SL	Full	30/06/2018	Sharda Worldwide Exports	Ornamental plant production
		Bentazone 480	Full	31/12/2015	Goldengrass	Ornamental plant production (narcissi)
		Bently	Full	31/12/2015	Chem-Wise	Ornamental plant production
		Buddy	Full	31/12/2015	EZCrop	Ornamental plant production
		Clayton Dent 480	Full	31/12/2015	Clayton Plant Protection	Ornamental plant production
		Euro Benta 480	Full	31/12/2015	Euro Chemicals	Ornamental plant production
		Hockley Bentazone 48	Full	31/12/2015	Hockley International	Ornamental plant production
		IT Bentazone	Full	31/12/2015	IT Agro	Ornamental plant production (narcissi)
		Mac-Bentazone 480 SL	Full	31/12/2015	MAC	Ornamental plant production (narcissi)
		RouteOne Benta 48 (13662)	Full	30/04/2015	Albaugh UK	Ornamental plant production (narcissi)
		RouteOne Benta 48 (15266)	Full	31/12/2015	Albaugh UK	Ornamental plant production
		RouteOne Bentazone 48	Full	30/04/2015	Albaugh UK	Ornamental plant production (only narcissi)
		RouteOne Bentazone 48	Full	31/12/2015	Albaugh UK	Ornamental plant production
		Tanaru	Full	30/06/2018	Agroquimicos Genericos	Ornamental plant production
		Troy 480	Full	30/06/2018	Agrichem	Ornamental plant production
		UPL B Zone	Full	31/12/2015	United Phosphorus	Ornamental plant production
		Zone 48	Full	31/12/2015	Agriguard	Ornamental plant production
Chlorpropham (pre- or post-crop-emergence)	Residual herbicide (K2) for annual dicotyledons and annual grasses	CleanCrop Amigo	Full	31/01/2015	United Agri Products	Ornamental plant production
		CleanCrop Amigo	Full	31/07/2017	Agrichem	Ornamental plant production
		Inturder	Full	31/07/2017	Agrichem	Ornamental plant production
Cycloxydim (for control of cereals from mulch)	Translocated post-emergence herbicide (A) for annual grasses and some other grasses	Laser	Full	31/12/2021	BASF	Ornamental plant production (propagating material)

Table 35 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use on narcissus or in outdoor ornamental plant production where the active ingredient has been used on narcissus continued

Active ingredient (and application stage for narcissus)	Action (with HRAC mode of action code) and target weeds	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Florasulam (post-crop-emergence or post-flowering)	Post-emergence herbicide (B) for annual dicotyledons	Boxer	2008/2826	30/06/2018	Dow AgroSciences	Outdoor ornamental plant production
		Starane XL	2008/2904	30/06/2018	Dow AgroSciences	Outdoor ornamental plant production
Fluazifop-P-butyl (for control of cereals from mulch)	Post-emergence herbicide (A) for annual and perennial grasses	Fusilade 250 EW	2012/1254	31/12/2021	Syngenta Crop Protection UK	Protected and outdoor non-edible flower crops. Protected and outdoor ornamental plant production
		Fusilade Max	2012/1321	31/12/2021	Syngenta Crop Protection UK	Protected and outdoor non-edible flower crops. Protected and outdoor ornamental plant production
Isoxaben (pre- or post-crop-emergence or post-flowering)	Soil-acting herbicide (L) for annual dicotyledons	Agriguard Isoxaben	Full	31/12/2021	AgriGuard	Ornamental plant production
		Flexidor	Full	31/12/2021	Dow AgroSciences	Ornamental plant production
		Flexidor 125	Full	31/12/2021	Dow AgroSciences	Ornamental plant production
		Flexidor 125	Full	31/12/2021	Landseer	Ornamental plant production
		Flexidor 125	Full	31/12/2021	Dow AgroSciences	Protected ornamental plant production
		Flexidor 125	2005/0891	31/12/2021	Landseer	Protected ornamental plant production
		Pan Isoxaben	Full	31/12/2021	Pan Amenity	Ornamental plant production
Linuron (pre- or post-crop-emergence)	Pre-emergence or pre-planting herbicide (C2) for annual dicotyledons	Afalon	2009/0877	31/12/2019	Makhteshim-Agan (UK)	Outdoor ornamental plant production
		Linurex 50 SC	2009/2474	31/01/2019	Makhteshim-Agan (UK)	Outdoor ornamental plant production
		Datura	Full	30/06/2016	Agrichem	Narcissus, ornamental plant production

Table 35 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use on narcissus or in outdoor ornamental plant production where the active ingredient has been used on narcissus continued

Active ingredient (and application stage for narcissus)	Action (with HRAC mode of action code) and target weeds	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Metazachlor (pre- or post-crop-emergence or post-flowering)	Residual herbicide (K3) for annual dicotyledons and annual meadow-grass	Agrotech Metazachlor 500 SC	Full	31/12/2021	Agrotech Trading	Ornamental plant production
		Alpha Metazachlor 50SC	Full	31/12/2021	Makhteshim-Agan (UK)	Ornamental plant production
		Butey	Full	31/12/2021	Chem-Wise	Ornamental plant production
		Butisan S	Full	31/12/2021	BASF	Ornamental plant production
		Clayton Buzz	Full	31/12/2021	Clayton Plant Protection (UK)	Ornamental plant production
		Clayton Metazachlor 50 SC	Full	31/12/2021	Clayton Plant Protection (UK)	Ornamental plant production
		Fuego 50	Full	31/12/2021	Makhteshim-Agan (UK)	Ornamental plant production
		Greencrop Monogram	Full	31/12/2021	Greencrop Technology	Ornamental plant production
		Makila 500 SC	Full	31/12/2021	Novastar Link	Ornamental plant production
		Marksman	Full	31/12/2021	AgriGuard	Ornamental plant production
		Mashona	Full	31/12/2021	AgChemAccess	Ornamental plant production
		Medusa	Full	31/12/2021	EZCrop Ltd	Ornamental plant production
		Metachor	Full	31/12/2021	Euro Chemicals s.r.o	Ornamental plant production
		Metazachlore GL 500	Full	31/12/2021	Globachem	Ornamental plant production
		Mezzanine	Full	31/12/2021	AgriGuard	Ornamental plant production
		Rapsan 500 SC	Full	31/12/2021	Globachem	Ornamental plant production
		RouteOne Metaz 50	Full	31/12/2015	Albaugh UK	Ornamental plant production
		Segundo	Full	31/12/2021	Agroquimicos Genericos	Ornamental plant production
		Standon Metazachlor 500	Full	31/12/2021	Standon Chemicals	Ornamental plant production
		Sultan 50 SC	Full	31/12/2021	Makhteshim-Agan (UK)	Ornamental plant production

Table 35 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use on narcissus or in outdoor ornamental plant production where the active ingredient has been used on narcissus continued

Active ingredient (and application stage for narcissus)	Action (with HRAC mode of action code) and target weeds	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Pendimethalin (post-crop-emergence)	Residual herbicide (K1) for annual grasses*	Aquarius	2009/3299	30/06/2016	Makhteshim-Agan (UK)	Outdoor narcissus grown for galanthamine production
		Aquarius	2009/3298	30/06/2016	Makhteshim-Agan (UK)	Outdoor ornamental plant production
		Cinder	2009/2189	30/06/2016	Makhteshim-Agan (UK)	Outdoor narcissus grown for galanthamine production
		Cinder	2009/2208	30/06/2016	Makhteshim-Agan (UK)	Outdoor ornamental plant production
		PDM 330 EC	2008/2862	31/01/2019	BASF Plc	Outdoor ornamental plant production
		Sherman	2009/0807	31/01/2019	Makhteshim-Agan (UK)	Outdoor narcissus grown for galanthamine production
		Stomp 400 SC	2008/2923	31/01/2019	BASF	Outdoor ornamental plant production
		Stomp Aqua	2009/2919	31/01/2019	BASF	Outdoor ornamental plant production

*The pendimethalin-based products approved for use in galanthamine production specify control of grass, knot-grass, pansy, speedwell and volunteer oil-seed rape as well as of weeds in general.

Table 36 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use in outdoor ornamental plant production but with their effects on narcissus unknown or known to include detrimental effects

Active ingredient	Effects on narcissus	Action (with HRAC mode of action code) and target weeds	Product name (with MAPP no. if more than one product)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Carfentrazone-ethyl	Used as haulm desiccant on narcissus	Contact herbicide (E) and haulm desiccant	Shark	2008/0552	31/01/2019	Belchim Crop Protection	Protected and outdoor ornamental plant production
			Spotlight Plus	Full	31/01/2019	Belchim Crop Protection	All non-edible crops
Clopyralid	Useful for controlling thistles but damage to narcissus recorded; controls volunteer potatoes in narcissus; but ineffective in controlling volunteer narcissus	Translocated herbicide (O) for many dicotyledons	Cilophar 400	Full	17/06/2014	AgripharDow	Ornamental plant production
			Dow Shield	Full	31/10/2019	AgriSciences	Ornamental plant production
			Dow Shield 400	Full	31/10/2019	Dow AgriSciences	Ornamental plant production
			Glopyr 400	Full	17/06/2014	Globachem nv	Ornamental plant production
			Lontrel 72 SG	Full	14/02/2015	Dow AgroSciences	Ornamental plant production
			Shield SG	Full	14/02/2015	Dow AgroSciences	Ornamental plant production
			Vivendi 200	Full	30/04/2017	Agrichem	Ornamental plant production
Desmedipham + ethofumesate + phenmedipham	Effects not known	Selective contact and residual herbicide mixture (C1+N+C1) for annual dicotyledons and annual grasses	Betanal Expert	2008/2823	31/01/2019	Bayer CropScience	Outdoor ornamental plant production
Ethofumesate	Effects not known	Pre- and (or) post-emergence herbicide (N) for annual grasses and dicotyledons	Nortron Flo	2008/2919	31/01/2019	Bayer CropScience	Outdoor ornamental plant production
Fatty acids	Effects not known	Fatty acids with various horticultural uses	Finalsan	Full	31/12/2021	Certis	Ornamental plant production
			Finalsan Plus	Full	31/12/2021	W Neudorff	Ornamental plant production
Florasulam + fluroxypyr	Effects not known	Post-emergence herbicide mixture (B+O) for annual and perennial dicotyledons	Starane XL	2008/2904	30/06/2018	Dow AgroSciences	Outdoor ornamental plant production
Flufenacet + isoxaflutole	Reported to result in leaf yellowing in narcissus	Residual herbicide mixture (K3+F2) for annual dicotyledons and grasses	Cadou Star	2008/2829	31/10/2019	Bayer CropScience	Outdoor ornamental plant production
Flumioxazine	Effects not known	Post-emergence herbicide (E) for annual dicotyledons and annual meadow grass	Digital	2008/2844	30/06/2018	Interfarm UK	Outdoor ornamental plant production
			Guillotine	2008/2897	30/06/2018	Interfarm UK	Outdoor ornamental plant production
			Sumimax	2008/2881	30/06/2018	Sumitomo Chemical Agro Europe	Outdoor ornamental plant production

Table 36 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use in outdoor ornamental plant production but with their effects on narcissus unknown or known to include detrimental effects continued

Active ingredient	Effects on narcissus	Action (with HRAC mode of action code) and target weeds	Product name (with MAPP no. if more than one product)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Fluroxypyr	Very damaging to narcissus; controls narcissus volunteers	Herbicide (O) for dicotyledons	Starane 2	2008/2925	30/06/2024	Dow AgroSciences	Outdoor ornamental plant production
Imazamox + pendimethalin	Effects not known	Pre-emergence broad spectrum herbicide (B+K1) for annual dicotyledons	Nirvana	2008/2894	31/01/2019	BASF	Outdoor ornamental plant production
Metsulfuron-methyl	Damaged flowers reported caused by spray drift. Along with other sulfonylurea herbicides, damaging to narcissus (reduced emergence, damaged flowers)	Contact and residual sulfonylurea herbicide (B) for annual dicotyledons	Jubilee SX	2008/2859	31/12/2015	Du Pont (UK)	Outdoor ornamental plant production
Napropamide	Effects not known	Soil-applied herbicide (K3) for annual dicotyledons and annual grasses	Devrinol (09374)	Full	31/12/2021	United Phosphorus	Ornamental plant production
			Devrinol (09375)	Full	31/12/2021	United Phosphorus	Ornamental plant production
			Jouster	Full	31/12/2021	AgriGuard	Ornamental plant production
			MAC-Napropamide 450 SC	Full	31/12/2021	MAC	Ornamental plant production
			Nappa	Full	31/12/2021	Chemsource	Ornamental plant production
Oxadiazon	Effects not known	Residual and contact herbicide (E) for annual dicotyledons and annual grasses	Clayton Oxen FL	Full	30/06/2015	Clayton Plant Protection (UK)	Ornamental plant production
			Festival	Full	30/06/2015	Bayer Environmental Science	Ornamental plant production
			Noble Oxadiazon	Full	30/06/2015	Barclay Chemicals	Ornamental plant production
			Ronstar 2G	Full	30/06/2015	Bayer CropScience	Ornamental plant production (container-grown)
			Ronstar Liquid	Full	30/06/2015	Certis	Ornamental plant production
			Standon Roxx L	Full	30/06/2015	Standon Chemicals	Ornamental plant production

Table 36 Herbicides (other than non-selective contact or systemic herbicides for pre-planting or dormant-season use) with full approval or EAMUs for use in outdoor ornamental plant production but with their effects on narcissus unknown or known to include detrimental effects continued

Active ingredient	Effects on narcissus	Action (with HRAC mode of action code) and target weeds	Product name (with MAPP no. if more than one product)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Relevant crops
Phenmedipham	Effects not known	Contact herbicide (C1) for annual dicotyledons	Betanal Flow	2008/2824	28/02/2015	Bayer CropScience	Outdoor ornamental plant production
Propyzamide	Effects not known	Residual herbicide (K1) for many weeds	Kerb Flo	Full	30/09/2016	Dow AgriSciences	Ornamental plant production
			Kerb Granules	Full	30/09/2016	Barclay Chemicals	Ornamental plant production (around)
Quizalofop-P-tefuryl	Effects not known	Post-emergence herbicide (A) for annual and perennial grasses. Panarex specifies control of black grass, couch grass and Italian and perennial ryegrass and wild oats as well of weeds and grasses in general	Panarex	2006/0364	31/12/2021	Certis	Ornamental plant production
Tepraloxydim	Effects not known	Systemic post-emergence herbicide (A) for annual grasses	Aramo	2008/2813	31/05/2015	BASF	Outdoor ornamental plant production

Table 37 Active ingredients listed in HDC's LIAISON database as available for use on outdoor narcissus solely through Long Term Arrangements for Extension of Use

Those active ingredients with proven use in narcissus production	Those active ingredients which may have application in narcissus production	Those active ingredients known or likely to have inimical effects on production
Chloridazon	Asulam	2,4-D
Metamitron	Bifenox	Amidosulfuron
	Bromoxynil	Dicamba
	Carbetamide	Flupyrsulfuron-methyl
	Chlorotoluron	MCPA
	Clodinafop-propargyl	Mecoprop-P
	Clomazone	Nicosulfuron
	Dichlorprop-P	Rimsulfuron
	Diflufenican	Tribenuron-methyl
	Fenoxaprop-P-ethyl	Thifensulfuron-methyl
	Ioxynil	
	Metribuzin	
	Propaquizafop	
	Propoxycarbazone-sodium	
	Prosulfocarb	
	Quizalofop-P-ethyl	
	S-metolachlor	
	Tralkoxydim	
	Tri-allate	
	Triclopyr	

Active ingredients available only in mixtures have been omitted, as have actives that appear as other products in Tables 34 to 36.). As is the case with active ingredients usable on narcissus via approvals for ornamental plant production generally, the LTAEU products are listed on the basis of being legally usable on the crop concerned: they are not necessarily suitable, relevant or even crop-safe: they should not be used on narcissus without due consideration of these factors.

11.2 Disease control

It is usual to apply a fungicide spray programme to control foliar fungal diseases, usually smoulder (which is ubiquitous where narcissus are grown) and white mould (which tends to occur in epidemics, especially in the South-West, though the disease is now also present in the East and sporadically in other parts of the country.[44] Fire and leaf scorch also occur, principally in the South-West, but usually at a fairly low level. A comprehensive fungicide programme is important where bulbs are being grown two-years-down or longer, because of the disease build-up in bulbs, debris and soil.

As well as controlling disease, a further effect of many fungicides is to delay foliar senescence, so increasing yields (Image 59). This effect may work through control of naturally occurring leaf fungi that degrade the leaf cuticle.[45,46] However, since bulbs are usually lifted before the leaves have died down, a delay in foliar senescence can be economically disadvantageous in the year that bulbs are to be lifted, so in the lifting year the spray programme is often curtailed after flowering to hasten die-down and lifting. Other results have shown that continuing the fungicide spray programme may enhance subsequent levels of neck rot by delaying the natural process of abscission that occurs in the bulb neck at the base of the green leaf lamina.

59 The results of an ineffective spray programme – early die-down (area in foreground)

Photo: Gordon Hanks

Table 38 Amounts of field-grown flower-bulbs in Great Britain treated with fungicides in the field, taken from the Pesticide Usage Surveys. Listed in descending order of usage in 2005

Active ingredient	Planted-ha treated (with total area grown)		
	1997 (4,751 ha)	2001 (5,237ha)	2005 (4,916ha)
Carbendazim	9,053	11,603	6,096
Chlorothalonil	2,925	5,485	5,653
Tebuconazole	66	3,488	4,489
Azoxystrobin	0	4,896	4,462
Mancozeb	4,394	9,187	3,986
Vinclozolin	7,124	9,994	1,800
Prochloraz	2,302	1,411	808
Carbendazim + prochloraz	0	169	682
Iprodione	2,292	625	607
Epoxiconazole + kresoxim-methyl	0	0	408
Maneb	382	398	221
Chlorothalonil + mancozeb	0	0	133
Mycobutanil	0	0	83
Prochloraz + propiconazole	0	0	5
Benomyl	570	1,311	0
Carbendazim + mancozeb	295	159	0
Carbendazim + vinclozolin	0	90	0
Cupric ammonium carbonate	0	192	0
Cyproconazole + prochloraz	0	112	0
Cyprodinil	0	141	0
Dichlofluanid	0	20	0
Mancozeb + metalaxyl	13	0	0
Propiconazole	2	0	0
Thiabendazole	26	31	0
Others*	219	286	185
Total	29,663	49,598	29,618

*'Others' means active substances used on <0.1% of the total area treated with pesticides.

When it is desired to maximise yields, when pest and disease considerations are not paramount, and when logistical considerations allow it, there may be advantages in delaying foliar senescence through the continued use of a fungicide spray programme.

The Pesticide Usage Surveys – field-applied fungicides

The Pesticide Usage Surveys provide much information about the fungicides applied to bulb crops, and give an impression of how growers rate different fungicides and, perhaps, advice on their use. Data from the last three surveys (1997, 2001 and 2005) are summarised in Table 38. Some interpretation is needed, because 'other bulbs', principally gladiolus, are included in the aggregated figures; however, in 2005 narcissus accounted for 86% of the total outdoor flower-bulb area. The table includes the total area planted, so the percentage of the whole crop being treated (or how many times it was treated) can be determined. Usage is expressed as the number of 'spray-hectares' so, for example, a 'percentage of crop treated' of 200 could mean that the whole area received two fungicide applications during the year.

The main findings were as listed below:

- Total fungicide usage was about the same in 1997 and 2005 (about 30,000 spray-hectares) but was recorded at about 50,000 spray-hectares in 2001, a peak that seems partly connected with a much increased use of carbendazim in that season.
- In 2005, the 'top five' fungicides – carbendazim, chlorothalonil, tebuconazole, azoxystrobin and mancozeb – accounted for 83% of the spray-hectares applied.
- The following fungicide active ingredients were less used but nevertheless accounted for a substantial part of overall usage: vinclozolin, prochloraz, carbendazim + prochloraz and iprodione.
- Several other active ingredients were used only to a small extent; for example, the use of cupric (copper) ammonium carbonate was recorded only in 2001.
- The reduction in the numbers of active ingredients listed over time shows the effect of the ongoing re-evaluation of pesticides.

- Over the eight-year period, carbendazim was consistently most used, while the use of chlorothalonil increased greatly, as did the use of newer 'chemistry' in the form of tebuconazole, azoxystrobin and epoxiconazole + kresoxim-methyl. Several other substances were lost or less used – vinclozolin, prochloraz (except in mixtures), iprodione and benomyl.

- In 2005, most fungicide applications were made at two-thirds to three-quarter of the full label rate. Is reduced-rate usage based on evidence of effectiveness at lower rates, because they are being used in tank-mixes, or for some other reason? In some cases using lower rates may lead to poor control and development of fungicide resistance.

Fungicide trials and usage

There have been relatively few disease-specific fungicide trials in the UK:

- For smoulder and fire, dithiocarbamate fungicides such as mancozeb were considered effective.

- For white mould, spraying with Bordeaux Mixture (a complex of copper sulphate and hydrated lime) was shown to be effective,[47] especially if a petroleum oil emulsion was added. Chlorothalonil,[48] mancozeb and tank-mix mancozeb + benomyl[49] were also shown to be effective.

- For leaf scorch, a benzimidazole spray programme was effective.[50] A copper-based fungicide may be useful.[51] Chlorothalonil and zineb/oil were also considered effective.

Many general trials of foliar fungicides have been carried out at Kirton, Rosewarne, Lisse and elsewhere, the results having been incorporated into the advisory literature of the time. Fungicides used in recent years in the UK and the Netherlands include chlorothalonil, iprodione, mancozeb and thiophanate-methyl (via LTAEU) as well as zineb/maneb, benomyl, procymidone and vinclozolin (which are not available or approved). Some copper-based fungicides are also available.

Fungicides currently available

Fungicides with full approvals or EAMUs for use in outdoor ornamental plant production or on narcissus are listed in Tables 40 and 41 (to be found at the end of Section 11.2). Table 40 lists those active ingredients which are either approved specifically for narcissus, or are approved for ornamental plant production generally and are known to have uses in narcissus growing. Table 41 lists those active ingredients approved for ornamental plant production generally, where their uses or effects on narcissus do not appear to be known.

This information was extracted from the CRD databases,[52] with checks made against the HDC LIAISON database[53]. Some points to note are:

- Several of the EAMUs relate specifically to narcissus grown for galanthamine production.

- Information from the two databases was in reasonable agreement.

- Particularly in the case of chlorothalonil-based products, of which there are many, some are labelled for outdoor, and some for protected, ornamentals, while others are not specifically labelled or include both situations.

- Searching for fungicides for use on narcissus will find products intended for application through dipping, HWT and on-line bulb spraying, as well as those intended for foliar application. As always, it is important to check details on the product label or EAMU for details of approved use.

In addition to these fungicides with full approvals or EAMUs, others are currently permitted for use in ornamental plant production through the LTAEU arrangements on an 'at own risk' basis. They should not be used on narcissus without full consideration of their suitability and crop-safety. They can be conveniently extracted from the HDC LIAISON database: when checked, this database listed for outdoor narcissus 87 fungicide products with full approvals or EAMUs and 364 that could be used under LTAEU. The additional list of active ingredients permitted under LTAEU (Table 42) includes many strobilurin, triazole and combined strobilurin and triazole products, and others, that might well be investigated for use in the control of narcissus foliar diseases. In cases where a product based on an active ingredient is available for use in ornamental plant production through a full approval or EAMU, there may be other products with the same active substance available through LTAEU (e.g. mancozeb-based products).

Fungicide spray programmes

Conventional advise would be to begin a fungicide spray programme soon after shoot emergence, once sufficient leaf surface is present to make the operation worthwhile (when leaves are about 10 cm tall). To manage the increased risk of infection following plant damage, an application is often also advised soon after frost damage.

The spray programme is then continued at appropriate intervals of 10 to 14 days until flowering, when pesticide sprays are discontinued before and during flower picking, taking account of harvest interval considerations. As a result of the damage to plants caused either by flower picking, or due to the presence of decaying flowers, a further one or two applications would be applied after flowering to control late-season infections.[54,55]

Until the 2000s a spray programme of up to six or seven applications was common, frequently using tank mixes. The programme should include fungicides from different mode of action groups, since this will reduce the likelihood of the development by the pathogens of fungicide-resistance.

In practice, it is often difficult to apply fungicides at target dates because of unsuitable weather, flower picking or harvest intervals. Finding suitable weather is a particular problem in wet, windy areas such as South-West England, where calm, dry 'spray days' are relatively few.

The 'HortLINK project' and disease forecasting

Fungicide spray programmes are not always successful, perhaps because there is little specific information on the most effective fungicides for managing particular pathogens.[56] With the aim of realising fewer but more effective fungicide applications, the forecasting and management of smoulder and white mould were studied in a 'Horticulture LINK' project funded by Defra, the HDC and industry partners (HDC Project BOF 41)[57] and continued in later HDC Projects BOF 41a,[58] 56,[59] 56a[60] and 59[61] (projects BOF 41a and 56 were co-funded by the Lincolnshire Fenlands LEADER+ and the Cornwall 'Objective 1' programmes, respectively). These trials included fungicides from the (then) newer fungicide groups, strobilurins and anilopyrimidines. Trials showed that it was possible to reduce the number of fungicide applications from the six or seven commonly applied at that time, to three sprays, provided these included the more effective active substances and were applied at appropriate timings.

In the HortLINK project predictive infection models were developed for smoulder and white mould, with the aim of forecasting the most effective spray timings and reducing the total amount of fungicide applied.[14] The main findings are listed here.

- Infection by smoulder and white mould spores requires (or at least, is strongly facilitated by) tissue damage, for example on plants with leaves damaged by hail. Heavy rain may not be damaging enough to assist infection, but the survival of the smoulder fungus on the leaf surface is enhanced in wet periods, and wind-blown rain is important for white mould development. Frost and flower cropping also cause significant damage to plants.
- Smoulder infection was shown to be maximal at temperatures of 4 to 16°C when this is accompanied by a period of leaf wetness of at least 24 hours. At non-optimal temperatures, longer periods of leaf wetness were needed to produce infections.
- For white mould, apply preventive sprays in high-risk crops, and treat outbreaks promptly. White mould infection was maximal at temperatures of 5 to 10°C when accompanied by a period of leaf wetness of at least 12 hours. At non-optimal temperatures, longer periods of leaf wetness were needed to produce infections.
- Although foliar diseases are usually less of a problem in the first crop year, spraying in the first year helps to reduce disease levels in subsequent years by leaving a smaller inoculum.
- Spraying should be considered as soon as practical after prolonged wet conditions and after crop damage.

The most effective fungicides in trials that involved a three- or four-spray programme each year are shown in Table 39 (with notes on the current availability of fungicides). For white mould, 'Amistar' + 'Folicur' had good curative action, and was also effective when there was a longer-than-usual between-spray period, for example due to unsuitable spraying weather. For smoulder, at least two of the listed tank mixes should be applied.

Fungicide sprays and Fusarium rot

These sprays may give some incidental control of bulb-rot pathogens, though this has never been clearly demonstrated.[62] In HDC Project BOF 43a, when 'Storite Clear Liquid' was applied in the field as a foliar spray towards the end of the growing season, or as a shoot/soil drench once the senescent foliage had been flailed off, it was not possible to detect the active ingredient, thiabendazole, in the bulb tissue samples sampled between one day and three weeks after its application.

Non-chemical control of foliar diseases

General hygiene, correct HWT and locating first year crops away from existing crops are useful measures in reducing foliar disease. Bulbs previously cold-stored produce more smoulder primaries that bulbs that were not.[63] Burning-over or defoliation late in the growing season was found to be effective in some trials.[7]

Table 39 Fungicides found to be effective in trials against smoulder and white mould

Disease and situation	Fungicide or tank mix	Current approval status of fungicide products
Smoulder	'Amistar' + 'Folicur' 'Bavistin DF' + 'Dithane 945' 'Bavistin DF' + 'Folicur' 'Bavistin DF' + 'Ronilan FL' 'Bavistin DF' + 'Scala'	EAMU for daffodils for galanthamine production 'Bavistin DF' - no longer available (alternative carbendazim product only as mixture with flusilazole under LTAEU) 'Dithane 945' - LTAEU 'Ronilan FL' - no longer available 'Scala' - EAMU
White mould	'Amistar' + 'Folicur'	'Amistar' 'Folicur' - EAMU
Post-flowering	'Bavistin DF' 'Dithane 945' 'Folicur' + 'Stroby WG'	'Stroby WG' – full approval

Table 40 Fungicides with either full approvals or EAMUs for use in outdoor ornamental plant production where there are known or likely uses on narcissus, or EAMUs for use on narcissus

Fungicide class (with FRAC mode of action code)	Target diseases for outdoor narcissus	Active ingredient	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Notes including any restrictions
Anilide + strobilurin (7+11)	Used to control many diseases; strobilurins are known to be useful in control of narcissus foliar diseases (*Botrytis*)	Boscalid + pyraclostrobin	Signum	2012/2141	31/07/2019	BASF	
Chlorophenyl (M5)	Effective against *Botrytis*, smoulder and white mould.	Chlorothalonil	Agriguard Chlorothalonil	2011/1131	28/02/2016	AgriGuard	
			Bravo 500	2011/1130	03/03/2015	Syngenta Crop Protection UK	There is a separate EAMU for bulb-dipping
			Life Scientific Chlorothalonil	2012/0380	28/02/2016	Life Scientific	There is a separate EAMU for bulb-dipping
			LS Chlorothalonil	2011/1883	31/05/2015	Kilcullen Kapital Partners	There is a separate EAMU for bulb-dipping
Dicarboximide (2)	Effective against narcissus foliar diseases	Iprodione	Rovral WG	2011/3200	30/04/2019	BASF	
Dithiocarbamate (M3)	Effective against narcissus foliar diseases including white mould	Mancozeb	Dithane 945	2010/0008	31/12/2018	Dow AgroSciences	Outdoor daffodil grown for galanthamine production; also available through LTAEU
			Karamate Dry Flo Neotec	Full	30/04/2014	Landseer	
		Maneb	Trimangol WDG	Full	31/12/2021	United Phosphorus	Listed as LTAEU on LIAISON database
Imidazole (3)	Controls many plant pathogens; has been used in bulb dips to control basal/neck rot	Prochloraz	Octave	Full	31/12/2021	BASF	
			Scotts Octave	Full	31/12/2021	Everris	
Strobilurin (11)	Strobilurins are used to control many diseases including foliar diseases of narcissus	Azoxystrobin	Amistar	2009/0443	31/07/2021	Syngenta Crop Protection UK	
			Aubrac	2010/0372	31/07/2021	AgChemAccess	
		Kresoxim-methyl	Beem WG	Full	30/06/2024	AgChemAccess	
			Kresoxy 50WG	Full	30/06/2024	AgriGuard	
			Stroby WG	Full	30/06/2024	BASF	

Table 40 Fungicides with either full approvals or EAMUs for use in outdoor ornamental plant production where there are known or likely uses on narcissus, or EAMUs for use on narcissus continued

Fungicide class (with FRAC mode of action code)	Target diseases for outdoor narcissus	Active ingredient	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Notes including any restrictions
Strobilurin (11) continued	Strobilurins are used to control many diseases including foliar diseases of narcissus	Picoxystrobin	Galileo	2008/2855	30/04/2019	Du Pont (UK)	
		Pyraclostrobin	Vivid	2008/2884	31/05/2014	BASF	
		Trifloxystrobin	Swift SC	2008/2882	31/01/2019	Bayer CropScience	
Thiothanate (1)	Controls many plant pathogens including root diseases.	Thiophanate-methyl	Cercobin WG	2008/1384	28/02/2016	Certis	Approved for container grown ornamental plant production
Triazole (3)	Triazoles control many plant pathogens, and tebuconazole is known to control *Botrytis*/ smoulder	Myclobutanil	Aristocrat	Full	31/12/2021	Agriguard	
			Clayton Lithium	Full	31/12/2021	Clayton Plant Protection (UK)	
			Crassus	Full	31/12/2021	Landseer	
			CS Myclobutanil	Full	31/12/2021	Chemsource	
			Pure Myclobutanil	Full	31/12/2021	Pure Amenity	
			RouteOne Butanil 20	Full	31/12/2021	Albaugh Europe	
			RouteOne Robut 20 (13646)	Full	30/09/2015	Albaugh UK	
			RouteOne Robut 20 (15273)	Full	30/09/2015	Albaugh Europe	
			RouteOne Robut 20 (15685)	Full	31/12/2021	Generica Europa	
			Systhane 20 EW	Full	31/12/2021	Landseer Ltd	
		Propiconazole	Bumper 250 EC	2009/0707	31/05/2014	Makhteshim-Agan (UK	
		Tebuconazole	Alpha Tebuconazole 20 EW	2007/1379	31/12/2021	Makhteshim-Agan (UK)	Outdoor daffodil grown for galanthamine production
			Bezel	Full	31/12/2021	Bayer CropScience	Ornamental plant production
			Deacon	2009/0095	31/12/2021	Makhteshim-Agan (UK)	Outdoor daffodil grown for galanthamine production
			Folicur	2004/1516	31/12/2021	Bayer CropScience	Outdoor daffodil grown for galanthamine production
			Mitre	2007/1370	31/12/2021	Makhteshim-Agan (UK)	Outdoor daffodil grown for galanthamine production
			Odin	2009/0322	31/12/2021	Rotam Agrochemical Europe	Outdoor daffodil grown for galanthamine production

Table 40 Fungicides with either full approvals or EAMUs for use in outdoor ornamental plant production where there are known or likely uses on narcissus, or EAMUs for use on narcissus continued

Fungicide class (with FRAC mode of action code)	Target diseases for outdoor narcissus	Active ingredient	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Notes including any restrictions
Triazole (3) continued	Triazoles control many plant pathogens, and tebuconazole is known to control *Botrytis*/ smoulder	Tebuconazole	Orius 20 EW	2007/1328	31/12/2021	Makhteshim-Agan (UK)	Outdoor daffodil grown for galanthamine production
			Savannah	2010/1176	31/12/2021	Rotam Agrochemical Europe	Outdoor daffodil grown for galanthamine production
			Starpro	2010/1217	31/12/2021	Rotam Agrochemical Europe	Outdoor daffodil grown for galanthamine production
			Toledo	2009/0575	31/12/2021	Rotam Agrochemical Europe	Outdoor daffodil grown for galanthamine production

Bulb dip and similar uses excluded.

In cases where a product based on an active ingredient is available for use in ornamental plant production through a full approval or EAMU, there may be other products with the same active substance available through Long Term Arrangements for Extension of Use.

Table 41 Fungicides with full approvals or EAMUs for use in outdoor ornamental plant production where the active ingredient does not appear to have been tested or used on narcissus

Fungicide class (with FRAC mode of action code)	Potential usage on outdoor narcissus	Active ingredient	Product name (with MAPP no. if more than one approval)	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Notes including any restrictions
Anilinopyrimidene + phenylpyrrole (9+12)	None known (controls many plant pathogens including *Botrytis*)	Cyprodinil + fludioxonil	Switch (13185)	Full	30/04/2014	Syngenta Crop Protection UK	
			Switch (15129)	Full	01/11/2014	Syngenta Crop Protection UK	
Bacillus subtilis (44)	None known (control of *Botrytis*)	*Bacillus subtilis* (strain QST 713)	Serenade ASO (14318)	2013/0706	31/07/2019	Fargro	
			Serenade ASO (15625)	2012/0475	31/07/2019	BASF	
Benzophenone (U8)	None known (controls many plant pathogens)	Metrafenone	Flexity	2008/2850	31/07/2019	BASF	
Dicarbamate (M3)	None known (controls many plant pathogens)	Thiram	Tercero	Full	31/12/2021	Agroquimicos Genericos	
			Thianosan DG	Full	31/12/2021	Universal Crop Protection	
			Triptam	Full	31/12/2021	Certis	
Phthalimide (M4)	None known (controls many plant pathogens)	Captan	PP Captan 80 WG	Full	31/12/2021	Calliope	Listed as LTAEU on LIAISON database

Table 42 Active ingredients listed in HDC's LIAISON database as available for use on outdoor narcissus solely through Long Term Arrangements for Extension of Use

Active ingredients which may have application in narcissus production		
Ametoctradin	Dithianon	Fluxapyroxad
Bixafen	Epoxiconazole	Isopyrazam
Carbendazim	Famoxadone	Metconazole
Copper oxychloride	Fenbuconazole	Penconazole
Copper sulphate	Fenpropidin	Pencycuron
Cymoxanil	Fenpropimorph	Prothioconazole
Cyproconazole	Fluquinconazole	Pyrimethanil
Difenoconazole	Flusilazole	Spiroxamine
Dimoxystrobin	Flutolanil	Sulphur
Dodine	Flutriafol	Tetraconazole

Some active ingredients may be available only as mixtures; active ingredients that appear in other products in Tables 40 and 41 have been omitted. As is the case with active ingredients usable on narcissus via approvals for ornamental plant production generally, the LTAEU products are listed on the basis of being legally usable on the crop concerned; they are not necessarily suitable, relevant or even crop-safe; they should not be used on narcissus without consideration of these factors.

11.3 Pest control

The Pesticide Usage Surveys – field applied insecticides and other pesticides

The surveys provide much information about the pesticides applied to bulb crops, and data from the last three surveys (1997, 2001 and 2005) are summarised in Table 43. Particularly in the case of insecticides, some interpretation is needed, because 'other bulbs', principally gladiolus, are included in the aggregated figures; although in 2005 narcissus accounted for 86% of the total outdoor flower-bulb area, gladiolus may receive significant applications of insecticides to control aphids, thrips, etc. The table includes the total area planted, so the percentage of the whole crop being treated (or how many times it was treated) can be determined. Usage is expressed as the number of 'spray-hectares' so, for example, a 'percentage of crop treated' of 200 could mean that the whole area received two herbicide applications during the year.

The main findings were as listed here:

- As found for foliar applied fungicides and herbicides, insecticide usage in 2001 was recorded at much higher levels than in 1997 or 2005. This may be an artefact of the survey methods.
- Three of the most used insecticides: chlorpyrifos, dimethoate and lambda-cyhalothrin - were recorded in the survey as being used to control large narcissus fly, with the use of lambda-cyhalothrin having increased notably by the latest survey. The 2005 report suggested that the use of organophosphorous compounds (such as chlorpyrifos and dimethoate) was likely to decline further, with replacement by pyrethrins (such as lambda-cyhalothrin).
- When used, dimethoate was used as four applications, on average.
- It is likely that much of the remaining insecticide, acaricide and molluscicide usage was targeted against gladiolus and other bulbous crops included in the survey, although slugs can be a problem to narcissus. The amount of usage of the minor pesticides was too small to draw reliable conclusions.
- In 2005, overall, insecticides were applied at about 90% of the full label rate.

Table 43 Amounts of field-grown flower-bulbs in Great Britain treated with insecticides and related pesticides in the field, taken from the Pesticide Usage Surveys. Insecticides listed in descending order of usage in 2005

Pesticide type and active substance	Planted-ha treated (with total area grown)		
	1997 (4,751 ha)	2001 (5,237ha)	2005 (4,916ha)
Insecticides/nematicides			
Chlorpyrifos	43	970	188
Cypermethrin	2	287	254
Deltamethrin	53	24	183
Demeton-S-methyl	57	0	0
Dimethoate	2,482	4,418	1,234
Gamma-HCH	3	0	0
Lambda-cyhalothrin	45	246	1,025
Malathion	0	0	40
Pirimicarb	29	293	82
Pymetrozine	0	0	113
Pyrimiphos-methyl	0	214	0
Thiacloprid	0	0	293
Others*	27	127	0
Total	2,741	6,579	3,412
Acaricides			
Others*	0	21	10
Molluscicides/repellants			
Metaldehyde	4	151	0
Others*	61	53	1
Total	65	204	1

* 'Others' means active substances used on <0.1% of the total area treated with pesticides

Large narcissus fly – forecasting and chemical control

Where large narcissus fly is a problem it would be useful to apply a suitable insecticide programme in the field. The biology of large narcissus fly has been extensively researched at Wellesbourne with Defra and HDC funding, and as a result a temperature-dependent HDC pest forecast is available (see Figure 19).[64] The forecast gives regional predictions of the date of mean fly emergence, egg-laying and egg-hatching, based on current weather data. However, those insecticides found to be most effective in trials are not currently available in the UK, while in some cases insecticides effective in laboratory tests have not been confirmed in field trials. Of the many insecticides evaluated in Cornwall, only dimethoate is now available in the UK (Table 44, to be found at the end of Section 11.3), but its effect in trials was inconsistent.[65]

Investigations in the Netherlands included using chlorpyrifos as a pre-planting cold soak, as a drench in spring, or as regular crop sprays.[66] It was found that chlorpyrifos soaks and drenches were less effective than regular crop sprays of omethoate applied at one- or two-week intervals during the egg-laying period.

Large narcissus fly – non-chemical control

In the absence of effective chemicals for large narcissus fly control, it may be possible in some seasons to utilise the predicted date for egg-hatch to defoliate the crop and lift susceptible crops early, circumventing the entry into bulbs of the larvae. This would lead to some loss of yield, the more so in 'early' years when the logistics of early lifting would also be difficult. In other years, the benefits might outweigh the disadvantages in some situations. The flies do not mate when temperatures are <20°C, and during an extended inactive period they are subject to losses by predation, so consistently cool weather in the spring may indicate a year when large narcissus fly damage is unlikely to be high.

In Cornwall, trials in which the foliage was removed by flailing or desiccated through burning-over with propane, prior to egg-hatch, gave inconsistent results.[67] Some other techniques for deterring large narcissus fly are mentioned in the literature. For example, surface cultivation deters egg-laying,[68,69] as does applying naphthalene.[68] Cultivation and using a pest barrier may be practical where only small areas of valuable bulbs are involved.

Narcissus leaf miner

The narcissus leaf miner has not yet been reported in the UK, but in the Netherlands egg-laying occurs before that of large narcissus fly. To combat it chlorpyrifos or omethoate is sprayed at two-week intervals in April and May.[3,70]

Bulb-scale mite

Despite the effectiveness of HWT, bulb-scale mite probably exists at low background levels in many bulb stocks, occasionally becoming a serious problem when infested bulbs are grown at glasshouse temperatures for forced flower production. The biology and management of the bulb-scale mite are being studied in a 'Horticulture LINK' project co-funded by Defra, the HDC and industry partners (HDC Project BOF 63).[71] New field trials using a range of acaricides are under way.

The quest for large narcissus fly control

In trials by ADAS and HRI in Cornwall, as well as in the Netherlands and other countries, many insecticides have been assessed against either the adult or larva. In the UK, granular and liquid insecticides were applied to the ridges during the growing season to target newly hatched larvae. Granular carbofuran and disulfoton were shown to be effective, and demeton-S-methyl, dimethoate and vamidothion were described as meriting further investigations.[65] Apart from dimethoate, these insecticides are not now available in the UK.

In the Netherlands it was shown that dimethoate, applied in spring, controlled large narcissus fly and narcissus leaf miner.[141] Omethoate, a compound effective against the adult insect at oviposition,[66,142] is no longer available in the UK. In trials in Poland, soil-incorporation of oxamyl or aldicarb in April or May was found to be most effective, though several other chemicals were reportedly satisfactory as granule or drench applications.[143,144] Trials were also carried out in Israel.[145]

In more recent HDC Projects, BOF 53 and 55,[146,147] adult flies were exposed to narcissus foliage treated with lambda-cyhalothrin (as 'Hallmark with Zeon Technology'), deltamethrin (as 'Decis'), spinosad (as 'Tracer') and thiacloprid (as 'Calypso'). Lambda-cyhalothrin was effective, and deltamethrin somewhat less so. In later experiments, the insecticides were also made up with added sucrose as bait: adding sugar made all the insecticides more effective, lambda-cyhalothrin remaining the most effective. However, in field trials of lambda-cyhalothrin, with or without sugar, at Wellesbourne, Kirton and on commercial farms, where four sprays were applied around the forecast fly emergence date, these findings could not be replicated.

Virus-vector aphids

Many viruses are transmitted to narcissus via aphids. It is difficult to control virus transmission from migratory winged aphids since, while they do not normally colonise narcissus, several common aphid species do land on and probe narcissus foliage, leading to virus transmission via the stylet during exploratory probing ('non-persistent transmission'). Wingless stages of aphids have been reported to infest narcissus, but only under atypically warm conditions.

For valuable stocks, where it is required to maintain freedom from viruses, aphid control is advisable. A spray programme should be started as soon as aphids are present. Spraying with either anti-feedant pyrethroid insecticides or mineral oils has been tested.

Sprays of pyrethroids (such as cypermethrin or deltamethrin) should be applied regularly, ideally at seven to ten day intervals if permissible. In HDC Project BOF 2a virus tested mother stock bulbs of 'Carlton' and 'Fortune' were planted adjacent to ordinary bulb stocks and sprayed regularly with pyrethroids over a six-year period. After six years few positive virus tests or foliar symptoms of virus had been seen, and there were no adverse effects of the spray programme on the crop.[72] However, in one study the application of systemic insecticides was shown to increase virus spread, possibly by increasing aphid irritability and probing before death.[73]

Mineral oil sprays (which disrupt the normal transmission of virus particles by altering surface tension) are not always successful, and can drastically reduce yield if applied too frequently (weekly).[74,75] Some dwarf cultivars (e.g. 'Tête-à-Tête' and 'Hawera') appear more sensitive to mineral oil sprays than standard cultivars.[76] Furthermore, in one report the incidence of NYSV was found to be similar in plots treated with mineral oils and in the untreated controls.[74] In HDC Project BOF 2a, regular spraying of mineral oils ('Actipron' or 'Fyzol 11E') produced shorter plants, paler foliage, earlier senescence, lower bulb yields and more smaller bulbs, while spraying 'Codacide' sometimes reduced bulb yield.[72]

In a survey of bulb growers' measures to control pests and diseases in the Pacific Northwest, the principal means of management of virus diseases was hand and (or) herbicide roguing of symptomatic plants.[77] While growers rogued 80 and 69% of their lily and tulip acreage, respectively, in this way, only 1% of the narcissus acreage was so treated. Few growers used pyrethroid insecticide or mineral oil sprays, which would be expected to greatly improve disease management.

Stem nematode

In the UK, nematicide treatments are not used in the field. In the USA, three weekly applications of systemic phosphates (e.g. demeton as 'Systox', not available in the UK) were reported to reduce nematode numbers in the leaves and bulb, and without phytotoxicity at the lower rates of use.[78] Other trials in the USA sought alternatives to HWT, such as soil sterilisation or applying nematicide at planting.[79] Foliar applications of oxamyl at various rates and times were found to reduce nematode levels in bulbs and leaves without causing toxicity. In the UK one oxamyl-based product has off-label approval for leaf miner control in outdoor ornamental plant production.

Slugs

Slugs have not attracted obvious attention as pests of commercial narcissus crops, but their feeding damage to the lower foliage is often seen and they can occur in large numbers on bulbs in the soil. According to the Pesticide Usage Surveys, molluscicides have been used on small areas of the crop. Slug management should be considered in the light of observed crop damage, past experience, and the factors affecting slug numbers at the site. It is understood that some growers apply slug pellets routinely, but this is not usual.[80] There are many products containing metaldehyde, and some with methiocarb, ferric phosphate and copper silicate that may be used on outdoor ornamentals.

Disposal of waste pesticides

Dilute pesticide waste (residual amounts and tank washings) should be disposed of according to Section 5 of the Code of Practice for using Plant Protection Products.[81] Briefly, this may be by application to a crop or area within the terms of the product approval, through a waste-disposal contractor, by disposal onto soil or grass under the terms of an authorisation under the Groundwater Regulations, by processing the waste or disposing to a lined biobed under the terms of an appropriate waste-management licence, or by disposal into a sewer under a trade effluent consent.

Figure 19 An example from the HDC/WHRI large narcissus fly forecast web-pages showing the expected date of adult fly emergence in 2010 at four locations

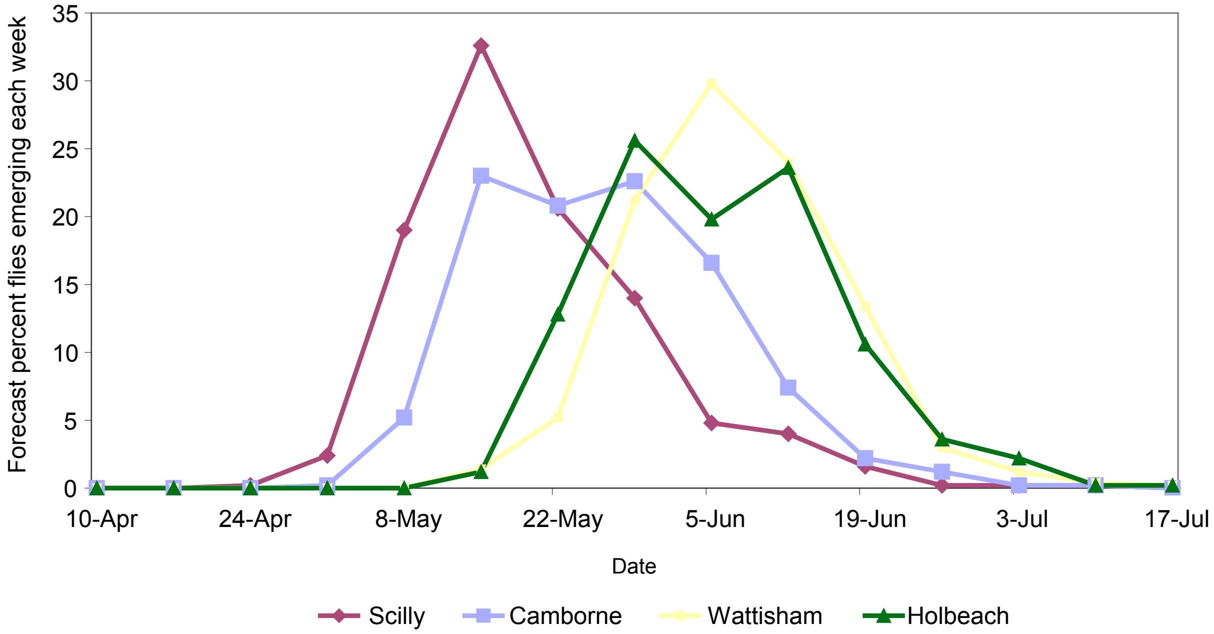

Table 44 Insecticides and molluscicides with full approvals or EAMUs for use in outdoor ornamental plant production, for the control of pests relevant to narcissus

Active ingredient	Target pest	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Approved crops
Deltamethrin	Aphids	Agriguard Deltamethrin	Full	31/12/2021	Agriguard	Ornamental plant production
		Agrotech Deltamethrin	Full	31/12/2021	Agrotech-Trading	Ornamental plant production
		Bandu	Full	31/12/2021	Headland Agrochemicals	Ornamental plant production
		Cleancrop Decathlon	Full	31/12/2021	United Agri Products	Ornamental plant production
		Decis	Full	31/12/2021	Bayer CropScience	Ornamental plant production
		Decis Protech	Full	31/12/2021	Bayer CropScience	Ornamental plant production
		Delta-M 2.5 EC (12604)	Full	31/12/2021	MAC	Ornamental plant production
		Delta-M 2.5 EC (14212)	Full	31/12/2021	MAC	Ornamental plant production
		Deltason-D	Full	31/12/2021	DAPT Agrochemicals	Ornamental plant production
		Euro Delta 25	Full	31/12/2021	Euro Chemicals s.r.o	Ornamental plant production
		Lamdgold Deltaland	Full	31/12/2021	Teliton	Ornamental plant production
		Milentus Deltamethrin	Full	31/12/2021	Milentus	Ornamental plant production
		Routeone Deltam 10 (13615)	Full	30/04/2015	Albaugh UK	Ornamental plant production
		Routeone Deltam 10 (15274)	Full	31/12/2021	Albaugh Europe	Ornamental plant production
Dimethoate	Large narcissus fly	Danadim	Full	31/12/2021	Headland	Ornamental plant production
		Danadim Progress	Full	31/03/2014	Headland	Ornamental plant production

Table 44 Insecticides and molluscicides with full approvals or EAMUs for use in outdoor ornamental plant production, for the control of pests relevant to narcissus continued

Active ingredient	Target pest	Product name	Full approval or EAMU approval no.	Product expiry date (use by date)	Marketing company	Approved crops
Ferric phosphate	Molluscs	Derrex	Full	31/12/2015	Certis	Includes 'all non-edible crops'
		Ferramol Max	Full	31/12/2015	Certis	Includes 'all non-edible crops'
		Ferramol Slug Killer	Full	31/12/2015	Growing Success Organics	Includes 'all non-edible crops'
		Ferrox	Full	31/12/2015	W Neudorff	Includes 'all non-edible crops'
		NEU 1181 M	Full	31/12/2015	W Neudorff	Includes 'all non-edible crops'
		NEW 1185	Full	31/12/2015	W Neudorff	Includes 'all non-edible crops'
		Sluggo (12529)	Full	31/05/2014	Omex Agriculture	Includes 'all non-edible crops'
		Sluggo (14788)	Full	31/12/2015	Omex Agriculture	Includes 'all non-edible crops'
		Sluxx	Full	31/12/2015	Certis	Includes 'all non-edible crops'
Metaldehyde		[Many products available]	Full	Varies, up to 31/12/2021	Various companies	Mostly include 'all non-edible crops' and bare surfaces, etc.
Methiocarb		Cobra	Full	31/12/2021	Interfarm UK	Includes 'all non-edible crops'
		Decoy Wetex	Full	31/12/2021	Bayer CropScience	Includes 'all non-edible crops'
		Draza Forte	Full	31/12/2021	Bayer CropScience	Includes 'all non-edible crops'
		Rivet	Full	31/12/2021	Bayer CropScience	Includes 'all non-edible crops'
		Zeal Plus	Full	31/12/2021	ChemSource	Includes 'all non-edible crops'
Oxamyl	Nematodes	Vydate 10G	2012/2322	31/12/2021	Du Pont (UK)	Includes 'outdoor ornamental plant production'

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12.0 Growing season operations (other than weed, disease and pest management)

12.1 Irrigation

In the UK narcissus are only very rarely irrigated when grown on silt soils, though irrigation may be used – if available for the potato crop - when they are grown on less water-retentive soils such as the Norfolk sands. In the Netherlands the irrigation of bulbs grown in sandy soils is normal, and it is recommended the crop should be irrigated when it is difficult to squeeze the soil round the roots into a ball. Dutch advice states that water should be applied at not more than 15 to 20 mm per application, since higher rates can damage soil structure.

Several factors suggest that irrigation might be considered more often by growers:

- Moderate irrigation appears to improve bulb growth, especially when applied after flowering in May and early June, when there is a full leaf canopy.
- Defra-funded research to develop a narcissus crop model showed that water availability was a major determinant of bulb yield.[1]
- Trials at Kirton[2] and in New Zealand[3] showed that irrigation increased the yield of larger bulbs, especially at higher planting rates or when growing vigorous bulb stocks.
- Polish research showed that yields are best in soils near field capacity, and that the levels of P and K in the roots increased with increasing moisture levels.[4,5]
- Water availability is known to affect such basic characteristics as root anatomy and the numbers of stomata.[6]
- Moister soil conditions make bulb lifting easier.

These factors need to be balanced against the following cautions:

- There is a danger of increased basal rot if the soil is warm when irrigation is applied.
- Late in the growing season excessive irrigation should be avoided: although it may increase bulb weight, it may also delay the 'ripening' of the bulb.
- The uneven growth that irrigation may cause can lead to split scales, detracting from the visual appeal of bulbs intended for the retail market.

12.2 Flower cropping and de-heading

Cropping in the field

Depending on local practices and current prices, several flower cropping options are available, picking may occur:

- In most years, including the first-year-down crop (using a warm-storage treatment to reduce HWT damage).
- Routinely, though not usually in the first-year-down.
- Only when the market price makes picking worthwhile.
- Not at all (if bulb production is paramount).

Over the last 30 years an increasing proportion of crops have been picked, and picking from first-year crops has become common; this reflects a healthy market demand for narcissus flowers. Figures for the period from 1997 to 2005, based on sampling in the Pesticide Usage Surveys are shown in Table 45.

Cropping stages for standard cultivars

The stage at which flowers are cropped is critical for market acceptability (Images 60 and 61). Narcissus were formerly cropped at the 'goose-necked' stage (or, before that, with open flowers), and it was long asserted that this was necessary to ensure proper flower development and opening with normal bending of the pedicel, stem extension and adequate vase-life.[7,8]

Despite this, current marketing considerations demand that flowers of standard cultivars are cropped either:

- For export markets, with no colour showing, at an 'upright pencil' or 'upright fat pencil' stage.
- For home (and especially local) markets, and if unavoidable, with a little colour showing and between the 'upright fat pencil' and 'early split spathe' stages.

In either case the overall length of the flower/stem should be at least 30 cm.

In picking cultivars such as 'Carlton' at the upright pencil stage, it is essential that the swelling bud has nearly filled the spathe, with only a small flap of empty spathe left at its tip (often referred to as the 'flag' or 'pixie hat'). However, not all varieties develop in an entirely similar way, so the amount of empty spathe is not always consistent and initially some trial-and-error may be needed, and the experiences of the grower will tell him when the bud is swollen enough to open into a good quality flower.

As well as possibly being too short, flowers picked too early can fail to develop or open normally, remaining small and more or less upright, without 'goose-necking'. When cropping flowers at such an early stage of development, it is almost inevitable that some flowers will be picked too early in an attempt to avoid criticism for picking too late. In practice, the decision of when to pick will be affected by the weather forecast, and the flowers may be picked at slightly earlier or later stages because of this. Fungicide spray programmes need to anticipate likely picking dates and the harvest intervals of products being used.

For these reasons, it can be argued that retailers need to be educated into accepting a slightly more developed bud than is currently required.

Table 45 The percentage of first, second and older crops from which flowers were picked, 1997 to 2005 from the Pesticide Usage Surveys

Crop year	Survey year		
	1997	2001	2005
1	67	71	79
2	77	97	95
>2	83	100	100

60 Daffodils can no longer be sent to market like this!

Photo: Warwick HRI and predecessors

61 Flower picking stages: 'upright pencils' (top), upright with spathe just splitting and showing colour (left) and goose-necked (right)

Photo: Warwick HRI and predecessors

Cropping stages for double cultivars

Unlike standard cultivars, doubles are cropped only when the spathe has split and colour can easily be seen. In this case the overall length of the flower/stem should be not less than 40 cm.

In double cultivars such as 'Dick Wilden' or 'Golden Ducat', flowering disorders are often encountered. The spathe may split well before the floral bud has fully grown, or the spathe may dry without splitting, enclosing a dead bud (looking like a 'drum-stick'). These problems are exacerbated in forced crops.

Cropping stages for tazetta cultivars

Tazetta cultivars are picked when the spathe is completely split and one floret is wide open.

Cropping and storage practices

Flowers from field crops are usually cropped by snapping, so the leaves are left intact. The use of knives should not be allowed, as this invariably causes damage to foliage, and the sap carried on the knife might transfer viruses between plants. Except for tazetta cultivars, stems should not be pulled, since this may increase the incidence of neck rot.[9,10]

Stems are usually bunched in tens, with heads level and held by a rubber band, and at intervals bunches are transferred to, and placed flat in, plastic trays. These should be transferred promptly to a cold store so that field heat is removed before packing: once packed, the flowers are very dense, so removing heat later is difficult.

Following the main flush of flowers ready for picking, many stocks produce a number of late, short-stemmed flowers growing in the base of the main foliage (Image 62). These are produced from lateral bulb units, in which flower initiation occurs later than in the terminal bulb units, and are ignored.[11]

62 Example of a late, short-stemmed flower produced by lateral bulbs

Photo: Gordon Hanks

Harmful effects of flower picking

'Daffodil itch' (also erroneously called 'lily rash') as a result of picking narcissus flowers was first described, from the Isles of Scilly, at least as long ago as 1910,[12] and the subject has been recently reviewed.[13] Briefly, an eczematous rash can develop through direct contact of the sap dripping from the cut-stem and skin of the picker. Granulomatous (inflamed) sores may develop at any point of direct trauma, and paronychia (a nail disease) can occur. The hands and wrists are most obviously affected, with the finger-webs very likely to impact on the cut ends of previously picked stems, the hands suffering if the base of the cut flowers is bumped against the palm to level the bunch, and the wrists being subject to dripping sap when as many bunches as practical are gathered up to take to the collection point. The rash may also appear on the chin and forearms, with a secondary rash on face and genitals. It is suggested that the incidence of daffodil itch has increased with the change from an hourly rate for cropping, to payment by the number of bunches picked. For some individuals, the condition may become quite serious, but few sufferers present to a doctor as the picking season is relatively short, so the condition is self-limiting.[14]

Some further points from the review are:

- Cultivars differ in the amount of sap exudation they create: 'Grand Soleil d'Or' and 'Paperwhite' are relatively low in sap, while some older trumpet cultivars, such as 'King Alfred' and 'Princeps', were notoriously troublesome.
- Narcissus sap contains calcium oxalate crystals of various shapes, but notably bundles of long, needle-like crystals (raphides) that are released with the mucilaginous sap (containing alkaloids) when the cells in the stem are ruptured.
- Narcissus appears to have little ability to produce an allergic response but, very rarely, sensitisation from prior picking may produce an allergic contact dermatitis, thought to result from penetration of the skin by raphides followed by a reaction to homolycorin and masonin, two of the alkaloids present in sap.

A number of simple precautions can be taken, and experienced pickers will develop strategies to reduce their contact with sap:

- Sensible and waterproof clothing should be encouraged, to minimise contact with dripping sap.
- Rubber or nitrile gloves should be worn, with the wrist-end closed with a rubber band or cuffs.
- Removing gloves or wiping hands before eating or visiting the bathroom.

Flower picking may also result in back-pain from stooping, repetitive stress injury to wrists from the plucking action, and chilblains on the back of the thighs and on the buttocks due to working with the back to the wind.

Effects of flower cropping on field stocks

Flower cropping may increase the incidence of foliar disease owing to the opportunity for pathogens to invade damaged surfaces,[15,16,17,18] but it also removes the significant photosynthetic contribution made by the stem.

Flower picking has been reported to increase the incidence of neck rot,[9,10] presumably by creating wound sites that can be infected, yet other studies have found reduced neck rot when flowers cropped.

Some authors reported markedly greater bulb yields when the flowers were not cropped,[19] yet others reported little or no effect of flower cropping on yields.[20,21]

These apparently contradictory results may be due to differences in cultural practices, cultivars or location, or to how carefully cropping and other treatments were carried out.

Whether flowers are cropped, de-headed or left intact, a prompt fungicide application soon afterwards is important for protecting the damaged plant surfaces, and for controlling the spread of fungal pathogens from the dead or dying flowers that often lodge between the leaves.

Should narcissus be de-headed?

Where flowers are not being cropped, 'heading off' may increase bulb production by removing a sink for nutrients and eliminating decaying flowers that would encourage fungal diseases. Trials from various locations have suggested some benefit of de-heading.

- In a study in the USA, yields were progressively reduced, compared with de-heading, when flowers were left intact or cropped half-way up the stem, when flowers were cropped at bud stage, and when cropped at full bloom.[22,23] Removing the flower bud as soon as the stem had grown enough to allow access gave yields similar to those of de-heading. Repeated annually, the effects on yield were cumulative.
- In a Dutch study, similar losses were found as a result of neither de-heading nor picking flowers; and the results were similar whether 'careful' or 'commercial' standards of flower removal had been used.[24]
- Removing leaves at cropping, compared with cropping flowers alone, further reduced yields (by 36% when only two leaves were left intact).[20]

Overall, de-heading narcissus is probably not economically worthwhile in the UK. In the Netherlands, de-heading machines have been developed for narcissus, and removing non-cropped flower heads is recommended, though this is aimed at the control of fire which is not usually a problem of UK crops.[25] For cultivars with brittle stems, significant damage would be expected from de-heading.[26]

12.3 Roguing, selection and inspection

Roguing

To maintain or improve the quality of bulb stocks, it is important to inspect crops periodically and identify and remove:

- Plants with virus symptoms.
- Rogue cultivars and other off-types.
- Plants with stem nematode lesions (called 'spikkels').
- Smoulder primaries.

Roguing is often the only practical option for managing virus levels in narcissus.

Manual roguing

Roguing should take place on a regular basis, and ideally two or three times each growing season. Early-season roguing is advantageous in removing infected plants before nematode numbers build-up with increasing temperatures. Some virus symptoms, however, such as those of narcissus white streak virus and narcissus late season yellow virus, appear only later in the season.

Virus spread in narcissus is usually slow and in patches, and control by roguing may be manageable if the incidence of virus symptoms is not high. Virus spread is proportional to the number of infected plants: in one study, after three years 16, 46 and 90% of healthy plants were infected in plots with initial infector levels of 10, 20 and 50%, respectively.[27,28]

Roguing requires careful crop walking and is a skilled and labour-intensive operation: consequently it is barely compatible with the economics of contemporary bulb growing and, therefore, increasingly omitted. Traditionally, roguing was carried out using a two-pronged fork known as a roguing iron, and an umbrella to shade the crop and make symptoms easier to see. The iron is inserted into the ridge under the affected bulb, which can then be cleanly removed without much collateral damage. Any diseased bulbs found and removed should be disposed of by burning or thorough composting. When a single plant or a small distinct group of plants shows symptoms of a stem nematode infestation, these and any other plants within a 1 m-radius, and the associated soil, can be dug out and disposed of safely.

Chemical roguing

In the 1970s various methods of roguing narcissus with contact herbicide were tested, such as using paraquat or glyphosate guns, gloves, sticks or aerosol sprays, treatments unacceptable today.[29,30,31,32] For example, roguing was investigated in the 1970s at Kirton, using the direct application of herbicides after de-heading. Glyphosate (as ‘Roundup’ at rates equivalent to 2, 4 and 8 L/ha) was the only still-available total herbicide of those tested, but was only partly effective. Paraquat (as ‘Gramoxone’ at rates equivalent to 10, 20 and 40 L/ha) was more effective, but is no longer available; the other materials tested (and found to be ineffective) were aminotriazole and paraffin. In the absence of any proven or permitted means of chemical roguing, the only option available is the physical removal of affected plants by digging, followed by safe disposal.

Selection

Improved stocks (called ‘superstocks’ or ‘greenstocks’, perhaps because they have healthy green foliage rather than the yellowish, stripy foliage of virus-infected plants) can be built-up through vigorous roguing and by selecting the best and largest bulbs or plants with the desired characteristics.[33,34] Ideally the best plants should be selected and grown-on in isolation, say 50 m from other stocks. Small, selected stocks could be grown-on initially in trays of sterilised growing media in vector-proof conditions, such as an insect-proof mesh house.[28]

Crop inspection and preparing for bulb sales

The following section summarizes the phytosanitary (plant health) requirements for bulb sales. If in doubt about the requirements, the local PHSI or other appropriate office should be consulted. Further information on plant health, imports and exports may be found at Fera’s plant health website.[35]

Sales within the EU

Where narcissus bulbs are to be sold or moved to another commercial grower within the EU (including within the UK) to be grown on, application must be made to the local PHSI office (or equivalent) for inspection with a view to the issuing of plant passports. A plant passport is not required where the bulbs have been prepared and are ready for sale to the final consumer. Plant passports are intended to ensure that only plants free from quarantine pests and diseases are traded. Once applied for, the submitted stocks will then receive a growing season inspection (GSI), primarily to ensure freedom from stem nematode (a ‘quarantine pest’ under EU legislation), and later a representative batch will receive a dry bulb inspection (DBI) to ensure the bulbs are free of soil.

Sales outside the EU[36]

For sales to countries outside the EU it is advisable to contact the local plant health office as early as possible in order to ascertain the phytosanitary requirements of the destination country. In addition to a GSI for pest and disease freedom, checks and tests for area freedom for quarantine pest and diseases (potato cyst nematode and potato wart disease) may be required. For some countries an import permit is necessary: this is usually obtained by the importer and lists any additional plant health checks required before a phytosanitary certificate can be issued. The permit allows the bulbs to enter the country through a plant quarantine station.

A DBI is required before a phytosanitary certificate for export can be issued. Bulbs need to be cleaned to a high standard of soil freedom (countries such as USA and Canada require complete soil freedom, with only a light covering of dust permissible). Freedom from pest and disease may have tolerances applied depending on the importing country, a general tolerance of 1.5% being applied to rots and narcissus fly larvae, and a nil tolerance for bulb-scale mite.

Regular exports to USA can be facilitated through a pre-clearance programme. This is a commercial programme but operated by PHSI and audited and monitored by USDA Inspectors. Growers and exporters have to be approved and must consistently demonstrate they produce bulbs meeting the export standards.

12.4 Miscellaneous chemical applications

Fertiliser top-dressings

The required amount of nitrogen fertiliser should, preferably, be applied as a top-dressing shortly before crop emergence, with a possible top-up in the second crop year if growth has been weak in the first.

Other applications

There are few potentially useful miscellaneous chemical applications that have been tested on field-grown narcissus crops.

Foliar nitrogen

The application of ammonium nitrate sprays was shown in some trials at GCRI to delay foliar senescence, increasing bulb yield by nearly 15% in one case. It was suggested this effect worked by replacing the failing nitrogen uptake from senescent roots.[37]

Plant growth regulators

According to the 2005 *Pesticide Usage Survey*, a cereal growth regulator, with active substances chlormequat + imazaquin, was used on 42 spray-hectares of second-year narcissus, presumably to control lodging. Many chlormequat products are available in the UK, some of which are approved for use in ornamental plant production generally, and products containing chlormequat + imazaquin may be available through LTAEU.

There is a report from Egypt that bulb soaks or foliar sprays with ethephon increased bulb production.[38] However, in the UK no beneficial effects on yield were found in extensive trials in which a range of plant growth regulators – auxins, gibberellins and cytokinins - were applied in the field.[39]

'Growth stimulants'

Many 'growth stimulants' of various types are advertised, and some may suggest a value in narcissus growing. For example, it was reported that repeated sprays of the short-stemmed cultivar 'Winston Churchill' with a 'foliar stimulant' ('M90'), tank-mixed with fungicides, increased stem length to a commercially useful extent.[40] Such materials will have to be judged on a case-by-case basis as they arise.

12.5 Operations between growing seasons

There are few operations to consider in the 'dormant' period between growing seasons.

Waterlogged furrows will assist the spread of stem nematode, which can normally move up to 1 m in a year. Where furrows have become waterlogged, or are liable to become so, drainage should be improved by breaking up the soil by running a single tine down the furrows in early-August, when roots will not be damaged (Image 63).

63 Waterlogged, compacted furrows need to be broken up

Photo: Warwick HRI and predecessors

During summer, between the growing seasons, crops should be kept tidy. The remaining crop foliage should be removed with a flail mower, and the soil surface cultivated to close cracks so that contact or translocated herbicides subsequently applied do not come into contact with and damage the bulbs, and this also helps to maintain generally good conditions around the bulbs. It can be achieved by a pass with a light ridged roller, or by re-ridging the crop (Image 64). Cultivation pushes crop debris into the furrows and leaves it there; re-ridging can incorporate debris into the ridge and tends to result subsequently in more smoulder.[41] In practice, re-ridging is not widely practiced, especially where 90 cm-ridges are used.

64 Poor re-ridging

Photo: Warwick HRI and predecessors

It is not clear whether there are beneficial effects for pest and disease control of re-ridging: in UK trials its effects on smoulder and neck rot incidence were inconsistent. In some cases even burning crop debris did not control these diseases.[42,43,44]

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13.0 Bulb lifting

13.1 Lifting date

The date (or crop stage) for lifting bulbs

Ideally, bulbs should be lifted when their stage of development is right for lifting and soil and weather conditions are suitable. Traditionally, narcissus bulbs were lifted when around 95% of the leaf surface had died down, usually in July in the UK. This practice maximised yield and ensured the bulbs were 'ripe' (or 'mature', that is had well-developed skins) when lifted. In contemporary bulb growing, however, the timing of the lifting operation is increasingly constrained by shifts to earlier marketing and sales, especially for export markets, so lifting is often stated in terms of 'lifting date' rather than 'crop stage'. Lifting may now be started in June or even in late-May, sometimes simply as a logistical consequence of the very large areas of bulbs grown.

As long as the lifting date is within reasonable bounds, there may be little practical consequence of varying it on subsequent flower and bulb yields. This is shown in Figure 20 for 'Carlton' lifted at Kirton between 15 June and 13 July; although there were minor differences in yield between the various treatments, overall there was no clear effect of earlier or later lifting on yields.[1]

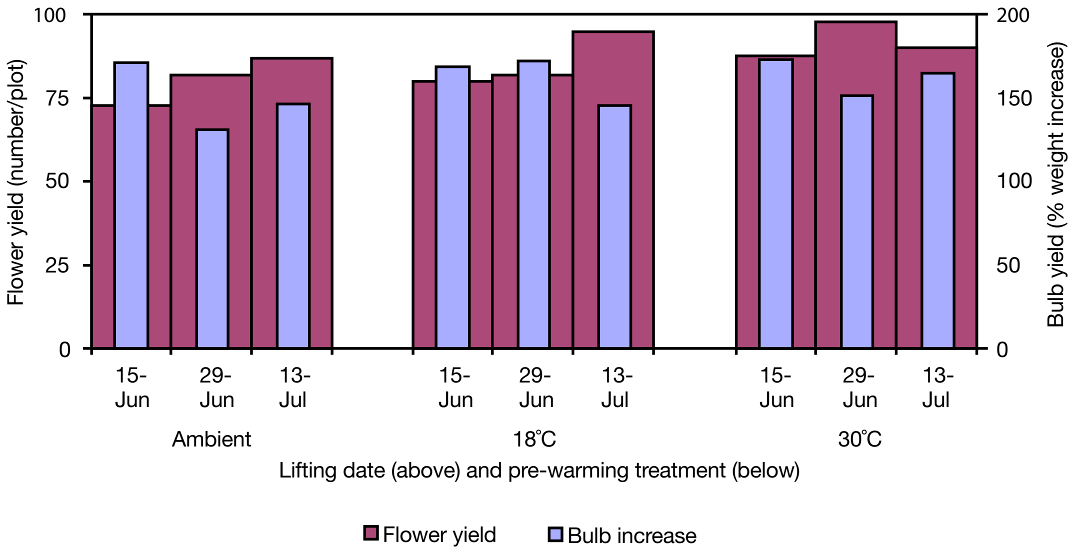
Consequences of 'early' lifting

When bulbs are lifted earlier, bulb yields and subsequent flower yields are inevitably reduced as a result of photosynthesis and assimilation being curtailed. During the growing season, the curve of bulb growth is sigmoidal – slow to begin with, then very rapid, then ending with a slow tailing-off. The rapid, or linear, phase of bulb growth extends from late-April to early-June (in Southern England), so earlier lifting may have a marked detrimental effect on yields. The choice of lifting date is therefore a balance between what is an acceptable loss of yield and its advantage in terms of marketing. Since the routine fungicide spray programme will delay leaf senescence as well as controlling diseases, the spray programme will have to be curtailed, by omitting the post-flowering sprays, if early lifting is planned.

Naturally, there are limits to early lifting: for example, starting to lift bulbs before the foliage has fallen flat and comes away from the top of the ridge with only moderate resistance, is not generally recommended. Several studies have shown that yield loss is severe if bulbs are lifted before the start of June, and very early lifting also leads to a reduced numbers of flowers subsequently.[2,3,4] In a trial at RHS Wisley - more related to the gardener's question of when it is safe to remove untidy narcissus leaves, but still useful to commercial growers - a range of defoliation dates was used with several cultivars.[5] It was found that removing leaves:

- Two weeks after flowering greatly reduced yield.
- Four weeks after flowering significantly affected yields, but was not destructive in all cultivars.
- Six weeks after flowering resulted in yields comparable with those of non-defoliated control plants.

Figure 20 Effect of lifting date on second-year flower and bulb yields for 'Carlton', following HWT on 3 August with or without pre-warming and partial pre-warming



The advantages of early lifting

Despite the above considerations, there are several advantages to earlier lifting.

- It is possible to dry, clean, grade and pack bulbs in time to meet sales deadlines, especially for exports.
- Bulbs are out of the ground before soil temperatures rise. Summer temperatures encourage basal rot at a critical stage for infection - when dying and dead roots are present.[6,7] Infection by the basal rot pathogen occurs between 13 and 29°C,[8] but with an optimum between 20 and 30°C, depending on conditions.[9]
- Early lifting allows earlier HWT, further improving the control of basal rot.
- Early lifting can be useful in pest avoidance:
    - Large narcissus fly larvae hatch and invade bulbs in late-June.
    - The spread of some viruses is proportional to the number of aphids, which increases with warmer weather.[10] In Dutch trials, virus infection increased by up to 72% when harvesting was delayed to 8 weeks later than usual.[11] In trials in Scotland with stocks having 7 or 10% of bulbs infected with narcissus yellow stripe virus, there was little increase in virus incidence over a year, but if the foliage was allowed to senesce slowly, a three-fold increase in incidence occurred.[12]

Early lifting means the bulbs are lifted with green leaves, which is impractical, so the foliage has to be removed before lifting. The critical factors controlling leaf senescence in narcissus are not known, though it appears to be stimulated by high temperatures, even if cooler weather then follows.

Early lifting and defoliation and other cultural treatments for narcissus fly avoidance

Defoliating narcissus prevents the adult fly from laying eggs on the foliage, while lifting before egg-hatch prevents the larvae entering bulbs; both dates can be predicted using the HDC large narcissus fly forecast.[13] In HDC Project BOF 37, early defoliation and lifting were tested as pest avoidance measures in trials at Kirton and on a commercial farm in Cornwall.[14,15] The results of the trial at Kirton are summarised here.

- In their first crop year, bulbs of 'Carlton', 'Dutch Master', 'Golden Harvest' and 'Ice Follies' were defoliated on 23 May or 20 June or were left un-defoliated. These dates corresponded to the predicted dates for egg-laying in an 'early' and a 'late' year.
- Defoliation in the first year resulted in a loss of flower yield in the second year; this was severe when defoliation was early (6 to 33% in different cultivars) and mild when defoliation was later (2 to 8%). 'Ice Follies' was less affected by defoliation date than the other varieties.
- In the second crop year, plots from each of the first-year treatments were lifted on 5 June, 19 June or 2 July, or were defoliated on 5 June but not lifted until 2 July. These dates corresponded to the predicted dates for egg-hatch in an 'early', 'middle' and 'late' year.
- Early lifting led to reduced bulb yields, more rotted bulbs, and fewer flower buds (the next year's flowers), all compounding the effects of early defoliation in the first year (Figure 21).
- Defoliating early but not lifting the bulbs until later, was less detrimental to yields than early lifting.
- All treatments reduced bulb yields when compared with plots that were untreated in the first year and lifted at the late date in the second year. Bulb losses were <20% when untreated in the first year and either lifted at the middle date in the second year, or defoliated early in the second year and lifted later. Other treatment combinations resulted in greater losses.

The data for this project were used to produce models for narcissus yields that could be integrated into a larger narcissus fly and crop model.[16] The model showed that there was scope for implementing cultural control strategies in relation to the timing of large narcissus fly activity and that the yield penalties, particularly due to early lifting, might not be as great as expected. It also showed it was likely that, as part of normal commercial schedules, some crops are lifted before at least some larvae have invaded the bulbs, automatically giving some measure of control.

Many other trials have been carried out in South-West England to find cultural methods to control or reduce large narcissus fly infestation.[17] These include early defoliation and early lifting, and also other treatments. For example, in trials in the Isles of Scilly, the following were investigated at various dates over the May to July period, when the insect is active:

- Defoliation.
- Defoliation, lifting and drying in windrows.
- Defoliation and burning-over.
- Covering with clear polythene for four or eight weeks.

All these treatments reduced the incidence of damaged bulbs to some degree. The most effective treatment, which totally prevented infestation in these trials, was defoliation in early-June followed by lifting and drying in windrows.

Late lifting

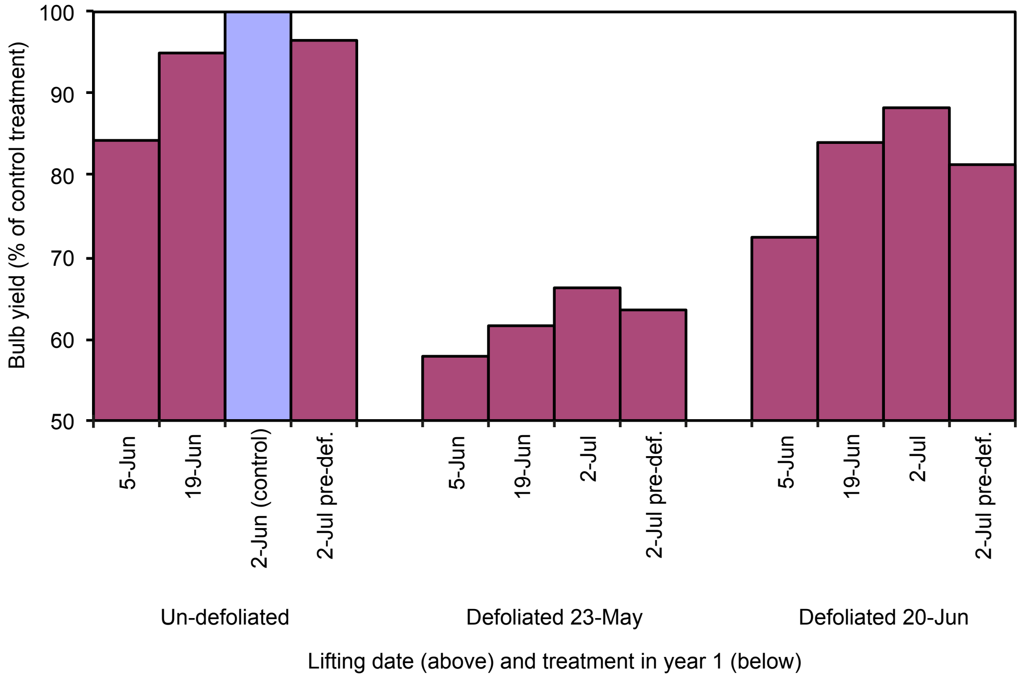
When desired to maximise bulb and subsequent flower yields (for example of a stock being built-up) and other factors are not paramount, there may be advantages of continuing the fungicide spray programme and lifting relatively late.

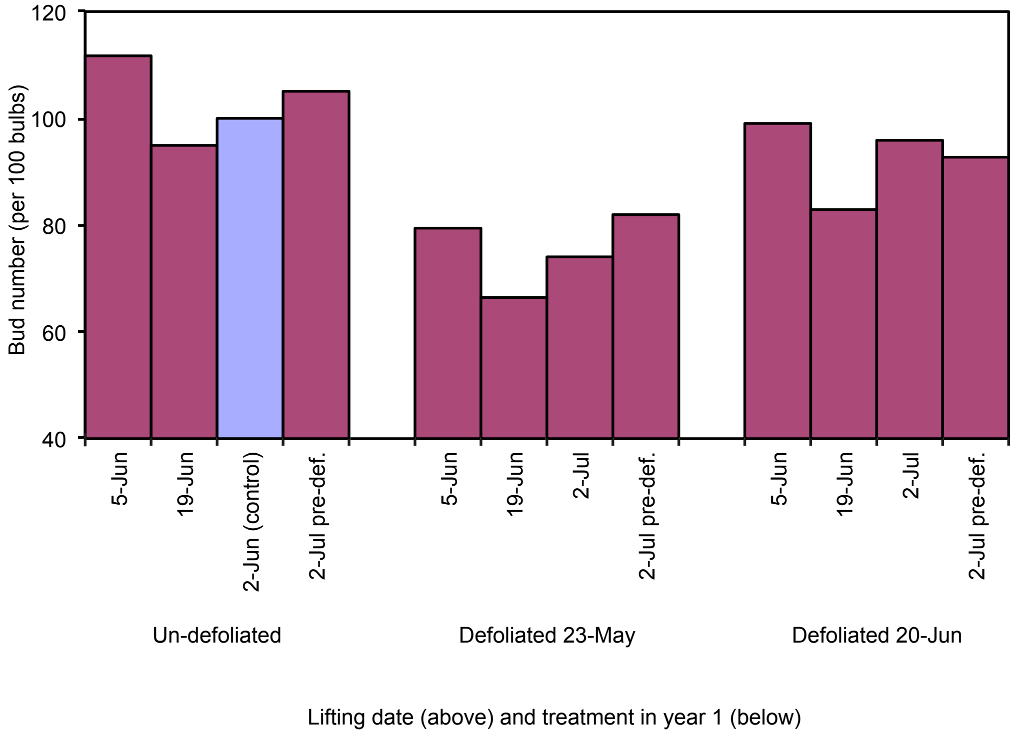
Under some circumstances, relatively late-lifting may be unavoidable, for example if lifting has to be delayed because the soil is wet. In these circumstances there is a danger of bulbs starting to re-root before lifting. It may also mean that HWT is given well after the ideal date.

Lifting stocks infested with stem nematode

Irrespective of the above considerations, it is routinely advised that bulbs should be lifted early if they are known, or even suspected, of being infested with stem nematode.

Figure 21 Effect of defoliation treatment in first crop year and lifting date in second crop year ('pre-def' means lifted before defoliation) on bulb yield (top) and number of flower buds (per 100, 10-12 cm grade bulbs) (bottom); values are averages across four varieties





Lifting infested bulbs should be followed by careful disinfection of all equipment and of all areas used. It may be more cost-effective to destroy badly infested stock, but if the stock is to be kept, it should receive HWT as quickly as practical in order to achieve more effective control.

Such bulbs should not be allowed to dry out between lifting and HWT, since this encourages the formation of nematode wool. Careful arrangements will need to be made for the storage and handling of such early-lifted, infested bulbs, in order to avoid contaminating healthy bulbs that will be lifted later.

Since it is probably impractical to avoid completely any contamination after lifting infested stock, the alternative approach is to restrict access to the area of the infested stock until other stocks have been lifted. Infested stocks are then lifted last, and there is less likelihood of contaminating other stocks (though nematode control will be less good). When there are infested crops on the farm, sensible precautions should be implemented: for example, entry to the stocks should be restricted, and boot dips and wheel washes should be suitably filled and used. Any unavoidable operations should be done at the end of the working day, to reduce the likelihood of subsequently contaminating healthy stocks.

13.2 Foliage removal

When a crop is to be lifted with green leaves, the foliage should be removed first. This avoids clogging machinery, and may reduce the spread of any infected material. Various methods of foliage removal are used – desiccation, mechanical removal or burning - though no comparative information on their relative effectiveness or possible subsequent effects on the plant appears to be available. It is preferable to allow some natural senescence before defoliation, and desiccants also work better after some natural die-down has occurred.

Sulphuric acid

The Pesticide Usage Survey reports for 1997, 2001 and 2005 showed that the only desiccant being recorded on narcissus was sulphuric acid ('77% clean sulphuric acid', a commodity substance), used on about 500 ha of narcissus annually. Until recently, sulphuric acid could be applied only by appropriate contractors working to strict protocols, including public notification of the site of intended application. Its use was revoked from 5 June 2010.

Crop and weed foliage was desiccated quickly by this method. Although a treatment using sulphuric acid might appear intrinsically harmful, no known adverse effects of the practice on the crop were known. Any alternative method of defoliation is likely to be judged by the standard achieved by careful sulphuric acid use.

Desiccation by contact herbicide

Previously, materials such as dimexan and dinoseb were available for desiccating narcissus foliage, though this resulted in neck necrosis in some cases.[18,19] For some years no suitable replacement has been available for this purpose.

In HDC Project BOF 52 the potato desiccant/herbicide carfentrazone-ethyl was evaluated at Kirton as an alternative to sulphuric acid or other desiccants.[20] The results indicated that the product tested was effective in desiccating narcissus foliage and broad-leaved weeds, without apparent damage to the bulbs. Carfentrazone-ethyl is now available (as 'Spotlight Plus', Belchim Crop Protection) for this purpose on narcissus under EAMU 2009/1003. It is recommended that, where early lifting is required and the foliage is still green and dense, two applications of product may be required to achieve complete desiccation. In this case a maximum total of 1.6 L product/ha is allowed, for example 1 L/ha followed seven days later by 0.6 L/ha. For lifting narcissus where the foliage is already wilting and beginning to senesce, a single application (1 L product/ha) should provide complete desiccation. The latest allowable application date is seven days before lifting. Its activity appears to be faster under bright, sunny conditions, which may limit its usefulness in the South-West when the weather is damp or in the cooler weather of Scotland.

Cultural factors and neck rot

The factors leading to neck rot were examined in HDC Project BOF 31b, using survey data. In field trials with 'Carlton' and 'Dutch Master' at Kirton, a range of cultural treatments was combined with flailing or top-bashing (more damaging) and inoculation of the damaged shoots with neck rot pathogens. The main findings were as listed here.

- Highly concentrated inocula of *Fusarium oxysporum* f.sp. *narcissi* were more effective than those of *Botrytis narcissicola* or *Penicillium hirsutum* in leading to subsequent neck rot when applied to damaged, defoliated shoots, though the rates of neck rot found were still relatively low.
- Severe top-bashing and inoculation led to the highest incidence of neck (and other) rots.
- A post-lifting dip in thiabendazole (as 'Storite Clear Liquid') and formalin reduced post-lifting bulb rots by 80 to 90%, compared with non-dipped plots. Pre- and post-lifting fungicide sprays of thiabendazole were much less effective.
- There were more neck (and other) rots in non-cropped than cropped plots. This was unexpected, and it appeared that the damaged stem ends created by cropping were able to 'seal' at a time when natural levels of pathogen inocula were low.
- There were more neck (and other) rots in plots which had received a regular fungicide spray programme than in non-sprayed plots; this was also unexpected, and it was suggested that the fungicide effect of delaying leaf senescence would mean that the formation of abscission layers in the bulb neck would also be delayed, allowing infection for longer.
- This potentially adverse effect of the fungicide programme was investigated in trials at Kirton and at ADAS Arthur Rickwood in HDC Project BOF 41a,[24] but relying on natural rates of infection rather than applying high rates of disease inocula. Six-spray programmes of each of seven fungicides were applied, and after lifting the bulbs were stored at 25°C and 80% relative humidity to speed the development of Fusarium rots for assessment. The incidence of neck rot (and basal rot) was not increased by any of the fungicide spray treatments, suggesting that, in normal conditions, there was unlikely to be an increase in neck rot as a result of a spray programme.
- The adverse effects of severe top-bashing followed by inoculation were mitigated by flower cropping and by not using regular fungicide sprays.
- Applying spore suspensions in April, May and June, or a mycelial suspension (used in June applications only) increased the incidence of bulb rots, especially when combined with applying a regular fungicide spray or not cropping flowers.
- The findings supported the idea that pathogens entering severely damaged shoots lead to neck rot, but only when other factors pre-dispose the bulbs to rots.

Mechanical flailing or top-bashing

Appropriate flailing machines can be used to remove narcissus foliage at a greater or lesser distance above the bulb neck, cutting either above soil level ('flailing') or into the soil of the ridge tops ('top-bashing'), depositing the cut foliage on the ground. Chain harrows can be used to remove foliage from the ridge tops, and this also helps break clods before lifting. When using mechanical foliage removal, it is common to remove foliage shortly in advance of, or immediately in front of, the bulb-lifting machine.

Care should be taken not to cut too far into the neck of the bulb when defoliating mechanically, nor to leave more than a day or so between flailing and lifting. Logically, the presence of damaged shoot tissue contaminated with soil and debris would be expected to predispose the shoots to fungal infection.

- A survey of UK crops in about 1990 showed that both these actions appeared to lead to increased levels of neck rot, and in this study no other husbandry factor showed any clear connection with increased neck rot.[21]
- However, no association between height of top-bashing and the occurrence of the neck rot pathogen was found in a survey a few years later (HDC Project BOF 28).[22]
- The link between severe top-bashing and neck rot was confirmed experimentally in HDC Project BOF 31b, which looked at a wider range of cultural factors affecting neck rot development.[23]

Foliage burners/driers

Trailed propane- and oil-burning foliage driers have been tested as an alternative way of desiccating narcissus foliage, though very low speeds are required to achieve a thorough effect. They may be prohibitively expensive to use for desiccation alone, but are used by Scillonian tazetta growers where there is a dual action as the treatment also advances 'Sols'.

13.3 Bulb lifting

Dedicated bulb lifters may be used, or machines designed for lifting potatoes or onions can be modified for the purpose. The effective separation of bulbs and clods is a key element in any good lifters, and the machinery should be designed or adapted to minimise mechanical damage to the bulbs, since damage is known to favour the spread of basal rot. Specialist machinery is available for lifting bulbs grown in beds on sandy soil.

Bulbs may be harvested in one or two stages.

One-stage lifting

A 'complete harvester' is used to achieve lifting and picking-up in a single operation. One-stage lifters vary in complexity, from small trailed machines to much larger ones. The larger machines may be either manned, to allow picking-off clods by hand, or un-manned, in which case further manual clod removal is required after transport back to the yard. The lifted bulbs are deposited into trailers or bulk bins.

Two-stage lifting

In two-stage lifting bulbs are elevated to the soil surface and then picked up manually or mechanically, usually after allowing several days for the bulbs to dry naturally *in situ*. Such natural drying (called 'windrowing') is the traditional and still usually preferred practice in South-West England. Picking-up bulbs by hand requires a considerable labour force. The bulbs may be collected into baskets, trays or net bags and then accumulated in bulk bins or trailers, depending on the scale of operations.

13.4 Bulb drying in the field (windrowing)

On many farms, and especially in South-West England, two-stage lifting is preferred. Bulbs are elevated to the surface by a lifting machine and left on the soil to dry naturally for several days (windrowing). As in all bulb drying activities, the objective is to surface-dry the bulbs and to desiccate the remaining foliage and adhering soil so that they can subsequently be easily cleaned.

In suitable dry and windy weather windrowing is economical, reducing drying and storage costs, but it has several disadvantages:

- Drying is uncontrolled and weather-dependent.
- If conditions are damp, the bulbs may be attacked by moulds or slugs or may re-root.
- Bulbs are liable to sun scorch and desiccation if too hot.
- Adequate labour is needed for picking-up bulbs.
- Without a modification of the usual procedures, post-lifting sprays cannot be conveniently applied.

In order to substitute for an on-line fungicide spray that might otherwise be given soon after transporting the lifted bulbs to the yard, various approaches have been used to apply a fungicide spray over the bulbs at lifting: for example, the bulbs might be sprayed as they fall from the elevator to the ground. The effectiveness of this application method has not been critically evaluated in comparison with conventional post-lifting spraying or dipping back in the yard. Clearly, however, good coverage would be needed, to compensate for spray lost on soil and clods amongst the bulbs.

13.5 Crop destruction

Growers may decide it is uneconomic to lift and process a poor bulb stock, possibly after leaving the crop down for several years while the gradually diminishing yield of flowers is utilised. Deliberate destruction of narcissus crops is difficult because few herbicides result in a complete kill.

There are few instances of the control of narcissus by herbicides being investigated systematically.

Chemical roguing

Chemical roguing of narcissus was investigated at Kirton in the 1970s.[25] Of the herbicides then tested, only glyphosate is still available, and it was only partly effective (much less so than a paraquat-based product). Glyphosate was tested as 'Roundup' at rates equivalent to 2, 4 and 8 L/ha.

Controlling narcissus volunteers in other crops

Bulb-lifting inevitably leaves a proportion of bulbs in or on the ground. It is important to remove these bulbs if they are not to become foci of pests and disease for other crops or for narcissus the next time they are planted in the field. Some volunteers will also, presumably, arise from the occasional fertile seed dropped by the crop but remaining inconspicuous for the first few years due to their small size. Control of narcissus would be expected through the application of glyphosate, though in practice it is not totally effective. Nor is it sufficient to rely on control by cultivation alone, since to some extent machinery can 'chip' and spread any remaining bulbs.

In HDC Project BOF 47 the control of narcissus volunteers in a winter wheat crop was investigated at ADAS Arthur Rickwood.[26] Narcissus cultivars 'Hollywood', 'Ice Follies' and 'Cheerfulness' were planted at 2 t/ha in winter wheat and herbicides were applied at wheat GS (growth stage) 31 (which corresponded to flowering in 'Cheerfulness' and flower senescence in 'Hollywood' and 'Ice Follies'). The following herbicides were tested:

- Metsulfuron-methyl + thifensulfuron-methyl (as 75 g/ha 'Harmony-M').
- Metsulfuron-methyl (as 30 g/ha 'Lorate').
- Carfentrazone-ethyl + metsulfuron-methyl (as 50 g/ha 'Ally Express').
- Amidosulfuron (as 40 g/ha 'Eagle').
- Fluroxypyr (as 2 L/ha 'Starane 2').
- Clopyralid (as 0.35 L/ha 'Dow Shield').
- Dicamba + MCPA + mecoprop-P (as 5 L/ha 'MSS Mircam Plus).

The results were as follows.

- All herbicides tested resulted in some phytotoxic effects on the narcissus foliage or growth following application, fluroxypyr being most effective and clopyralid having least effect; 'Ice Follies' was the least affected cultivar.
- The three metsulfuron-methyl-based sulfonylurea herbicides, but not amidosulfuron, significantly lowered narcissus emergence rates in the following year (carfentrazone-ethyl + metsulfuron-methyl for 'Cheerfulness' only), and also resulted in narcissus with no flowers or deformed flowers. The other herbicides tested were without such effects.
- There were no significant effects of any of the herbicides on the yield of narcissus bulbs when lifted after two years, or on the number of harvested bulbs with internal damage.
- As expected from the labels, there were no effects of any of the herbicides on winter wheat yield.
- None of the herbicides controlled narcissus effectively, but some reduced subsequent emergence and somewhat damaged normal growth and flower development. The sulfonylurea herbicides metsulfuron-methyl + thifensulfuron-methyl (as 'Harmony-M') or metsulfuron-methyl (as 'Lorate') could be used to give a measure of control of narcissus groundkeepers in winter wheat.

Crop destruction

From the above results the options for crop destruction appear to be using a glyphosate-based product or a sulfonylurea herbicide, but the use of either of these would involve careful consideration of the following crops. Both types of herbicides would be only partly effective, needing to be followed through with appropriate cultivations and possible further herbicide applications.

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14.0 Bulb handling for re-planting or sale

14.1 Post-lifting sorting, cleaning and pesticide application

Post-lifting handling

The lifted bulbs may be handled in bulk bins (of about half or one-tonne capacity) or in loose bulk in trailers. However the bulbs are lifted, it is important that they are progressed promptly to the handling, drying and (if required) fungicide application processes, minimising any interim storage arrangements. Where two-stage lifting with windrowing has been used, it is important not to lose the advantage of the prior drying. Freshly harvested bulbs should not be left in trailers overnight, as they will rapidly heat up, increasing the risk of Fusarium rots and soft rot (*Rhizopus*).

The extent of handling in the yard will depend on the type of lifting machine used and how much on-board mechanical or manual handling there has been. Where lifting has resulted in large amounts of soil, clods, stones or bulb-clumps being brought back to the yard, an array of separating lines will be required. Vibrating and barrel riddles will be needed, along with a significant cleaning/ inspection gang. At the end of the line the bulbs are either transferred to bulk bins and moved to the drying wall, or dumped in loose bulk on the drying floor, if required receiving a fungicide treatment en route. Large quantities of soil and other debris may need to be returned to the field, and any damaged or diseased bulbs should be suitably disposed of. Where more intensive cleaning, splitting and inspection has taken place in the field, correspondingly less extensive arrangements may be needed in the yard.

A fungicide may be applied at this stage, either by cold dipping or on-line spray application. If so, then depending on the destination of the bulbs, and whether all are to be treated with fungicide or only those intended as re-planting stocks, some preliminary grading or separation may also be needed at this stage. Whatever the scheme used, it is important for the bulbs to be moved to the drying facility promptly.

An alternative way of separating bulbs from soil is a fluidised bed separator.[1] This equipment has been seen in the USA but not in the UK.

The Pesticide Usage Surveys – chemicals applied directly to bulbs

The Pesticide Usage Surveys for 2001 and 2005 included chemicals “applied directly to bulbs at lifting”. The figures are summarised in Table 46, with usage expressed as the number of ‘planted-hectares’ of bulbs treated. Disinfectants, fungicides and insecticides are included in the table (materials shown as ‘seed treatments’ are excluded, though the terminology used was not entirely clear). The data showed:

- Disinfectants were recorded in only the 2005 survey, when they were recorded on a small proportion of crops, with treatments about equally divided between formaldehyde and peroxyacetic acid, which are no longer applicable.
- Thiabendazole was used on a significant volume of crop in 2001, but on only a small proportion in 2005; only very small amounts of other fungicides were recorded.
- A small amount of chlorpyrifos use was recorded, but in 2001 only.

Table 46 Amounts of field-grown flower-bulbs in Great Britain treated directly with chemicals at lifting, taken from the Pesticide Usage Surveys

Active ingredient	Planted-ha treated (with total area grown in brackets)	
	2001(5,237ha)	2005 (4,916ha)
Disinfectants		
Formaldehyde	na*	25
Peroxyacetic acid	na*	20
Fungicides		
Benomyl	3	0
Prochloraz	50	0
Thiabendazole	283	20
Insecticides		
Chlorpyrifos	19	0

*zero or data not available.

Fluidised bed separator

In fluidised bed separation non-homogeneous solids to be sorted are suspended in a solid, liquid or gaseous medium and the mix pumped along a trough, behaving as a fluid with the lighter particles moving to the surface. The material to be separated is mixed with, say, sand, and continuously circulated in a vibrating trough, with air fed into the base of the trough to create a buoyant, fluidised sand bed within which the suspended material sinks according to its density. As the material is carried across the fluidised region by the circulating sand, less dense materials remain near the surface and are conveyed out of the sand by an inclined, perforated flight fixed across the width of the trough, while heavier materials sink deeper and are conveyed out of the trough by a further, lower, perforated flight downstream of the fluidised zone. Sand particles pass through the perforated flights and are re-circulated continuously within the trough.

Fluidised bed technology has been applied to separating bulbs, stones and soil in a sand bed. The equipment has been seen in the USA but has not been encountered in the UK.

Development of a post-lifting, cold soak treatment

A post-lifting cold soak in formalin, given within a week of lifting, has been known as an effective measure against basal rot since the 1930s.[2,3,4,5] Later, a fungicide was added, and from the 1970s the toxic mercury fungicides previously used were replaced by a benzimidazole fungicide such as thiabendazole or benomyl.[6,7,8,9,10,11,12,13] Trials showed that:

- A 10 or 30 minute soak was more effective than a momentary (10 second) dip.
- A 30 minute soak was more effective one day after lifting than seven days after lifting.
- Later treatment could be improved by using a longer soak (e.g. for four hours, if delayed to seven days after lifting).

In the UK, thiabendazole (as 'Storite Clear Liquid') and formalin became the standard post-lifting cold soak treatment for cultivars susceptible to basal rot, probably incidentally controlling other moulds such as *Penicillium*. A prompt cold soak is effective presumably because it acts before much post-lifting spread of infection has occurred, and prior to moving the bulbs to a higher temperature for drying and storage. In some trials a post-lifting thiabendazole plus formalin dip was much more effective than a thiabendazole post-lifting spray in reducing the incidence of bulb rots.

Current application of post-lifting cold soaks

The option of using a post-lifting cold soak was severely limited in 2008 by the withdrawal of formalin and the restriction of the use of 'Storite Clear Liquid' to one application per year (accompanied by a 75% reduction in the concentration that could be used in a soak). Bulbs known to be infested with stem nematode should never be cold-dipped, because cold formalin is known to be ineffective in controlling nematodes, so dipping could simply spread them. However, it was considered acceptable for stocks understood to be 'clean' to be treated in this way (though there would be some danger of spread if there were low, non-symptomatic levels of stem nematode).

The use of an iodophor disinfectant (as 'FAM 30') was evaluated as a replacement for formalin in HWT (HDC Projects 61a and 61b). In these trials 'FAM 30' was used at 4 or 8 L of product/1,000 L of water. HDC trials (BOF 61a, b) showed the material was free of phytotoxic effects on daffodils.

Where possible to use a post-lifting cold-soak, the following should be noted:

- 'Prompt' is usually understood to mean as soon as practical after lifting, and certainly within 24 hours.
- The duration of the cold-soak is probably not critical: durations of 15 to 30 minutes are often used.
- The term 'cold' usually means that water is used direct from the supply without heating, though in some US trials the water was used at 25°C (this would not be recommended in the UK because of the implication of such temperatures for basal rot development).
- Following dipping bulbs should be dried quickly.
- Although bulb soaks may be intuitively thought of as more thorough than a superficial bulb spray, using soaks imposes extra costs in subsequently drying bulbs and disposing of spent dips.

Post-lifting fungicide spray treatment

Applied shortly after lifting, a thiabendazole (as 'Storite Clear Liquid') post-lifting, on-line bulb spray has been shown to be as effective as a cold-soak.[14,15] Spray treatments are cheaper to apply than soaks, subsequent bulb drying is quicker, and the incidental spread of other pests and pathogens is less likely.

- The only active ingredient approved for this use in the UK is thiabendazole, as 'Storite Clear Liquid' or 'Tezate 220 SL'; both products have full approvals currently expiring 31 December 2015.
- The fungicide is usually applied via a simple arrangement of nozzles in a simple spray hood, applied at some convenient point along the bulb handling line. It is important to have the nozzles placed so as to give a good coverage of the surface of the bulbs. The use of a roller table has been recommended, to help achieve good coverage, though narcissus bulbs do not turn well on such lines. There may be some arrangement to collect and re-circulate the fungicide solution draining through the roller or conveyor.
- Low-volume ultrasonic and electrostatic (including 'spinning disc') spray applicators have also been tested and were found to be as effective against basal rot as a conventional spray.[16]
- To ensure the correct rate of product is applied per tonne of bulbs, calibration of the sprayer, and rate of passage of bulbs along the line, are important.
- In trials at Kirton around 1990, other thiabendazole formulations then available were found to be less effective as post-lifting sprays against basal rot in HWT.[17]

In HDC Project BOF 31a captan and prochloraz, as well as thiabendazole, were shown to be effective against basal rot and free of significant phytotoxic effects when applied as post-lifting sprays.[18] Although captan and prochloraz are not approved for this purpose, the finding indicates that other fungicides may be worth trialling with a view to application for a EAMU. In the same project, imazalil was found to be ineffective when applied as a spray, while fludioxonil, guazatine and quintozene fungicides were ineffective against basal and neck rot pathogens.

Post-lifting insecticide treatment

Other than a fungicide, it is not usual in the UK to apply other pesticides to narcissus at this stage. In trials in Poland, however, it was demonstrated that a one-hour insecticide soak, immediately after lifting, was effective against large narcissus fly larvae.[19,20] The insecticides used (isofenphos and carbofuran) are not approved in the UK, but the method might conceivably be investigated in the future should the need arise and suitable insecticides be available.

14.2 Bulb drying

The options for bulb drying

Rapid and efficient bulb drying is essential for achieving good bulb quality and controlling basal rot, since the pathogen does not spread effectively under dry conditions.[21,22] There are several considerations in choosing the method of bulb drying.

- The scale of the operation – most growers will handle bulbs in bulk, but small or specialised enterprises may still handle bulb in small units such as trays and may rely more on 'natural' drying and ventilation rather than on having specialised facilities.
- Bulbs may be handled in various forms of bulk bins or crates dried and ventilated on a 'letter-box' drying wall system, or they may be treated in loose bulk with on-floor drying. Sometimes it is convenient to use on-floor drying in the initial stages and move to bulk bins on a drying wall later.
- Bulb drying may utilise ambient air or air at controlled temperatures.
- The first stage of bulb drying may use 'high temperature drying', ambient air or air at a controlled temperature.

De-humidification has been tested in bulb drying from time to time, without any clear recommendations for its use being evident.

First and second stage bulb drying

Bulb drying can be divided into first and second stages.[23] A computer simulation of drying times, based on air flows, temperature and bed depth, has been developed and is in reasonable agreement with experience in practice.[24]

First stage drying

The first stage consists of the removal of surface water and is essential for the control of surface moulds and other fungi. The rate of loss of surface water depends on the rate of air movement and its temperature, and high rates of air movement are necessary.

Second stage drying

Second stage drying extends to the removal of internal water and ensures bulbs are thoroughly dry. High rates of air movement are not needed.

Drying temperatures and basal rot

UK advice on bulb drying temperatures hinges largely on the temperature response of the basal rot fungus, the subject of a number of studies. Recommendations centre on drying and storing bulbs outside the optimum temperature range of the basal rot fungus, for example:

- Experiments in the UK showed that the incidence of rotting bulbs, and the numbers of propagules of the basal rot pathogen isolated from the base plate of healthy bulbs, increased with increasing storage temperatures from 15 to 24°C, then declined somewhat to 30°C.[25,26]
- In some earlier studies of basal rot it had been shown that bulbs should be stored below 25°C,[21,27] and later work in China confirmed the incidence of basal rot was greater with temperatures over 19°C.[28]

The choice of drying temperature is complicated by data that distinguishes the temperature response of the basal rot fungus cultured on solid media or in liquid media:

- On solid media the pathogen grew rapidly at temperatures of 20 or 25°C, but growth was slower outside this range and had ceased at 40°C, confirming earlier findings in the USA that the optimum temperature for growth was 24°C and that there was little growth at 35°C.[29]
- In liquid media, however, it was found that growth of the pathogen was rapid over the whole range 15-35°C, and had not ceased entirely even at 45°C.

It has been argued that in a freshly-lifted bulb, conditions might be more like those of liquid culture, so warmer air would, initially, favour pathogen growth: the rate of moisture removal from the tissues would be more important than the drying temperature itself.[30] Following first stage drying, conditions in the bulb might be more like those in culture on a solid medium, indicating that, by this stage, temperatures less than 20°C or over 30°C would be suitable. The safety of drying narcissus bulbs at 35°C has therefore been questioned on the basis of culture experiments with the basal rot pathogen on solid and liquid media.

Drying temperature options

Standard UK advice states that drying may be carried out at 18°C (but no higher), with the option of a short initial period ('first stage drying') at 35°C.[31] In practice there are three options:

Ambient temperature drying

This is often used, but the results will be dependent on actual temperatures. The temperature should be kept below 20°C, though on warm summer days in the UK, ambient temperatures will sometimes be higher.

Controlled temperature drying at 18°C

This is the preferred option where facilities for high temperature drying are not available.

High temperature (35°C) drying

35°C-drying was developed in the UK and is used for first stage drying only, being followed by ambient or 18°C drying for the second stage. As well as the convenience of rapid surface drying in two to three days, 35°C drying produces cleaner bulbs, since the outer skins and soil contamination are more easily removed. There is no increase in basal rot due to the period actually at 35°C.[32] However, it is likely that bulbs will spend a significant amount of time at temperatures between 20 and 30°C whilst warming and cooling at the start and end of the treatment. Therefore the protocols and equipment used should be capable of rapid heating and cooling in order to minimise these lag periods.

A number of Dutch recommendations state that a lift of 2 to 3°C above ambient temperatures should be used for drying narcissus.[33] This is contrary to the consensus of UK advice based on knowledge of the basal rot pathogen.[34]

Air-flows and other considerations in first and second stage drying

As stated above, a high rate of air movement is necessary in first-stage drying. For high temperature drying, flows of 425 m^3/hour/tonne are needed for bulbs in loose bulk, and, allowing for leakage, 770 m^3/hour/tonne for bulbs in bulk bins. For drying at ambient temperatures, higher rates are needed. With lower air-flows, bulbs at the base of the stack dry substantially faster than those at the top, subsequently leading to variations in bulb performance. Relative humidity should not exceed 75%, and during the first stage there should be no re-circulation of air.

In second-stage drying high rates of air movement are not needed: 170 m^3/hour/tonne is sufficient for loose bulbs and 300 m^3/hour/tonne for bulbs in bins. The humidity can be 80-85%, and during the second stage there should be minimal re-circulation of air.

Some Dutch systems for drying in bins use much higher air flows, say 1,000 or 500 m^3/hour/tonne for first and second stage drying, respectively. These higher rates are suitable for Dutch designs of drying walls and the types of bins used, but it is thought they could not be transferred to UK systems.[35]

Bulbs may lose 20-25% of their lifted weight during drying, cleaning, etc., so it is important that drying does not continue to the point of excessive weight loss or desiccation. Desiccation can easily happen with small-bulbed types.

During the drying/storage period, bulbs are extracted in batches for cleaning, inspection, grading, re-packaging, etc. Suitable conditions should be provided, and the bulbs should be returned to appropriate storage conditions promptly.

Drying in bulk bins on a drying wall

Bulbs in bulk bins require a special drying facility, the 'letter-box' drying wall. Ideally, the drying wall should have the capacity to match the size and needs of the bulb operation. The wall is a vertical enclosed space, usually constructed of timber (except near the heater) and forming a system of ducting that brings forced air from a heater and blows it evenly to letter-box shaped outlets on the outer face of the wall. The letter-boxes correspond with the openings of the pallet bases of the bulk bins, so the drying air is directed into the bins, and individual letter-boxes (slots) can be shut-off when not in use (Images 65 and 66). The slots are arranged in a number of vertical and horizontal rows, on one or both sides of the wall, against which the bulk bins will be stacked. The specification of the heater, fans and any air-directing baffles, and design of the ducting and outlets, require appropriate expertise to achieve the desired, even temperature and air distribution. Naturally, the design of the drying wall must conform to the parameters of the particular bins being used.

The bulk bins usually have a capacity of about half or one tonne of bulbs. They usually have solid sides and a slatted pallet base, and the fork-lift slots of the pallet base form the air duct for drying and ventilating the bulbs. The sides of the bins often have a small gap at the top (the height of the side panel is slightly shorter than the corner posts); alternatively, there may be no gap but a series of holes drilled across near the top of the side panel.

65 Front view showing 'letter boxes' (slots) in a drying wall

Photo: Warwick HRI and predecessors

66 Rows of bulb bins extending from drying wall (on left); note foam 'closers' on outside edge

Photo: Warwick HRI and predecessors

The bins are placed against the letter-boxes of the drying wall in vertical stacks corresponding to the number of horizontal rows of slots in the wall, building up a line of bins stretching out from the wall, the length of which is appropriate to the capacity of the heater and fans. The pallet bases at the outer ends of the bin rows are closed with a temporary 'closer', usually a thick section of foam rubber. Thus the air flow from a letter box is forced into its line of pallet bases and upwards through the bins, some exiting through the narrow gaps or holes at the top of the bin sides, and the remainder through the top of the stack. Critical to achieving the target air flows through the bulbs are the dimensions of the side gaps (or holes), the integrity of the bins, the accuracy of bin stacking, the effectiveness of the closers, and the length of the stack of bins out from the wall. The top bins in each stack may be covered with a sheet of plywood to direct more air out through the side gaps.

Clearly, there can be many variations on these exact arrangements. In one, the letter-boxes and closers are arranged so that the air flow from the wall enters alternate pallet bases and is forced both upwards through the bulbs and downwards (through the bin below), some exiting through the alternate, outwards pallet bases, and the remainder at the top of the stack.

In practice, the bulbs in the bins nearest the wall, and especially on the wall-side of those bins, can be difficult to dry. It is thought that the speed and direction of the air-flow entering the pallet bases of the first bins can cause a venturi effect, causing damp air to be sucked into the bins and re-circulated. Growers may deal with this by exchanging the position of bins next to the wall with those furthest away. Proposed solutions include leaving a 10 to

20 cm gap between the wall and the first stack of bins, or placing an empty box next to the wall as a 'spacer'.[36]

Air flows through the bulbs will be seriously reduced by the presence of many small bulbs, soil and loose bulb skins in the bins, so only properly graded and cleaned bulbs can be expected to dry efficiently this way. Since bulbs of different sizes will present different resistance to the flow of air, thereby drying at different rates, ideally bins containing bulbs of different grades should be placed on separate lines of the drying wall, though in practice this is seldom done.

Air flows through bins on a drying wall have been studied in the Netherlands using computational fluid dynamics software.[37] Taking the average flow through the bins as 100%, it was shown that flows through individual bins varied between 60 and 180%. Methods of improving air flows were investigated: the simplest and most effective was by covering the open top bins, which reduced the variation to between 80 and 120%. Air flows are often set deliberately high to avoid risks. By adjusting the overall ventilation to the minimal acceptable rate, equivalent to 60% in this example, an energy saving of about 30% was obtained.

The bulbs will become surface-dry starting at the bottoms of bins and the bins nearest to the wall. Heated air exiting from the tops of the stacks of bins should be cold, until surface moisture has been removed from the bulbs in the stack. Over time, bulbs in different positions will therefore experience different conditions during the process: it is generally assumed that these graduations are not of practical significance.

Drying in loose bulk, on-floor

Loose bulbs can be elevated on the floor of a bulk store fitted with air ducts, for drying like grain or onions, a system arguably more uniform and efficient (but less convenient to handle) than drying in bins on a wall. The depth of the bulb stack should be regulated. Provided that ducting and fan specifications are correct, a 2.4 m-deep layer of bulbs will surface-dry in 53 hours at 30°C and 45 hours at 35°C. Many of the considerations applying in bin-drying to drying rates and bulb temperatures will apply, in different forms, to bulbs being dried in loose bulk.

Other drying systems

On smaller farms, bulbs may be handled in small containers such as bulb trays, and some not-so-small growers may prefer this system because of the ample air spaces around the thin layers of bulbs. If so, the trays may simply be stacked in a well ventilated or open shed, or even outdoors, allowing sufficient air spaces between stacks of containers. Alternatively, to avoid problems due to unsuitable weather and to hasten drying, the trays may be dried under ceiling fans in a shed or controlled-temperature store. Small numbers of bulk bins can be dried using various arrangements of portable fans blowing into the pallet base or using 'fan tops' fitted with fans blowing downwards, or by placing bins over flow ducts in a bulk drier. In either case an arrangement of 'closers' or polythene film stapled around the bins is needed to direct the air-flow through the bulbs.

14.3 Bulb storage

Temperature and ventilation

Once dry, bulbs are often stored at ambient temperatures in sheds, or even outside, but it is preferable to store them in a controlled temperature of 17 to 18°C. Lower temperatures can slow development and render the bulbs susceptible to HWT damage, while higher temperatures, above 20°C, favour the development of basal rot. The ambient summer temperature of the area needs to be considered in deciding whether controlled-temperature storage is likely to be cost effective.

Bulb storage carries on from second stage drying, and free movement of air around the bulbs is still essential. Storage, once the bulbs are dry, is sometimes called conditioning. Stagnant, moist air around the bulbs will encourage mould growth and re-rooting. Where bulbs are held in bulk bins, continued use of fans will be needed. The fans are often turned on for 12 hours in 24, often avoiding daytime when warm, moist air would be brought in, causing the bulbs to 'sweat'. Air-flow rates should be at least half of the second stage rate. When bulbs are in trays or have already been transferred to net bags, passive ventilation may be sufficient, but if in doubt air circulation should be enhanced using fans.

If bulbs are kept at high humidity above 30°C, soft rot due to *Rhizopus* can develop and reduce the bulbs to a musty mass. This can also occur in the transportation of bulbs or in propagation (during the incubation of 'chips')

In trials with highly infested stocks, even when no fungicide has been applied post-lifting or in HWT, the consistent use of optimal bulb drying, storage and HWT regimes reduced the level of basal rot markedly.[38,39] Some dwarf cultivars, such as 'Tête-à-Tête', are susceptible to fungal pathogens such as *Penicillium*, and special care is needed with drying, storage and fungicide treatments.[40] Higher ventilation and circulation rates are needed throughout storage for these cultivars.

Pollution

Ethylene

Little information is available on the harmful effects of ethylene on narcissus, a factor that has to be considered in many other flower crops. It was reported in the 1930s that ethylene concentrations as low as 1.5 ppm (or 0.75 ppm for 'Paper White' cultivars) retarded leaf and stem elongation, while 3 ppm or more caused a variety of leaf and bud distortions.[41] Although there do not appear to be modern data about the effects of ethylene on narcissus bulbs, it would be sensible to avoid exposure to sources of ethylene, such as flowers or fruit, during storage.

Sprout suppressants

There was formerly concern that narcissus bulbs might be affected by storage in the same facilities as used for potatoes, because of the use of sprout suppressants (tecnazene and CIPC). In HDC Project BOF 37, trials showed that a relatively mild exposure of bulbs to these chemicals had some minor effects on growth and yield when subsequently forced or grown-on in the field.[42]

Although these materials are no longer available, this serves as a warning that bulbs should not be allowed to come into contact with pesticides used on the farm for other crops, in case there are similar effects.

Hydrogen fluoride

Hydrogen fluoride can cause leaf scorch in narcissus when it occurs as an air pollutant.[43]

Propylene oxide

The sorption of propylene oxide by various commodities has been studied in Turkey.[44] Narcissus bulbs took up less propylene oxide than the other products studied (wheat, corn and cocoa beans), and all commodities desorbed it rapidly once removed from the source.

Low quality irrigation water

In trials in Texas, USA, the tolerance of cut-flower crops and bedding plants to low-quality irrigation water – direct nursery runoff, wetland-treated direct nursery runoff and municipal tap water spiked with elevated salt levels - was examined for landscaping purposes.[45] The flower quality of *N. tazetta* 'Galilee' was only slightly reduced by all three low-quality water supplies (including water high in soluble salts in the heat of summer), in comparison with non-amended tap water, and yield was unaffected.

Salt

From time to time anecdotal reports of damage to narcissus growing near the coast have been attributed to the effects of blown sea spray or salt accumulation, but no research appears to have been carried out on the subject.

14.4 Bulb washing

In the UK narcissus bulbs are not usually washed to remove soil, though under wet conditions it may be difficult to produce the clean bulbs preferred for sale, and especially the virtually soil-free bulbs needed for some export markets. The disadvantages of bulb washing include the considerable likelihood of spreading of pests and pathogens, the increased cost associated with re-drying bulbs, and the disposal of washings. While some UK growers do use bulb washers when necessary, there are strong concerns about the spread of basal rot during the process.

Bulb washing, drying regimes and subsequent bulb quality were investigated at Kirton in HDC Project BOF 16.[46] The objective was to investigate bulb washing following normal drying and cleaning, as it was deemed sensible to wash bulbs only if this were still necessary after the normal processes of drying and cleaning. The results highlighted the value of 35°C drying and of using the grading line in producing clean bulbs. Washing, even using simple equipment, was effective in producing soil-free bulbs, but the incidence of basal rot was invariably increased. Adding formalin to the washer, or dipping in formalin after washing, did not control this increased incidence of basal rot.

The need for bulb washing should be considered on a case by case basis, depending on lifting conditions, soil type, bulb shape, the incidence of basal rot, the susceptibility of the cultivar to basal rot, and the destination of the bulbs. However, bulb washing should not be considered until a disinfectant more effective than formalin becomes available to bulb growers.

Bulb washing for producing soil-free bulbs

Bulb washing and other regimes for producing soil-free bulbs were tested in HDC Project BOF 16. The effects of bulb washing were tested following normal drying and cleaning, as it was deemed sensible to wash bulbs only if this were still necessary after the normal processes of drying and cleaning.

Following lifting, bulbs of several cultivars ('Carlton', 'Golden Harvest', 'Barrett Browning', 'Magnet' and 'Dutch Master') were:

- Treated with 'Storite Clear Liquid' as an on-line spray or in a cold soak with formalin.
- Dried (at ambient temperatures or for three days at 35°C and then ambient temperatures).
- Cleaned and graded.
- And then either:
  - Left un-washed as controls.
  - Washed in plain water, dipped in formalin solution and re-dried (at ambient temperatures or at 35°C for two days and then ambient temperatures).

Bulbs were assessed seven days later, and again following storage for six months at ambient temperatures.

The main findings were:

- Either 35°C drying or washing produced bulbs with virtual or substantial freedom from soil, and the combined treatment resulted in complete soil freedom.
- For bulbs of long-necked cultivars and bulbs harvested from a clay (as opposed to silt) soil, a further passage along the cleaning/inspection/grading line was also needed to achieve equivalent results.
- Non-washed bulbs dried at ambient temperatures were not soil-free at assessment.
- Clay-grown bulbs dried at 35°C were not soil-free at assessment.
- Post-lifting dipping, washing and drying at ambient temperatures all increased the incidence of basal rot in stored bulbs, compared with post-lifting spraying, not washing, and drying at 35°C.

The result that washing with formalin did not prevent subsequent bulb rots confirmed earlier results obtained at Kirton using 'Golden Harvest'.[47]

14.5 Bulb cleaning, inspection and grading

Once dry, bulbs are withdrawn from storage and passed along a conveyer system that will include:

- The removal of loose skins and soil by vibrating riddles, brushes and dust extractors.
- Bulb splitting and removal of damaged and diseased bulbs by hand.
- Grading over a series of riddles.
- Collection and, if required counting, weighing and packing, of different grades of bulbs.

It is advantageous to organise bulb operations so that re-planting stocks move quickly through to HWT and planting, bulbs for sales being separated and despatched promptly.

Mechanical damage

Mechanical damage, which could lead to bruising, infection or poor appearance, should be minimised at all stages in this process, by reducing drops and cushioning surfaces. Dutch trials with drops of 25 cm showed that narcissus bulbs are susceptible to damage in the first 10 days after lifting and also later, in autumn, and damage was increased by subsequently storing bulbs at ambient temperatures rather than at 17°C.[48] Mechanical damage to the base plate was shown many years ago to lead to infection by the basal rot fungus.[49,50] However, later studies at Kirton failed to show a correlation between simulated mechanical damage and the later development of bulb rot.[51]

Inspection

Ideally, diseased and damaged bulbs should be removed at all stages of bulb handling, although this is labour-intensive and needs skilled, committed workers, and may be impractical when handling bulbs in bulk. Bulb inspection should involve 'feel' as well as sight, enabling soft, base-rotted bulbs to be detected. In practice, it is very likely that large numbers of bulbs affected by basal rot are sometimes replanted with the healthy bulbs, perpetuating stock problems. Diseased bulbs would include those with obvious rots, damaged base plates, and dried, rotted bulbs (mummified bulbs and 'puffers'). At present there are no automated methods of detecting and removing diseased narcissus bulbs, though several methods have been suggested.

Grading and packing

When grading narcissus bulbs it is usual to bump bulbs along a series of riddles of progressively larger size. Because narcissus bulbs are asymmetrical or flattened on one side, round riddles (as used with tulip bulbs, for example) are considered unsuitable, and long-slot riddles are used instead. Although other grades may be used, in the UK narcissus are usually graded in 2 cm-wide bands, bulbs of 10-12, 12-14 and 14-16 cm grades being primarily for sale, and smaller and larger grades being used as re-planting stock. Some cultivars have relatively small bulbs and smaller grades are used. Machines for counting and weighing bulbs are available. Graded narcissus bulbs for sale are often collected in 25 kg lots in plastic mesh bags, which are then stacked on pallets. Some suppliers improve the air flow around the bulbs by using 'chimneys' in the centre of their pallets. Pallets may be wrapped using net wrap, but cling film should not be used as it severely restricts air movement. After grading, bulb storage should continue under the same conditions as before, at 17-18°C with adequate air movement.

Automated methods for detecting rotted bulbs

'Floater-sinker' methods were tested at Rosewarne.[53,54] Lighter, infected bulbs generally tended to float, but this was not entirely reliable as proportion of apparently healthy bulbs also floated. If used, such a procedure could, in any case, spread disease, so a disinfectant would be needed and HWT should follow promptly.

There is scope for testing more sophisticated methods of detection, such as nuclear magnetic resonance, where the appropriate technology is already in place in the food processing industry for the internal inspection of products.

Plant health inspection and plant passports

Where bulbs are being sold for growing-on they will require a dry bulb inspection (DBI) by PHSI as part of the plant passport or other export procedure. The DBI is a follow-up to the earlier growing season Inspection (GSI), ensuring there is freedom from soil and that other conditions are satisfied for the issuing of the appropriate certification. Further information on plant health issues and imports and exports may be found at Fera's plant health website.[52]

Where the inspections are not satisfactory, PHSI may give instructions on any limitations imposed. Without a plant passport, bulb sales may still be permitted, but for retail sale or landscape use only, in which case the bulbs must be labelled as such.

The plant passport should include the following information:

- The phrase 'EC Quality'.
- 'UK', to show they were grown in, or imported into, the UK.
- 'EW', a code for the PHSI in England and Wales.
- The grower's unique Defra registration number.
- An individual serial, week or batch number or invoice number.
- The botanical name.
- The variety name.
- The quantity in the consignment.
- The country of production of the consignment, if they have been imported from a third country.

In addition to the plant passport requirements, narcissus are included in those genera which host 'quality' pests and diseases and must therefore be accompanied by a supplier document confirming goods are being traded substantially free of quality-affecting organisms. In the majority of cases this document will be the same as the plant passport, and separate arrangements will only need to be made if plant passports are not already being issued.

14.6 Preparation for transport, transport and after-care

Fumigation

Although it is not known to be practiced with exports of UK bulbs, commodities (including narcissus bulbs) for export from other countries may be fumigated to ensure freedom from pests. Before being withdrawn, methyl bromide was used for this purpose, and was known to be effective against bulb-scale mite[55,56,57] and small and large narcissus flies.[58,59] No suitable alternative materials appear to be available in the UK now.[60]

Alternative methodologies, including modified atmosphere and 'vacuum-hermetic fumigation' methods, have been developed in Israel for use on exported tazetta bulbs.[61,62,63,64,65]

Transport

The exact protocols used will vary with the destination and the supplier, and the following may give some guidance:

- For deliveries in the UK, ambient temperature transport in curtain-sided lorries.
- For Europe, transport at 17°C in temperature-controlled refrigerated trailers with vents open to give some air exchange.
- For the USA, transport in Reefer container box-sets at 17°C with vents open and multiple air changes per hour.

The use of lower temperatures may result in condensation if the container is unloaded at higher temperatures. Humidity control is not considered necessary, even for the longer journeys, because of the high air exchange rates pertaining. A temperature logger may be enclosed for export to the USA. Whatever the destination, the quickest practicable transits are planned. These procedures prevent the losses due to 'heating in transit' observed in earlier years. On receipt, bulbs should be stored in well-ventilated, ethylene-free stores at 13 to 17°C.[66]

Hypobaric (reduced pressure) storage has been investigated in the USA as an aid to shipping.[67] Bulbs were stored for two weeks at 76 mm mercury and 17°C prior to cooling. Low-pressure storage retarded bud growth, though eventual flowering was not affected, compared with control bulbs stored under ambient conditions.

Bulb storage conditions at point of sale

While this is not a part of the normal bulb-handling carried out by the producer, it is desirable, wherever possible, to help promote good practice in the storage and display of bulbs at the retailers. The following notes are based on one of the HDC Pest and Disease Identification Cards:[68]

- The state and quality of bulbs should be checked at receipt and at intervals. 'Golden Harvest' and 'Carlton' are good cultivars to use to monitor quality and storage conditions. While an attractive skin finish can be important to customers' reactions, remember that not all cultivars have the same external appearance, skin colour or shape. It is also the inside of the bulb that is important for its growth and performance.
- Narcissus bulbs are prone to a number of pest and disease problems that can be exacerbated by unsuitable conditions while on display at retailers, potentially leading to dissatisfied customers. The retailer should be aware of the symptoms of:
  - Basal and neck rots – dark, rotting areas internally, spreading from the base or top of the bulb.
  - Large narcissus fly larvae - brown granular areas internally above the base plate.
  - Bulb-scale mite and stem nematode - brown rings or spots in the scales.
- Checks may necessitate cutting a few bulbs lengthwise and across and looking for the above symptoms. The presence of small flies (the small narcissus fly) indicates the presence of damaged bulbs, which will need to be removed. Small narcissus flies attack only bulbs that are already damaged.
- Basal rot and other rots are made worse by keeping bulbs above 20°C or in humid or poorly ventilated conditions. Many areas where bulbs are displayed are glasshouse type structures that provide the ideal conditions for basal rot development. Now that bulbs are in the retail stores as early as August, bulbs may be in unsuitable conditions for many weeks before purchase.
- The ideal storage and display conditions are below 20°C and shaded from hot sun. There should be good air circulation round the bulbs to prevent 'sweating' or hot-spots.
- Do not display bulbs in bulk containers, but in small slatted trays or boxes with the layers only a few bulbs thick. If necessary, store the main stock away from unsuitable point of sale conditions, replenishing displays as needed.
- Customers should be reminded to plant their bulbs soon after purchase, or, if not, to store them in cool, well ventilated conditions.

Controlled atmosphere and vacuum treatment for narcissus fly in exported bulbs

'Vacuum-hermetic fumigation' modified atmosphere treatment

This treatment was carried out in a plastic, two-part enclosure accommodating 10 x ca. 0.9 t shipping pallets of bulbs, including samples of bulbs infested with large narcissus fly larvae. Pallets were loaded into the lower part of the enclosure, and the upper part of the enclosure put in place and the two parts zip-sealed to make an air-tight structure. The enclosure was constructed of polythene film over a light supporting framework, and was equipped with a heater, circulation fan and vacuum connections.

At the start of treatment, a low vacuum (200 Pa) was applied to minimise free space within the module. A minimum temperature of 30°C was maintained in the module and the internal temperatures varied from 30 to 32°C. The hermetic seal of the module and the respiration of the bulbs rapidly resulted in a depletion of oxygen (O_2) and an accumulation of carbon dioxide (CO_2) within the module, reaching 0.1% O_2 and 25% CO_2 in 48 hours. Previous small-scale laboratory tests had established that a treatment time of 34 hours was required to achieve a 99% kill (the 'LD_{99}') of larvae under these conditions, so the large-scale treatment was continued for 48 hours. There were no surviving larvae at the end of treatment. Laboratory tests also established that, in a MA of 90% CO_2 an LD_{99} was achieved in 24 hours.

'Vacuum-hermetic fumigation' vacuum treatment

Vacuum treatments were carried out in a standard plastic commodity storage/transport module, half the size of a standard 20 foot (ca. 6 m) container, and with a vertical zip seal at one end. Bulbs and samples with larvae were loaded into the module in ca. 0.4 t containers. Previous laboratory tests had established that a treatment time of 24 hours was required to achieve a LD_{99} of larvae. A vacuum of 50 mm mercury was applied and maintained for 24 or 48 hour. The temperature in the module varied between 22 and 36°C. After a 48 h treatment there were no surviving larvae and the slightly deformed containers returned to their pre-stressed shape.

In tests, samples of bulbs from each treatment were grown on for observations. In contrast with standard methyl bromide fumigation, no phytotoxicity (compared with untreated controls) was observed as a result of the vacuum and modified atmosphere treatments described, although when a modified atmosphere of 90% CO_2 was applied there was slight phytotoxicity, smaller florets and shorter stems being produced.

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15.0 Bulb forcing

15.1 Bulb forcing concepts

The information in this section has been largely derived from standard advisory textbooks published for the UK,[1,2,3] the Netherlands[4,5,6] and the USA,[7] augmented with commercial publications[8] and information from the scientific and technical literature.

Before the development of bulb forcing allowing the production of truly early flowers, some earliness was achieved using bulbs lifted early or grown for a season in a warmer climate.[9] Unlike other spring-flowering bulbs – such as tulip, hyacinth or iris – in narcissus floral initiation occurs in May, so the earliest stages of flower growth take place relatively early in the year, with flower formation said to be 'complete' (i.e. all the parts of the flower, though still small, have been initiated) before mid-August. In narcissus, therefore, temperature treatments given after lifting are relatively ineffective for producing early flowers.[10,11] Except for tazetta cultivars, under natural conditions the cold of winter is necessary if rapid shoot growth and flowering is to take place once temperatures have risen sufficiently to permit it. In bulb forcing, an optimum cold period is provided artificially and the bulbs are then moved to a glasshouse for flowering, which follows rapidly and synchronously, so minimising the time spent in the glasshouse. Appropriate scheduling is used so that several 'rounds' of forcing can be managed each winter-spring period. Flower yields are dependant on the cultivar and size of bulbs forced, but are typically 18,000 to 30,000 flowers per tonne of bulbs, equivalent to producing about 20,000 flowers per 100 m^2 of glasshouse.

Forcing techniques were developed in the Netherlands in the 1930s[12,13,14,15] and were quickly followed up and adapted for use elsewhere. A bulb forcing programme consists of several elements:

- Early bulb lifting – allowing forcing programmes to begin earlier.
- Intermediate temperature storage – holding the bulb until it reaches a developmental stage where it can respond to subsequent warm and cool treatments.
- Warm storage – speeding the bulb's response to cool treatment.
- Cool storage – providing the winter cold that spring-flowering bulbs need before they can grow-on quickly to flowering, the different cultivars varying in the length of cold storage required.
- Low-temperature holding period – if necessary, holding bulbs until their glasshouse slot is available.
- Flower production in the glasshouse.

These methods enable pre-Christmas cropping to be achieved with many cultivars, previously impossible for most before late-January. However, producing progressively earlier flowers may bring with it some loss of quality (such as small, starry flowers), uneven growth, and a relatively longer time in the glasshouse (meaning increased heating and cropping costs). Therefore a 'trade-off' has to be considered between producing early forced flowers (with potentially greater returns) and the extra costs and loss of quality incurred. Because of the (then) demand for early flowers, extensive research was carried out to develop schedules for early and extra-early flowering. In contemporary bulb growing, however, there appears to be only a limited market for pre-Christmas narcissus, with most forced narcissus production concentrated into January, aiming to supply the market before outdoor narcissus are available in quantity.

15.2 Cultivars for forcing

Many cultivars are suitable for forcing, and these can be grouped into flowering periods, such as early, mid or late forcing varieties, so a succession of flowers can be obtained over a long season. The suitability of cultivars for forced flower production in different periods depends on the length of cold storage required by different cultivars and other inherent qualities that make them suitable or unsuitable for forcing at different dates. In contemporary narcissus growing there is less demand for early or late forced flowers.

Table 47, extracted from Dutch information, shows the suitability of 32 cultivars for forcing over early to late periods.[16] For each combination the length of cold storage required is shown, and the resultant time from placing the bulbs in the glasshouse to the end of cropping (the glasshouse period). The length of cold storage varies over a small range, from 14 to 18 weeks, with an average of just under 16 weeks, and is usually defined by the number of 'cold-weeks' needed to achieve flowering in the minimum glasshouse period, and therefore with greatest economy. Here, the glasshouse period of the cultivars varies between 18 and 30 days for the earliest forcing, shortening to between 15 and 25 days for the latest forcing. In a comparable example from the UK, the cold-weeks of 12 popular cultivars varied between 14 and 17, with an average of 15½ weeks.[17] This is a good agreement of figures, taking account of different climates and methods of husbandry in the two countries.

Some of the cultivars currently most used for forcing in the UK are listed in Table 48. There is relatively little interest in forcing newer or alternative cultivars, simply because narcissus are marketed at the upright green pencil stage with no colour showing. As stated elsewhere, it is the large, yellow flowers that the market really wants. Some white cultivars are still forced, but they are less popular than formerly.

Some cultivars are unsuitable for forcing for a variety of reasons, such as:

- The loss of flowers (bud blasting) when forced, for example 'Golden Ducat' and many other double cultivars.
- Thin, weak stems leading to lodging under forcing conditions, for example 'Quirinus'.
- Those that have spathes that tend to go brown before splitting, for example 'Saint Keverne'.

Table 47 The length of the cold period and glasshouse period of 32 narcissus cultivars in early to late forcing*

	Date of moving to glasshouse							
	Until 17 December		17 Dec. - 24 Jan.		24 Jan. - 24 Feb.		24 Feb. - 24 Mar.	
Cultivar	**Cold store (weeks)**	**Glass-house (days)**	**Cold store (weeks)**	**Glass-house (days)**	**Cold store (weeks)**	**Glass-house (days)**	**Cold store (weeks)**	**Glass-house (days)**
Ballade	na	na	16	25	15	22	15	20
Barrett Browning	15	19	15	19	14	17	14	16
Brighton	18	26	17	21	16	19	15	18
Carlton	16	24	15	24	14	22	14	20
Cheerfulness	na	na	na	na	18	25	17	15
Cragford	15	21	14	20	14	19	14	18
Dick Wilden	16	24	16	30	16	28	16	25
Dutch Master	17	28	17	23	16	21	15	19
Exception	na	na	16	25	16	23	16	20
Flower Drift	na	na	17	22	16	21	15	20
Flower Record	na	na	17	20	16	19	15	18
Fortissimo	na	na	na	na	17	22	16	20
Fortune	15	18	15	20	14	19	na	na
Geranium	na	na	na	na	18	25	17	23
Gigantic Star	16	22	15	20	14	19	14	19
Golden Harvest	15	24	15	22	14	20	14	19
Holland Sensation	na	na	17	22	16	20	16	18
Ice Follies	16	20	15	20	15	18	14	16
Johann Strauss	16	20	16	20	15	18	14	16
Juanita	15	18	15	16	na	na	na	na
Jules Verne	17	26	17	22	16	22	16	20
Las Vegas	na	na	18	24	17	22	16	20
Mount Hood	na	na	na	na	16	24	16	22
Professor Einstein	17	30	16	26	16	24	15	22
Redhill	na	na	na	na	16	20	16	20
Salome	na	na	na	na	18	28	18	22
Tahiti	na	na	na	na	17	22	16	18
Texas	na	na	16	30	16	28	15	25
Unsurpassable	na	na	16	25	15	23	15	20
White Lion	16	26	16	25	15	23	na	na
Yellow Cheerfulness	na	na	na	na	18	25	17	25
Yellow Sun	15	22	15	20	na	na	na	na
Cold store (weeks) minimum	15		14		14		14	
Average	15.9		15.9		15.8		15.4	
Maximum	18		18		18		18	
Glasshouse (days) minimum		18		16		17		15
Average		23		22.5		21.9		19.8
Maximum		30		30		28		25

na Not applicable (this cultivar unsuitable for this forcing period).
* Based on cold storage at 9°C until 1 December, then 7°C, and then 5°C if the shoots become too long, and a glasshouse temperature of 15-16°C (except for red-cup and double cultivars which were grown at 16-18°C).

Table 48 Popular cultivars in UK forcing

Cultivar	Classification	Forcing period*	Optimum cold storage (weeks)	Notes
Carlton	2Y-Y	Mid/late	16	
Dutch Master	1Y-Y	Mid	17	
Fortune	2Y-O	Early/mid	15	Corona colour poor if forced early
Golden Harvest	1Y-Y	Early/mid	15	
Ice Follies	3W-W	Early/mid	16	Reduced demand for white flowers
Juanita	2Y-O	Early/mid	na	
Tamara	2Y-Y	Early	na	
Unsurpassable	1Y-Y	Mid	16	

na Not available.
* Early, mid-November to late-December; mid, late-December to late-January; late, February and March.

15.3 The stages of bulb forcing

Initial storage of bought-in bulbs

Where bulbs are bought-in for forcing it is generally advised that they should be unpacked immediately, to provide ventilation, and dealt with promptly. If they need to be stored temporarily, this should be:

- At about 17°C, which neither advances nor retards development.
- At a relative humidity not exceeding 75%, to prevent rooting and *Rhizopus* development.
- With adequate air movement, to prevent the development of fungal diseases.

HWT or warm storage to control bulb-scale mites?

Conventionally, bulbs for forcing are not given HWT because it is well known to damage the flower buds which are already developing at this time. More recently, sporadic problems with bulbs infested with bulb-scale mite, which multiply rapidly under forcing conditions, have suggested that some control would be desirable. Research at the former Central Science Laboratory (HDC Project BOF 25a)[18] investigated the temperature and duration of HWT necessary to kill bulb-scale mites and eggs. In contrast with what would be required to control stem nematode, only a relatively mild HWT treatment, such as one hour at 44.4°C, was needed (at that time formalin was added to the dip). Such treatments do not call for pre-warming or pre-soaking, do not cause any manifest damage to the flowers, and only stocks infested, or suspected of being infested, with bulb-scale mite need be treated. This treatment is becoming more widely used in the UK prior to forcing bulbs.[19] Following HWT, the bulbs should be dried before the start of cooling. Although suggested by earlier research, it does not now appear that a mild warm ('dry heat') treatment (such as a three-hour period at 42°C) is as effective as mild HWT is in controlling bulb-scale mite.

Bulb lifting date

If narcissus are lifted in late-July, all floral initials (except the trumpet or cup) will already have formed, so that process cannot be altered by subsequent temperature treatments unless the bulbs have been lifted earlier than usual. Traditionally, for early forcing the bulbs would have been lifted from early-June, though in contemporary bulb growing this is now becoming the norm.

Intermediate temperature storage

As a result of of the restrictions on beginning cold storage before adequate development of the flower initials has taken place, bulbs may be stored at an intermediate temperature (17°C) after lifting for two to four weeks until cold treatments can begin. The temperature of 17°C is important, as storage above 20°C delays flower formation (and increases basal rot), while lower temperatures slow development generally.

Warm storage

Warm storage does not advance flower development, but the bulb's subsequent response to cool temperatures is improved. The warm storage period does not appear to be critical, with treatments of five to 14 days at 30 to 34°C being effective. The treatment can be combined with post-lifting bulb drying in a forced air drying system, or can be given in a store capable of reaching the required temperature. Possibly, any mild HWT applied might also contribute to the warm storage treatment. It is important for the warm store to have good air exchange and a relative humidity not more than about 75%, otherwise bulbs may be seriously affected by soft rot due to *Rhizopus*. When a warm storage treatment is used, intermediate storage at 17°C may be needed again afterwards.

Pre-planting treatment

Soaking narcissus in gibberellic acid before cooling or planting decreased the time to shoot emergence, but did not advance the eventual flowering date or increase flower size.[20]

Cool storage – the basic methods

In order to produce quality flowers, cool storage should not begin until all parts of the flower, including the trumpet or cup, have been initiated ('Stage Pc' of floral development).[21,22,23,24] Traditionally, this would have been determined by regular dissection of the flower bud, but this now appears to be little practised, and instead bulb cooling is generally started in mid-August, or by 1 September at the latest.[19]

Traditional 'plunging' has largely been replaced by providing controlled-temperature cooling in a cold store, though some more traditional methods may be used, depending on the geographical situation, when the flowers are required, and the facilities and amount of labour available. After a sufficiently long cold period has been received, the bulbs are moved to a heated glasshouse for flower production.

Whatever the cooling method used, it is important that the growing medium is kept moist throughout.

Controlled temperature cooling

The bulbs, either planted in trays or dry bulbs to be planted later are placed in a controlled temperature store, usually at 9°C, the optimum for cooling narcissus bulbs, though this may be lowered later to prevent excessive growth. The relative humidity should be maintained at 95 to 100%, if necessary by damping-down the floor. In large stores some air movement should be provided through fans, but air exchange through the normal opening and closing of the doors is considered adequate. Controlled-temperature storage gives a predictable picking date because the length of cold storage needed to produce flowers in a fixed period at a given glasshouse temperature can be determined experimentally for any cultivar. If the length of the cold requirement of a cultivar is not known, the bulbs can be moved to the glasshouse when the flower-bud can be felt in the neck of the bulb.

Traditional cooling outdoors

Traditionally, bulbs were planted in trays (often called 'flats') or other containers and placed ('plunged') outdoors on a 'standing ground' (or 'outdoor rooting bed') where they were kept cool, usually by covering with 20 to 30 cm of straw, and moist; frequent watering is likely to be needed in the early stages. Plunging may be started once outside temperatures have fallen to about 9°C (or a higher temperature, up to a maximum of 13°C, if the bulbs have been pre-cooled).

The extent and rate of cold treatment is dependent on ambient temperatures, so early forcing will be impossible if the winter is too mild or too short to satisfy the cold requirement, or if winter is too cold, which slows growth or prevents housing because of frozen conditions. If rooting through into underlying soil is a problem, it can be prevented by placing the trays on polythene sheeting. In frost-prone areas it is important to maintain good contact between the tray base and the underlying soil, as air pockets can lead to sub-zero temperatures that can damage bulb growth. Standing grounds are in danger of infestation by nematodes if poor quality bulb stocks are used. It is likely that rodent control will be needed.

The bulbs can be moved to the glasshouse when the flower-bud can be felt in the neck of the bulb. Bulbs should not be housed when frozen, and in any case moving the trays from the frozen ground or stack can be difficult.

Cooling outdoors in a 'stack'

In the 'stack system', a development of traditional plunging, palletised stacks of planted trays are placed outside in a sheltered position and surrounded by a straw wall or thick polythene sheeting. In this situation it may be difficult to keep the trays adequately watered and therefore cool.

Glasshouse systems

Also utilising natural winter cold, narcissus may be planted directly in the ground, either in a glasshouse that is left unheated until the bulbs have received sufficient cold, when the heating is turned on, or in an outside bed that can be covered by a mobile glasshouse when the bulbs have been sufficiently cooled.

The bulbs can be planted once temperatures have fallen to about 9°C, unless they have been pre-cooled, in which case they may be planted at a temperature up to a maximum of 13°C. Bulbs should be planted close-packed and with the top of the bulbs 2.5 to 5 cm deep.

Cold storage with pre-cooling

The procedures previously described can be modified to improve the economics of forcing by using pre-cooling. Pre-cooling refers to providing the first part of the cold period (often six weeks at 9°C, though the duration is not critical) to the dry, unplanted bulb ('dry-cooling'). After dry-cooling the bulbs are planted ('boxed') and the cold treatment is completed either in a controlled temperature store (then termed 'double-cooling') or outdoors (called 'wet cooling'). This procedure provides cheap cold storage while the outside temperatures may be high, and delays the labour requirement for planting until after the busy summer period. The bulbs in one 'dry store' will require a much larger amount of 'wet' storage space.

Cooling can be done successfully in ventilated bins in the store, or on palletised trays. During dry-cooling it is important that relative humidity is below 75% in the store, otherwise there may be premature rooting. There should be good air circulation around the bulbs, and any 'hot spots' in the store should be eliminated. Bulbs can, if needed, be stored for several months under these conditions.

Low temperature holding period

At the standard controlled temperature store temperature of 9°C, even the slow shoot growth eventually becomes excessive and it may be necessary to reduce the temperature. Various regimes have been used, such as:

- Reduce temperature to 7°C on 1 December, and then to 5°C if shoots still grow too long.[25]
- Reduce temperature to 5°C on 20 October, and then to 0-2°C on 1 January or when the shoots grow too long.[26]
- Reduce temperature to 5°C on 1 December and then to 0-2°C on 1 January.

Narcissus growth is difficult to stop entirely under these conditions, requiring a virtually frozen growing medium. If frozen, the trays should be thawed carefully before moving to the glasshouse other growing environment. Temperatures of -2°C and lower are potentially damaging.

15.4 Bulb forcing schedules

Forcing schedules for the UK

For obtaining forced narcissus early in the season, progressively more complex temperature treatments are needed. For the earliest forcing, several alternatives are possible.

Late-season forcing

- Bulbs lifted in July.
- Stored at 17°C or ambient temperatures until Stage Pc.
- Planted in October to early-November.
- Placed outdoors in a stack or on the standing ground, or in a 9°C cold store.
- Moved to a glasshouse at 15°C when (if from outdoors) the flower bud is in the neck of the bulb (mid-January to February) or (if from 9°C storage) after the requisite number of weeks at 9°C.
- Cropped February to March.

Mid-season forcing

- Bulbs lifted in July.
- Stored at 17°C until Stage Pc (early- to mid-August).
- Pre-cooled for six weeks at 9°C from Stage Pc (or later if not required early).
- Planted in mid-September to early-October.
- Placed in a 9°C cold store or outdoors in a stack or on the standing ground.
- Moved to a glasshouse at 15°C when (if from outdoors) the flower bud is in the neck of the bulb (mid-January to February) or (if from 9°C storage) after the requisite number of weeks at 9°C.
- Cropped late-December to late-January.

Early-season forcing

- Bulb lifted mid-June to early-July.
- Warm-stored at 35°C for five days as soon as possible after lifting.
- Stored at 17°C until Stage Pc (early- to mid-August).
- Pre-cooled for six weeks at 9°C from Stage Pc.
- Planted in August to mid-September.
- Placed in a 9°C store.
- Moved to a glasshouse at 15°C after the requisite total number of weeks at 9°C.
- Cropped late-November to late-December.

Very early forcing – alternative post-boxing temperatures

- Bulbs lifted mid-June to early-July.
- Warm-stored at 35°C for five days as soon as possible after lifting.
- Stored at 17°C until Stage Pc (early- to mid-August).
- Pre-cooled for six weeks at 9°C from Stage Pc.
- Planted in August to mid-September.
- Placed in a cold store to get either four weeks at 6.5°C then four weeks at 13.5°C, or six weeks at 9°C then two weeks at 15.5°C.
- Moved to a glasshouse at 15°C in early- to mid-November, after a total of 14-15 of weeks cold storage.
- Cropped early- to late-November.

Very early forcing – reduced cold treatment

- As above until planting.
- Placed in a cold store at 9°C.
- Moved to a glasshouse at 15°C in late-October to early-November, after a total of 11-12 weeks at 9°C.
- Cropped early-November.

Very early forcing – pre-Pc cooling

- Bulbs lifted mid-June.
- Warm-stored at 35°C for five days immediately after lifting.
- Pre-cooled for six weeks at 9°C immediately after warm-storage.
- Planted in early-August.
- Placed in a cold store at 9°C.
- Housed at 15°C in late-September after a total of 12-14 weeks at 9°C.
- Cropped late-October to early-November.

Schedules for Dutch bulbs forced in the USA

An example of a forcing schedule, utilising a 9°C cold store or outside rooting, is shown in Table 49.[27] This employs both pre-cooled and untreated bulbs, spread over eight rounds of forcing to produce flowers from December to March, and taking some account of regional differences in temperatures.

15.5 Bulb planting

Planting

Narcissus bulbs for forcing are usually planted in wood or plastic bulb forcing trays ('flats') (about 61 x 31 x 11 cm), 'dual purpose trays' (about 61 x 45 x 11 cm), potato chitting trays (about 76 x 45 x 8 cm) or similar containers, preferably with some form of corner post to aid stacking. The preferred option is a plastic tray measuring 60 x 40 x 11 cm, in which case five trays then fit on a standard 1 m x 1.2 m pallet. Before the advent of plastic trays, bulb forcers were cautioned against using 'fresh kipper boxes or newly creosoted boxes' because of possible root damage![28] For mechanical handling, trays up to 1 x 1.5 m may be used.[29]

The bulbs are usually planted on a shallow (4 - 6 cm) layer of growing medium. Deeper planting is unnecessary and there may be more crop damage and more contamination of the stems by growing medium.[30] Planting is usually by hand, placing bulbs upright and close-packed. Broadcasting bulbs saves time, but reduces the numbers of bulbs planted in each tray and leads to delayed and irregular flowering.[31] Various extents of mechanical or semi-mechanical planting may be used.

Bulb planting density is only crucial only as far as making the most economical use of glasshouse and store space. Dense planting provides support and leads to slightly longer stems, while less dense plantings may be easier for pickers. If planted directly in glasshouse or tunnel beds or outside, planting densities between 75 and 150 bulbs/m^2 have been tested.[32]

Following placement of the bulbs on the layer of growing medium, further growing medium or sand is added, roughly to the top of the container, to keep the bulbs in place but leaving the bulb 'noses' clear of the compost to allow for clean picking. The planted containers are watered well at this stage, to reduce the need for watering in storage. The trays can be stacked on pallets, with an irrigation frame surrounding the pallet and having horizontal nozzles for directing water in between each layer of trays.

Once in the cold store, bulbs should be inspected at least weekly, watching for drying out or dry-spots, pests and diseases, and excessive growth.

Although watering can present practical problems in large stores, it is sometimes necessary, and various over-head irrigation arrangements may be used.

Requirements of the growing medium

For the business and its operatives, bulb forcing growing media should be:

- Inexpensive, consistent, easy and pleasant to handle, and light in weight.
- Suitable for re-cycling, and sustainably sourced.
- 'Relatively sterile' or sterilisable.

Repeated sterilisation of peat by steam – or by various soil sterilants when available - had no adverse effects on narcissus subsequently forced in it.[33,34,35]

For the bulbs, the media should:

- Have adequate air- and water-holding capacity (a wide range of air-filled porosity values is acceptable, provided water management is appropriate).[36]
- Provide physical support to the bulbs.
- Have a pH between 4.0 and 7.0, though there is some divergence in the lower pH limit, with some sources recommending a pH between 6.0 and 7.0; in trials there were no differences in narcissus forced in non-amended peat of pH 3.2 and the same peat neutralised with lime.[37]
- Have low nutrient and salt levels.
- Have a conductivity not exceeding 300µS.[9]

Nutrients are not usually added to the growing medium. However, there have been reports (from sand culture experiments)[38] of reduced flower colour and texture when nitrogen is omitted, and of reduced scent when phosphate was left out.

Growing media and alternatives

A great variety of substrates has been used successfully in forcing narcissus. These include:

- Peat – the standard material; medium or coarse sphagnum peat is often recommended.
- Mixtures of peat with sand, bark, perlite, vermiculite or similar materials.
- Many waste materials, often because they are locally available and cheap, such as rice hulls, wood waste, green compost, etc., which may be used on their own or as diluent for peat or other bought-in materials.
- Experimentally, materials as diverse as softwood sawdust, bark, rock-wool, coir and composted sewage sludge have been used successfully, as well as, in mixture with peat, farm yard manure, shredded paper and chopped straw.[9]

Due to their internal nutrient reserves, narcissus are relatively non-demanding, and forced narcissus can be an ideal subject for utilising waste materials. When using non-standard substrates, however, growers should be aware of the possibility of chemical, biological or physical contaminants.

Table 49 Forcing schedule for Dutch narcissus bulbs in the USA

	Required cropping time							
Stage/treatment	**December First half**	**December Second half**	**January First half**	**January Second half**	**February First half**	**February Second half**	**March First half**	**March Second half**
Bulb treatment	Pre-cooled	Pre-cooled	Pre-cooled	Untreated	Untreated	Untreated	Untreated	Untreated
Storage at receipt	Plant immediately or 9°C	Plant immediately or 9°C	Plant immediately or 9°C	15-17°C	15-17°C	15-17°C	15-17°C	15-17°C
For controlled-temperature cooling								
Pre-planting temperature	9°C	9°C	9°C	9°C	15-17°C	15-17°C	15-17°C	15-17°C
Planting date	Through September	September to mid-October	September to mid-October	Early-October	Early-mid October	Mid-October	Early-November	Mid-November
Post-planting temperature	9°C	9°C	9°C	9°C	7-9°C for at least 10 weeks, then 0-2°C to slow shoot growth if needed	7-9°C for at least 10 weeks, then 0-2°C to slow shoot growth if needed	7-9°C for at least 10 weeks, then 0-2°C to slow shoot growth if needed	7-9°C for at least 10 weeks, then 0-2°C to slow shoot growth if needed
For outdoor cooling								
Planting date	Early-October	Early-mid October	Mid- to late-October	Early-October	Early-mid October	Mid-October	Early November	Early- to mid-November
Soil temperature requirements	Should be 9°C (or maximum 13°C if bulbs pre-cooled for nine weeks)	-	-	-	-	-	-	In areas with soil temperatures below 5°C by early-December, plant by 1 November and mulch bed to retain warmth

15.6 Growing and picking

Glasshouse conditions

Cooled narcissus should be moved to the glasshouse once the requisite total number of weeks of cold storage has been received (including any weeks of pre-cooling), or when the flower-bud can be felt in the neck of the bulb, or as required if the cooled bulbs are being held at 0-2°C. When housing bulbs cooled outdoors, this should be done once the floral bud can be felt in the base of the shoot, or, for early forcing, when the bud is clearly through the neck of the bulb.

Trays may be placed on the floor or on benches, the latter giving a few days' earlier cropping. They can be placed initially on the floor and moved up later, giving longer stems and better utilisation of glasshouse space.

In early forcing rounds, stem length can be increased by laying paper or black polythene over the shoots. Lower temperatures can also be used to give longer stems, though at the expense of increasing the time in the glasshouse.

An air temperature of 15 to 16°C is commonly used and is optimal for fastest growth, but glasshouse temperatures are usually adjusted up or down (between 0 and 18°C) to provide a limited manipulation of the cropping date. Some Dutch sources recommend a generally higher glasshouse temperature of 16 to 18°C.[39] Glasshouse temperatures of 13°C for the first few days, followed by 16-18°C,[40] or of 13-17°C night and 15-18°C day,[41] have also been recommended. Lower temperatures produce flowers with longer stems and deeper colours.

Glasshouse temperatures should definitely not exceed 16°C for some cultivars: 'Helios' produces excessive leaf growth at higher temperatures, while 'Fortune' produces pale coronas.[40] This temperature should also not be exceeded for double and red cup cultivars.[39]

Bulbs must be watered fairly liberally at all times, to avoid root damage. Excessive glasshouse humidity may lead to disease, while low humidity may lead to desiccation of the spathe, preventing normal bud opening, especially in double cultivars.

Crop support is not usual, though may be helpful in later rounds of the longer-stemmed cultivars. Although not usual, a growth regulator may be used to reduce stem length and reduce crop flattening.[42]

As far as is known, some glasshouse factors do not appear to affect the growth of forced narcissus:

- Carbon dioxide enrichment (700-800 ppm) did not show any benefits.[43]
- High light intensities are unnecessary, 11,000 to 27,000 lux being adequate.[39]
- No information appears to be available about the effect of photoperiod on stem extension.
- Forced bulbs are not usually fertilised: trials showed little difference in performance in a variety of substrates when liquid fed once, twice or four times a month.[44]
- Narcissus cultivars do not respond to 'DIF' (differential day/night temperature) treatments.[45]

Use of plant growth regulators

At present, the only growth regulator that has been tested successfully on narcissus and is approved for use in ornamental plant production is 2-chloroethylphosphonic acid (2-CEPA, also known as ethephon) as 'Cerone', which has a EAMU (2012/2366) expiring 31 Jan 2020. The EAMU gives the following information:

- The maximum individual dose is 1 L product/ha, the maximum total dose is 1 L product/ha/crop and it must be applied in a minimum of 125 L water/ha via conventional sprayers including hand-held sprayers.
- The material is an anticholinesterase organophosphorus compound and must not be used by those under medical advice not to work with such compounds.

No information is provided specifically for the treatment of narcissus. However, the material was extensively tested on narcissus at Kirton and this was reflected in an earlier label which stated:

- The product may be used on protected narcissus "to shorten stems for pot plant and cut flower production."
- The product may be used on protected narcissus to shorten "cut flowers at 0.5 L product/1,000 L water using 4.4 L of solution/1m^2 of box surface."
- Users are advised not to treat naturally dwarf varieties and to test a small number of new varieties before treating large areas.
- Cultivars known to be tolerant are listed as including 'Barrett Browning', 'Carlton', 'Golden Harvest', 'Fortune' and 'Lizard Light'; many others have been dwarfed experimentally.

Factors affecting cut-flower quality

Some aspects of production have been examined in the Netherlands for their effect on post-harvest quality.

- There were no differences in post-harvest quality between flowers cropped at the start, middle or end of the cropping period or forced at 15 or 20°C, but cropping at 17°C rather than 12°C about halved vase-life.[46]
- In a survey of Dutch flowers, quality and vase-life in most cultivars were not reduced by early-forcing, provided flowers were cropped at the appropriate stage.[47]
- A long, undamaged basal leaf sheath holds the stem and leaves together well, improving appearance. Long basal sheaths are encouraged by later forcing, longer cold treatment, and a cold storage temperature of 9°C or more, but not by deeper planting or covering plants after housing.[48,49]
- Bud shape, a strong flower with good texture, firm, clean foliage and close grading by length and weight, are all aspects that improve the perception of narcissus flower quality.[50]
- Stems of forced narcissus should not normally be contaminated with growing medium, avoiding the need for washing.

- Vase-life was similar in flowers cropped at pencil or early-goose-neck stage, but greatly reduced when cropped at a loose bud stage.[46]

Pests, diseases and disorders

Potentially, the forced crop can be attacked by many of the general pests and diseases of narcissus. Sometimes there is little that can be done at this stage, for example if basal rot becomes evident and it is the stock that is the problem. Some specific problems of forced crops are listed here.

Bulb-scale mite

Relatively small numbers of bulb-scale mites may become evident as they multiply rapidly in the warmth of a bulb-forcing glasshouse, and they may even appear as a deposit on some shoot surfaces. It will be too late to counter the characteristic saw-tooth damage along the base of the leaves and stem, which is an expression of damage caused inside the bulb many months before. If active bulb-scale mites or their damage became evident, endosulfan was formerly available and was used in the glasshouse as a drench of the shoots and growing medium, but no suitable replacement is now available in the UK. 'Frosting', that is, moving infested trays outside the glasshouse overnight in frosty weather, was formerly said to offer some control, but recent experiments have shown that this is unlikely to be fully effective.[51]

Smoulder

Infested bulbs may produce some shoots with 'primary' symptoms of smoulder, such as blackened, distorted shoots possibly with grey fungal growth apparent. In a forced crop this is unlikely to present a significant problem, but it is probably a good practice to cut out and dispose of such shoots, certainly if the bulbs are to be re-claimed. Secondary lesions – often blackened areas at the tips or sides of leaves – may also appear, and may affect the amount of leaves cropped with the stem. Rooting is not affected. Some late-season cultivars, including 'Barrett Browning', 'Explorer', 'Gold Medal' and 'Van Sion', appear to be susceptible.

Root scorch

A root scorch, due to the smoulder pathogen, has been described in Dutch literature. There is generally weak growth, poor rooting, and the outside of the base plate is corky and brown.[52]

Penicillium mould

Mould may become evident in forcing on the tops of the bulbs and on damaged shoots, but is not considered to be a problem.

Frost damage

Exposure to frost may result in a gradation of symptoms, from very weak growth to slightly reduced growth and yellowish leaves. The base plate may take on a grey discolouration. This is only likely in bulbs that have been cooled outdoors: any exposure to temperatures below -2°C is potentially detrimental, exposure to temperatures of -3°C for two days will result in evident damage, and exposure to -5°C causes immediate damage.[52]

Flowering disorders

Some double cultivars, and particularly 'Golden Ducat', have a propensity when forced to produce 'drum-sticks' – stems bearing a desiccated but un-split spathe enclosing a dead bud. The phenomenon was investigated in HDC Project BOF 27.[53]

Flower picking

Some key points are:

- Flowers should be picked at the stage required for the market, usually an 'upright pencil' with no colour showing for exports, possibly slightly later for UK markets.
- Flowers are cropped with the foliage by cutting through the leaf sheath with a knife close to the neck of the bulb, so as to keep the stem and leaves together.
- The stems are usually bunched in 10s, with either a single elastic band placed near the base, or one at the base and another two-thirds the way up the stem, clear of the neck.
- Good organisation, distribution of sundries and collection of the picked bunches are essential for reducing costs (Images 67 and 68).
- Grading stems to length can be done by machine, but this is not common because of the cost.

67 A dense, even forced crop, showing leaf sheaths

Photo: Warwick HRI and predecessors

68 Well organised cropping in the USA

Photo: Gordon Hanks

Flowering disorders in forced double cultivars

The double cultivar 'Golden Ducat' tends to produce 'drum-sticks' – stems bearing a desiccated but un-split spathe enclosing a dead bud. This type of bud necrosis may also occur, to a lesser extent, in field-grown crops, in other doubles, and occasionally in single cultivars. It was investigated with a range of forced double cultivars ('Cheerfulness', 'Dick Wilden', 'Golden Ducat', 'Ice King', 'Tahiti' and 'Texas') in HDC Project BOF 27.

In this study 98% of 'Golden Ducat' flowers were affected, and between 15 and 36% of flowers of the other five cultivars. Bud death appeared to result from an inadequate uptake or transport of water to the rapidly growing, very demanding flower, which then became desiccated. In 'Golden Ducat', pedicel and flower growth ceased, and the water content of leaves fell, during the first week in the glasshouse.

This bud failure was investigated in a series of experiments.

- The spathe appeared to play a crucial role by continuing to block light from the pedicel, preventing goose-necking.
- Various applications of generally growth-stimulating plant hormones had little effect in reducing bud loss, except for a small positive response to gibberellic acid in some cultivars. Retarding growth by applying the regulator 2-chloroethylphosphonic acid (ethephon) (as 'Ethrel C') did not reduce losses.
- Fungicide sprays (often effective in maintaining longevity) and drenches of calcium nitrate (which can enhance water transport) only slightly reduced bud losses in some cultivars.
- The incidence of bud loss increased, only slightly and in some cultivars, as the glasshouse temperature was raised from 14 to 18°C.
- Under atypically low glasshouse humidity, bud loss was only slightly increased.
- Bulbs forced six weeks later, following an additional storage period at 1°C, showed slightly less bud loss.

15.7 Re-claiming forced bulbs

After forcing, bulbs may be either dumped or re-claimed, largely depending on the current value of the bulbs, the economics of growing-on, and any significant pest or disease issues. The trays of bulbs are re-stacked on pallets and allowed to die-down naturally outdoors. They are recovered from the growing medium, normally by use of a rotary barrel riddle, as and when labour is available; the growing medium can also be re-cycled. To control pests and diseases, which may have been exacerbated by the warm temperatures employed in bulb forcing, and in order to complete the re-claiming operation before the start of bulb lifting, growers should aim to have re-claimed bulbs ready for HWT and re-planting in May.

Before HWT, pre-soaking is normally recommended, since ex-forced bulbs will have many internal cavities through resource depletion and desiccation. When carrying out HWT, take account of any special recommendation for re-claimed bulbs. They should then be grown-on in the field for two or three years to recover their vigour.

Sometimes re-claimed bulbs are sold on, for example for use in pre-packs. This is a practice that can have an adverse effect on sales because of poor bulb quality immediately after forcing, and should be discouraged.

Non-reclaimed bulbs and waste from reclaiming bulbs should be disposed of appropriately, and following the current regulations of the Environment Agency. There are agricultural exemptions which will permit composting and 'return to field' scenarios, but the grower must register for these exemptions.

15.8 Long-term storage for retarded flowering

In commercial floriculture, long-term storage methods have been developed for narcissus bulbs, either to facilitate transport to the Southern Hemisphere, or to produce very late flowers when a niche market is identified. Both warm and cool storage methods have been used.[54]

Retarding by warm storage

- Dutch researchers and producers stored bulbs at 28°C and 70% relative humidity from lifting (in July) until shipping the following year, allowing planting in South Africa in August.[55]
- In trials, long-term storage at extreme temperatures (-1.5° or 34°C) was detrimental to the bulbs. However, good results were obtained by storage at temperatures between 25.5 and 31°C, followed by 10 weeks storage at 17°C.[55]
- The best results were obtained by storage at 30°C from lifting to mid-October, followed by -0.5°C until late-December then 25.5°C until shipping in February-March and planting in April.[55]
- For longer storage, 25.5°C was used from late-November.[56]

Warm storage can be prolonged for a year, making all-year-round flowering possible. This has been investigated with several standard cultivars in the UK.[57,58,59,60] Bulbs were stored for several months from lifting at 26°C and 70% relative humidity, then at 17°C for four weeks before being planted and placed at 9°C for six weeks; after this they were transferred to cool growing conditions. The normal cold requirement did not seem to apply, but the 9°C period promoted root growth. The required flowering dates could be attained by 'holding back' the plants at 2-5°C as necessary.

Retarding by low temperatures

- Long-term storage at low temperatures was investigated in the USA in the 1930s.[61] Bulbs were stored at 1°C from November for up to 10 months. Vegetative growth was satisfactory, although the flower buds died, indicating that prolonged cold storage for non-cropping purposes should be satisfactory.
- It was later reported from the Netherlands that bulbs could be shipped in September following storage at 20°C, then planted in November at 5°C for one month and then at 0°C until as long as July, flowering satisfactorily.[54]
- Alternatively, as shown in the UK, bulbs can be frozen at –1.5°C over winter and spring, planted and then stored at 7°C for three weeks followed by 9°C for two weeks and then 1°C as required, flowering thereafter taking place in four to six weeks.[58] This is similar to procedures used in the Netherlands to produce 'ice-tulips' year-round.

15.9 Some specialised forcing techniques

Direct-forcing

In some cases it is possible to provide all the cold treatment required for forcing to the dry, unplanted bulb, rather than planting the bulb part-way through the cold period. This method, called direct-forcing or '5°C forcing', was developed for forcing tulips. All the cool storage is given to the dry bulb, usually at 5°C, after which they are planted directly in the glasshouse soil. Although this requires much less cold store space and shifts the labour requirement for planting to the winter period, it has the disadvantage of relatively slow development and hence requires a longer time in the glasshouse compared with standard forcing.

Direct forcing has been tested with narcissus bulbs only on a limited scale, and in trials has met with variable results,[62] sometimes resulting in slow flowering and smaller flowers.[63] As far as is known, the technique is not used commercially. However, promising results were obtained using the following techniques:

- Cool the dry bulbs for 10-12 weeks at 9°C, then plant and move to a glasshouse running at 16°C.[64]
- Cool the dry bulbs for nine -12 week at 5°C, following either:
  - One week at 34°C then two weeks at 17°C, after lifting, for December flowering.
  - Storing at 17°C before cooling, for January or February flowering.[65]
- Following 5°C cooling, make successive plantings from November to January into soil at 10-13°C, flowering in January to March.[66]

Hydroponics and aeroponics

It is possible to force narcissus bulbs on water in the 'pin-trays' used for tulip bulbs.[67] The results were broadly successful, but the method is not used commercially, as far as is known. This is presumably because of the large and irregular size of narcissus bulbs and the relatively low value of the crop compared with tulips, which grow very well under such systems.

Following trials in Italy, narcissus forcing using an aeroponics system, a 'cultivation column' in which the bulbs were supported and the roots sprayed with a nutrient solution, was reported.[68,69] Normal flowering and earlier cropping were seen, along with a 260% increase in flower production per unit floor area.

15.10 Energy conservation in bulb forcing

Structures

The costs of bulb forcing may be reduced by using the normal forms of glasshouse insulation, such as polythene liners, alternatives to glass, thermal screens, windbreaks, etc. Since they do not need high-intensity (photosynthetic) light, extra insulation in the form of opaque materials can be installed at no detriment to forced narcissus. Alternatively, redundant buildings can be insulated with foam and set up with low-intensity lighting; specialised forcing buildings (*schuurkassen*) have also been described.[70,71,72,73] Some of these alternatives are claimed to make up to a 90% saving in energy use.

Narcissus bulbs may also be planted in unheated glass or polythene, or outdoors, using mobile heaters or mobile tunnels if required, to produce slightly earlier crops.[74,75,76,77] Mobile glasshouses are still considered to have produced some of the best and heaviest narcissus crops.[78] The bulbs are planted 2 to 5 cm deep after the soil temperatures have fallen to 9°C (or higher if the bulbs have been pre-cooled for nine weeks, or heat-treated and pre-cooled).

Growing under artificial light

Trials of lamp types and intensities for forcing narcissus under low-intensity light showed that tungsten lamps were as effective, or better, than more expensive installations such as low- or high-pressure fluorescent or low-pressure sodium lamps.[79] From extensive trials carried out at Kirton, the following recommendations were made.[79,80]

- Tungsten lights should be suspended 1.0 to 1.5 m above the crop, using a circuit loading of 50 W/m^2.
- Provide a 12 hour day, if appropriate timing this to take advantage of off-peak rates. Using seven hour days increased the percentage of weak-stemmed plants to about 50%.
- No particular ventilation and air circulation is thought necessary, normal opening and closing of the doors being considered adequate.
- Foliage and flowers raised under this regime are paler than those of glasshouse crops, and stems tended to lodge. However, by using a growth regulator, 2-chloroethylphosphonic acid (2-CEPA, ethephon) as 'Cerone', stems were strengthened and shortened even under a seven hour day, producing a similar percentage of marketable stems to that of a glasshouse crop.

Some Dutch information recommended using higher light levels, either tungsten lamps at 125 W/m^2 circuit loading, or tubular fluorescent lamps at 40 W/m^2, both mounted 0.45 m above the crop.[74]

With a view to understanding further the low lighting requirements of forced narcissus, researchers in Poland investigated the growth of several cultivars under short-days of low irradiance in white, blue, red, yellow or green light. Light colour did not affect flowering date or flower yield, but narcissus under blue light formed shorter, more rigid shoots and shorter leaves than under light of other colours.[81] In related studies narcissus cultivars were grown under long-days and high irradiance in white, blue, red, yellow or green light.[82] The flowers of all cultivars were poor under red light, while under white and blue light the stem stiffness of some cultivars was improved.

15.11 References

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16.0 Flower handling and marketing

16.1 Flower handling, transport and packing

There are ADAS Leaflets[1,2,3] and HDC Factsheets[4,5] that describe the post-harvest care of narcissus flowers and cut-flower care in general. The vase-life of narcissus was reviewed in HDC Project BOF 32.[6]

Immediate post-picking treatment

Field-grown narcissus are usually bunched in tens, using one or two rubber bands, and placed flat in plastic trays for transport to the pack-house. In some weather conditions the stems of outdoor flowers may need washing to remove adhering soil.

The procedure for glasshouse flowers will vary according to circumstances - they may be treated as the outdoor crop, or may be placed flat in cardboard flower boxes or upright in buckets of water.

Under warm conditions the stems should be cooled rapidly after picking to remove field heat.

Storage of cut-flowers

Storage procedures at the farm or nursery immediately after picking should take account of the following factors, but note that much of this section also applies to how the flowers are treated during transport and at the packers:

- Vase-life and quality are lost if the storage period is extended too far. Following storage for 14 days at 1-2°C and 90% relative humidity, up to 25% of the vase-life may be lost, with some flowers failing to open in the vase.[7,8] Further increasing the storage period may reduce eventual flower size.[9]
- Poeticus and double cultivars open less well than standard cultivars after storage.[10]
- UK trials at Kirton and elsewhere showed that stems should be cooled promptly and stored at 1-2°C and 90% relative humidity, and that under these conditions dry storage or packing dry is adequate. Even goose-neck flowers can be stored, dry or in water, under these conditions, for four to seven days, without loss of vase-life.[1]
- More recently, with the strict insistence of the markets on receiving narcissus at the 'upright pencil' stage with no hint of colour showing, experience has shown that cooler storage - at 0.5°C - is necessary to prevent the slow development of the bud which will occur even at 2°C.
- Following picking, narcissus stems continue to elongate from the basal meristem, and, if stored horizontally, uneven growth will result in curvature of the stem (Image 69). At a temperature of 2°C or less, however, the amount of bending is slight.[11]
- Normally, narcissus stems are stored dry. However, should the stems be held at temperatures above 5°C, they must be stored in water.
- No special anti-ethylene precautions – such as using ethylene scrubbers or protectants like silver thiosulphate - are needed. Nevertheless, it is sensible to avoid obvious sources of atmospheric pollutants, and to ventilate flower handling and storage areas with fresh air, ensuring at least one air exchange per hour.[12]
- When daffodil stems are stored in water, it is not usual to include a flower conditioner in the buckets. Following a review of this recommendation, no reliably useful conditioner was identified, other than when using narcissus in mixed bouquets.[13]

69 Stem bending in storage (below): normal stems (above)

Photo: Warwick HRI and predecessors

Some earlier Dutch trials indicated there was no difference between dry storage and storage in water when stored at 0 to 10°C for up to nine days, though results were better following the cooler temperatures.[14] This apparent discrepancy with the UK trials results mentioned above may have been due to operating at the time under less stringent conditions relating to the required picking stage.

Other approaches to flower storage

Some other approaches to the storage of narcissus flowers have been researched.

Storage and transport in boxes

Storage in boxes has been investigated in several trials in the UK. Comparing storage in fibre-board boxes with non-boxed wet or dry storage, the non-packed flowers lasted slightly longer. This was probably due to faster cooling without boxes, but in any case the vase-life of non-stored controls was only two days longer than for the variously stored flowers.[15] Using insulated boxes for transport was found to be ineffective, since the flowers eventually reached a higher temperature under these conditions.[16]

Vacuum cooling

Vacuum cooling has been tested in the UK, cooling from ambient to 1°C in 30 minutes. Vacuum cooling was not detrimental, but also it offered no real advantage.[17]

Narcissus flowers and ethylene

Narcissus flowers are rated as only "slightly sensitive" to ethylene, although, in severe cases, the symptoms can include flower wilt. No special anti-ethylene precautions are therefore needed. Research in the Netherlands demonstrated that vase-life was only slightly increased following storage in a humidified, ethylene-scrubbed nitrogen atmosphere, compared with open storage, while it was reduced in humidified, ethylene-scrubbed air.[25] Tests in the UK showed that including an ethylene-scrubber in a market box did not enhance vase-life.[16]

Although narcissus cut-flowers are not sensitive to external ethylene, endogenous ethylene plays a key role in flower development. After 1 hour, pollination or wounding results in a persistent evolution of ethylene, producing gradients of ethylene and ACC (an ethylene biosynthesis inhibitor) from stigma to ovary. The trumpet (or cup) wilts shortly after pollination, and there is a second period of ethylene evolution before the decay of the style. Ethylene also stimulates pollen germination and the growth of the pollen tube.[26]

When exposed to 1µL/L ethylene, narcissus flowers senesced prematurely, with water-soaking of the perianth segments. Pre-treating the flowers with 1-methylcyclopropene (1-MCP, an inhibitor of ethylene action) prevented this ethylene-enhanced senescence. Non-pollinated flowers produced negligible amounts of ethylene, while following cross-pollination significant ethylene was produced and the flower senesced prematurely; pre-treatment with gibberellic acid, and particularly with 1-MCP, prevented this effect of pollination.[27] Apparently independently of these ethylene effects, holding narcissus flowers in a solution of abscisic acid (ABA) also advanced senescence of the flower, and endogenous ABA increases at the time of senescence.[28]

Sub-zero dry storage

Storage at –0.6°C was unsuccessful in UK trials.[10]

Dry storage in nitrogen

Dry storage in 97 to 100% nitrogen at 0 to 27°C was investigated in the USA.[18] Storage in 100% nitrogen enhanced vase-life, compared with storage in air, while storage in 99 and 97% nitrogen was less effective. When stored for three weeks at 0 to 4°C in 100% nitrogen, vase-life was as long as for fresh-cut flowers. These effects on vase-life were not related to carbon dioxide output. The respiration rate of the flowers increased 900-fold when transferred from 0 to 21°C.

Narcissus in mixed bouquets

Generally it has been advised that other cut-flowers should not be placed in the same vase with narcissus, or in water previously used for narcissus, because exuding narcissus sap seriously harms flowers of some other common species,[19] including tulips, anemones and ranunculus that are often seen in mixed spring bouquets.[13] Although not all narcissus cultivars cause the same degree of damage – 'Carlton' was regarded as particularly aggressive – few have been properly tested and it has been generally regarded that all were best avoided.[20] Tazetta cultivars appear to be less toxic than standard cultivars.[13]

The harmful effect of narcissus stems is due to the mucilage that seeps from the cut stem ends.[21,22] This may dissipate in time: after 24 hours in separate vases, it was shown that tulip and narcissus could be safely placed together in the same vase.[21] Some chemicals, including sugar, can reduce the inimical effect of narcissus sap.[23] Curiously, it has been reported that including a cut narcissus flower, or just narcissus mucilage, in the vase with Dutch iris delayed their senescence; the effect was due to narciclasine in the sap, which reduced the activity of proteases associated with plant senescence.[24]

One recommendation is to place narcissus stems in a conditioning solution – 'Chrysal CVBN' – and allow them to 'seal' before putting them in the mixed bunch. This conditioner should also be put in the transport solution. Successful mixed spring posies (that also have the benefit of scent) are now being carried in some supermarkets, especially just after Christmas.[13]

Packing and transport

At some point in storage the stems will occasionally be sleeved, when the time out of the cold store should be kept to a minimum. Trimming to length should not normally be necessary at this stage.

Careful storage and packing should ideally be followed by cool-chain distribution, taking, in all, less than seven to ten days. This should result in achieving 80% of the vase-life of the fresh-picked stems.[1]

16.2 Cut-flowers in the retail and consumer stages

Once despatched from the growers or packers, the flowers might be thought of as the concern of the retailer, but it is in the interests of the industry as a whole to educate retailers and end-users how to treat the produce to extract maximum quality and consumer enjoyment.

Conditions at the retailers

Whenever possible, flowers should be stored in a cool place until they are put on the sales floor. The flower display should ideally be sited away from excessive drafts or sources of heat. There should be adequate levels of water in the flower buckets. The water level – commonly observed to be too low to be effective - should be checked soon after receipt and at regular intervals while on display. Staff should be made aware of the need to treat flowers with care and ensure the bottoms of all stems are kept in water. Stems often become suspended above the water level due to customers extracting bunches and not putting them back fully into the bucket.

Advice for consumers

Advice on how to get the best out of cut-flowers abounds in popular writings and anecdotal advice. The producers, packers or the retailers might include basic advice as a service to customers, stressing commonsense actions such as:

- Removing the stem base by cutting it off at an angle with a sharp knife (whether or not there is an advantage of cutting while the stem is held under water is unclear).
- Removing any damaged parts that might fall into the vase and foul the water.
- Properly using any supplied sachets of 'flower food'.
- (Generally speaking) not placing narcissus in the vase with other types of flower).
- Placing vases in a relatively cool position in good light but away from bright sun, draughts and ripening fruits.

Flower foods

Many constituents of flower foods have been tested on narcissus experimentally, as shown in Table 50, but narcissus are considered generally unresponsive. It is usual to sell narcissus cut-flowers without a sachet of flower food. However, the use of 'Chrysal Bulb' flower food in the vase is reported to have a positive effect on vase-life, flower opening and colour retention in narcissus, compared with using plain tap-water, though there are differences in varietal responses.[29]

Where narcissus are included in mixed spring posies, the addition of 'Chrysal Clear Narcissus' flower food helps to negate the harmful effects of the narcissus sap and to ensure a minimum vase-life of five days in the consumer's vase.[29]

Table 50 Compounds tested for their ability to extend the vase-life of narcissus cut-flowers

Treatment	Effect	Reference
Immerse bulbs in GA_3 before planting	No effect on vase-life	30
Harvest into silver nitrate (25 ppm) + sucrose (1.5-6.0%)	One to four day increase in vase-life compared with plain water	31
Above + antimicrobial product	Reduced vase-life	As above
Dip fresh-cut flowers into BA or BA + 2,4-D	One to two day delay in senescence	32,33,34
Ditto, into NAA or kinetin	Less effective than above	As above
Ditto, into 2,4-D	Ineffective	As above
Store two weeks at 0.5°C then dip flower in BA prior to dry shipping	Effective, extended vase-life	As above
Pulse flowers with STS	Slight increase in vase-life, higher concentrations toxic	35
Pulse flowers with silver nitrate or STS	Significant increase in vase-life	36
Pulse flowers with STS and GA_3	STS treatment increased vase-life, GA_3 increased vase-life only slightly	37
Spray with cobalt chloride while in vase	Three day extension of vase-life	38
Treat with silver nitrate or BA in vase	No effect on vase-life	39,40,41
Treat with cycloheximide in vase	Delayed senescence two days; high concentrations prevented bud opening	42
Treat with rhizobitoxin analogues or sodium benzoate in vase	Extended vase-life	43
Treat with various preservatives in vase	Some locally made formulations containing sucrose (30-70 g/L) and silver salts (30-60 mg/L) effectively maintained water uptake, the best increasing vase-life by 50%	44
Treat with GA_3 in vase	Vase-life extended	45
Treat with GA_3 or NAA or benomyl in vase	Vase-life prolonged by five to nine days	46
Treat with ABA biosynthesis inhibitors (fluridone or 1,1-dimethyl-4-(phenylsulphonyl)semicarbazine)	Did not extend vase-life	47
Treat with 8-HQ citrate in vase	Good control of microbes in water	48
Treat with cobalt chelate or STS and sucrose or 8-HQ in vase	Maintained water uptake, 30-50% increase in vase-life	49,50

Abbreviations: BA, 6-benzyladenine; GA, gibberellic acid; NAA, naphthaleneacetic acid; STS, silver thiosulphate; 2,4-D, 2,4-dichlorophenoxyacetic acid; 8-HQ, 8-hydroxyquinoline.

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17.0 Pot-plant production

17.1 Cultivation

Cultivars

Either dwarf or standard cultivars can be utilised as pot-plants. Naturally dwarf cultivars, predominantly 'Tête-à-Tête', but also some better cultivars such as 'Jetfire', have the benefits of small size, multi-flowered stems and attractive, often scented, florets. Many dwarf cultivars have been trialled, including 'February Gold', 'Jack Snipe', 'Hawera' and 'Baby Moon', many producing attractive pot-plants with good stem numbers and a long shelf-life of 10 to 18 days when kept at 18°C.[1]

Using standard (tall) cultivars for potting can have the advantage of using cheaper bulbs, such as 'Ice Follies' and 'Carlton'. In the UK, varieties such as 'Mount Hood' and 'Bridal Crown' have been popular, but today growers may prefer to use more recent, naturally short cultivars such as 'Crewenna'. Tall cultivars grown in pots may benefit from treatment with a growth regulator, though this is not the current practice in the UK.[2]

In addition to potted narcissus grown as temporary house-plants, a wide range of cultivars is grown in pots for direct planting into the garden or tubs. This provides a spring opportunity for selling bulbs.

Dwarf narcissus may be also grown in containers mixed with other flower-bulbs (crocus, hyacinth, etc.).[3]

Production methods

Pot-grown narcissus production is a modification of normal forcing methods covered previously. Greater details can be found in a number of textbooks.[3,4,5,6] Some points to note are listed here:

- Due to the fact that even one poor plant in a pot may spoil the whole pot and lead to rejection, bulbs used for pot work must be of high quality and must be free of pests and diseases, such as bulb-scale mite, that may cause damage quickly when grown at higher temperatures.
- Planting arrangements can vary, for example three bulbs in a 10 cm-diameter pot for 'Tête-à-Tête', or six standard bulbs in a 20 cm-diameter pan or half-pot.
- Where the bulbs are sufficiently regular in shape, the bulbs in a pot should be planted the same way round to achieve greater uniformity (with the rounded side facing the edge of the pot).
- Cold store temperatures should be 9°C initially, decreasing to 5°C when the roots emerge from the pots and to 2°C when the shoots are 2.5 cm-high.
- Growing temperatures should be 16 to 17°C, and certainly not above 18°C.
- Narcissus bulbs are often planted in relatively small containers, so as 10 cm- or 15 cm-diameter pots for dwarf and standard cultivars, respectively, so the restriction of plant height is important. A growth regulator may be used to shorten stems of standard cultivars; this can include control of stem length in the glasshouse and (or) and of post-harvest stem extension after sale.
- Pots should be marketed (or stored at 0-2°C to await marketing) once the shoots are about 5 cm tall for 'Tête-à-Tête' or about 12 cm tall for standard cultivars.
- Mixed containers of dwarf narcissus with other bulbs would usually be sold immediately after cold storage.[3]

Use of growth regulators

Partly in response to the popularity of pot-grown bulbs in the USA, extensive 'dwarfing' trials have been carried out in the UK, the Netherlands and the USA (Image 70). The regulators 2-chloroethylphosphonic acid (2-CEPA, also called ethephon), paclobutrazol and flurprimidol, applied in various ways (foliar sprays, substrate drenches and pre-planting bulb soaks) were found to be effective for use on narcissus, while others, including the widely used daminozide and chlormequat, were not.[7,8,9,10,11,12,13]

70 Effect of 2-CEPA (as 'Ethrel') on 'Ultimus': increasing dose from left to right

Photo: Warwick HRI and predecessors

Stem length is typically reduced by 20 to 30% by treatment. Applied correctly, 2-CEPA produces a stouter plant, not just a dwarfed one, and the retardant effect persists and controls post-flowering stem growth. There are no adverse effects on flowering date, post-harvest quality or shelf-life. To achieve good results, growth regulators should be used with care, though much is commonsense. As the usual method of application is by drenching the growing medium, it should be uniformly but not excessively moist at the time of application, and after application irrigation should be restricted until there has been time for the plants to take up the retardant solution.

At present, the only growth regulator that has been tested successfully on pot-grown narcissus and is approved for use in ornamental plant production is

2-chloroethylphosphonic acid (2-CEPA, also known as ethephon) as 'Cerone', which has a EAMU (2012/2366) expiring 31 Jan 2020. The EAMU gives the following information:

- The maximum individual dose is 1 L product/ha, the maximum total dose is 1 L product/ha/crop and it must be applied in a minimum of 125 L water/ha via conventional sprayers including hand-held sprayers.
- The material is an anticholinesterase organophosphorus compound and must not be used by those under medical advice not to work with such compounds.

No information is provided specifically for the treatment of pot-grown narcissus. However, the material was extensively tested on narcissus at Kirton and elsewhere and this was reflected in an earlier label which stated:

- For pot-plants, this solution may be applied at, for example, 56 ml/12 cm-half-pot containing six bulbs.
- Users are advised not to treat naturally dwarf varieties (though this has been shown to produce very good pots of 'Tête-à-Tête').
- Users should test a small number of an unfamiliar cultivar before treating large amounts; cultivars known to be tolerant are listed as including 'Barrett Browning', 'Carlton', 'Golden Harvest', 'Fortune' and 'Lizard Light'.

Other useful information from trials of 2-CEPA on pot-grown narcissus is listed here:

- 2-CEPA is effective used as a substrate drench[14,15] or foliar spray.[3,16,17] It has been shown to be unsuitable if used as a one to 24 hour pre-planting bulb soak, or as a substrate drench at planting time.[12,18]
- As a guide, for substrate drenches the optimum treatments demonstrated include 480 ppm a.i. applied at 15 cm shoot height[14] and 1,000 ppm a.i. at 8 to 10 cm.[12] Treatment at 15 or 20 cm height is less effective.[15]
- For sprays, optimum treatments were 1,000 or 2,000 ppm applied at 7.5 to 10 cm shoot height, repeating the application if needed (e.g. in late treatments, taller varieties or when forcing after a long cold storage period).[3]
- Using a growth regulator is more useful later in the season or after a longer cold period, though higher application rates may be needed.[12,14,15]
- Earlier applications or higher rates of a retardant may cause damage in the form of delayed and poor flowering.
- Treatments were found to be effective in a variety of substrates, including soil, peat, bark and peat-perlite mixes.[15]
- Treatment was effective at glasshouse temperatures from 10 to 21°C.[12,15,19]

Some products based on other growth regulators – including chlormequat, daminozide and paclobutrazol – are available in the UK through full approvals or EAMUs for application in ornamental plant production generally (others are restricted to specified crops or situations).[20] Of these, only paclobutrazol is likely to be effective on narcissus.

Other means of restricting growth in pots

Besides using a growth regulator, some restriction of height in pots can be achieved through cultural techniques including:

- Planting late (late-November or early-December) at 2°C.[21]
- Using a higher glasshouse temperature.[22]
- In 'Tête-à-Tête', using pre-cooling and a cold-store temperatures of 2 or 5°C (but this also gives a longer glasshouse period); using a lower cold-store temperature is also useful for taller cultivars.[23,24]
- Using the following optimum storage:
- Six weeks at 9°C plus eight weeks 5°C for December forcing.
- Six weeks at 5°C plus eight weeks 2°C for February forcing.
- 14 weeks at 2°C for March forcing.[23,24]

The following cultural methods were ineffective in producing good pot-plants:

- Storing bulbs at 25°C rather than 17°C before cooling.
- Shortening the cool period by two weeks.
- Using a two week rooting period.[23,24]

Disease control in 'Tête-à-Tête'

Despite other excellent qualities, 'Tête-à-Tête', like other dwarf cultivars, is susceptible to several fungal pathogens (*Penicillium* species, *Botrytis narcissicola*, *B. cinerea* and others), so the quality of pot-plants is highly dependent on the quality of the bulb stock. There has been much R&D in the Netherlands for improving 'Tête-à-Tête' quality as a pot-plant, and the following points are important:[25,26,27,28,29,30]

- Care in handling of the bulb stock is critical, paying particular attention to rapid and thorough bulb drying, maintaining low humidity, a good air circulation, and 20°C in storage before use.
- If available, soak bulbs in an appropriate fungicide at storage and at planting.
- Planting the bulbs before the start of cooling, using a substrate with a high percentage of black peat and covering the bulbs with sand.
- Cool the potted bulbs for 12 to 14 weeks at 9°C then 5°C for early forcing, or 9°C then 2°C for late forcing.
- Use a cool glasshouse temperature for forcing.

Alternatives to pot-plant sales

There are many alternative and added-value formats in which narcissus can be grown for sale, as well as the opportunity to present the plants in a tasteful container as a classier product. Tazetta bulbs are sold in (or with) containers with pebbles, for water-culture in the home, the bulbs being 'planted' so that only the base plate is immersed.[3] Standard cultivars can be grown in the same way.[31]

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18.0 Tazetta narcissus

18.1 Flower and bulb production outdoors

Tazetta bulb production in different climates

Israel

Tazetta cultivars require a frost-free climate for natural-season growing, and are produced mainly in Israel.[1,2] The bulbs are planted in October, lifted in June, and stored at ambient temperatures (25-30°C) which retard the bulbs naturally until temperatures fall low enough to allow growth. Floral initiation takes place after lifting, in July or August, and flowering will occur before winter if other conditions are favourable. Alternatively the bulbs may be retarded by storage at 30°C, when they produce flowers late, in April or May.[1]

The Netherlands

Bulbs imported from Israel to the Netherlands are stored at 30°C from receipt until planting in spring. In trials, the best bulb yields were obtained when bulbs were planted in April or May and harvested in late-October.[2,3,4] Alternatively, the bulbs may be stored at 2°C, though prolonged cold storage has been shown to result in damage to the leaves.

The Isles of Scilly

In northern Europe a suitable climate for growing tazetta cultivars is found in the Isles of Scilly, where cultivar 'Grand Soleil d'Or' (often called 'Soleil d'Or' or 'Sols') is the characteristic crop. Here, bulb production is secondary to production of the early, fragrant flowers,[5] with the natural-season crop flowering from early-December onwards. Production from bulbs imported from Israel is usually satisfactory in the first year, but subsequent growth may be poor: these cultivars appear to need higher temperatures for successful production.[3]

Cultivars for the Isles of Scilly

The main tazetta cultivars grown on the Islands are listed in Table 51.[5]

Cultural methods in the Isles of Scilly

The cultural methods employed for growing tazetta cultivars in the Isles of Scilly have largely been adapted from those used for standard narcissus.[6] Tazetta culture has been greatly influenced by the local requirement to extend the flower cropping season and maximise flower yields for sales to the UK mainland. The procedures, initially developed with 'Sols', include the following:

- Leaving crops down for several years, benefiting from the high summer soil temperatures.[7]
- Early lifting and warm storage to advance and improve flower production by about a month, for example lifting in mid-May and storage for four weeks at 27°C before HWT.[8]
- Warm storage: nine days at 32°C or five days at 35°C are equally effective.
- 'Burning-over' to advance flowering and improve yield and quality.
- Covering the crop with polythene film, either in early-summer to advance flowering, or in late-summer and autumn to retard it.[7,9,10]

Table 51 The main tazetta cultivars grown on the Isles of Scilly, listed in approximate order of flowering (earliest at the top); natural-season flowering, except where indicated

Cultivar	Classification
'Paper White'	8W-W
'Innisidgen'	8Y-O
'White Pearl'	8W-W
'Grand Soleil d'Or' (advanced)	8Y-O
'Hugh Town'	8Y-O
'Grand Primo'	8W-Y
'Grand Soleil d'Or'	8Y-O
'Avalanche'	8W-Y
'Scilly Valentine'	8Y-O
'Royal Connection'	8Y-O
'Grand Soleil d'Or' (retarded)	8Y-O
'Grand Monarque'	8W-Y
'Silver Chimes'	8W-W
'Golden Dawn'	8Y-O

Burning-over

On the Isles of Scilly, straw was traditionally burnt on the fields to clean them, and this resulted in the tazetta cultivars flowering earlier the next year. In the 1970s transport charges became too expensive for the import of straw to be sensible and, instead, tractor-mounted propane burners were used across the fields of 'Sols'; this also led to subsequent earlier flowering, the more so if several runs were made. The same response was found in other tazetta cultivars, including 'Paper Whites'.[10,11] The effect was attributed to the response of tazetta bulbs to the ethylene present in the smoke, an effect well known in the growing of Dutch iris.[11,12] The crop could also be covered with polythene film and smoke pumped under it.[5,6]

Cultural methods for growing tazetta cultivars in cooler climates

In unsuitable climates, or simply to enhance growth, tazetta cultivars can be grown under protection.[13] However, trials at Rosewarne and Trenoweth showed that tazetta cultivars could also be converted to summer crops, enabling bulb production to take place in climates where the bulbs were not naturally hardy.[14,15,16] This involves using a warm-storage programme to retard flowering:

- Lifting bulbs in late-October.
- Storing bulbs at 30°C over winter.
- Storing bulbs for four weeks at 25°C.
- Planting outdoors in March.

This retarding technique was also used successfully with a number of tazetta cultivars grown in the field at Kirton.[17]

Transient exposure to sub-zero temperatures, either during growth or after harvest, is damaging to many flower-bulbs. In experiments in Israel, the hardening of bulbs of *Narcissus tazetta* 'Ziva' to freezing stress was investigated.[18] While acclimatisation by hardening at 2°C was unsuccessful, it was found that a single soil drench with a growth regulator produced daughter bulbs that were not injured by freezing at –2°C for 12 hours. The mechanism of this response is not known, but the finding suggests a possible route for further investigations.

Pests and diseases of tazetta cultivars

Tazetta cultivars are resistant to basal rot. While many other narcissus pests and diseases affect them, the following are specifically relevant:

Smoulder and leaf scorch

The often very humid conditions in the Isles of Scilly in the early part of the year mean that tazetta cultivars are particularly prone to smoulder and leaf scorch. An appropriate fungicide programme should be applied.

'Soil sickness' or 'root rot' due to *Pratylenchus penetrans* and *Nectria radicicola*

In the Isles of Scilly the nematode *Pratylenchus penetrans* attacks the bulbs, leading to a 'root rot' in conjunction with the fungus *Cylindrocarpum (Nectria) radicicola*. 'Soil sickness' has been investigated in the Isles of Scilly in HDC Projects BOF 50 and 50a. Following surveys of patches of crops showing depressed growth, trials were carried out on two sites where both *P. penetrans* and *C. radicicola* were present. The vigour of tazetta cultivar 'Royal Connection' was compared:

- Following growing the 'biofumigant' plant *Tagetes patula* 'Ground Cover' in the year preceding bulb planting.
- Using soil sterilisation with 1,3-dichloropropene (now withdrawn) prior to planting the bulbs.
- Using the combined biofumigant and soil sterilisation treatments.

Compared with untreated plots after two years' growth, the combined treatment resulted in the most vigorous growth and the lowest number of *P. penetrans*, though this effect was lost following a further year's growth at one of the two trial sites.

Aphelenchoides nematodes

Tazetta cultivars are resistant to basal rot, but serious losses have been reported in Israel due to the nematode *Aphelenchoides subtenuis*.[19] The nematode infects the roots, leading to secondary infections (e.g. *Fusarium*) that cause bulb rotting. This syndrome has been called 'basal plate disease', and should not be confused with basal rot. In China, *Narcissus tazetta* var. *chinensis* is attacked by nematodes of *Aphelenchoides* species. While the bulbs grew normally following HWT for 45 minutes at 50°C, or 25 minutes at 55°C, the complete control of the nematode was not achieved.[20]

Bacterial rot due to *Pectbacterium carotovorum*

Rots due to *Pectbacterium* (formerly called *Erwinia*) *carotovorum* have occasionally been seen in bulbs of cultivars 'Paper White' and 'Grand Soleil d'Or' from the Isles of Scilly. Infection can result in complete destruction of the bulbs,[21] but, as no specific control is available, management depends on visual inspection and sorting of bulbs.

Flower picking

Flowers of tazetta cultivars are usually picked when the spathe is completely split and the first floret is wide open.[6] Cropping is usually by pulling, thus ensuring a long stem, but this can result in stems that are very prone to bending.[22]

Traditionally, 'Sols' were kept in the pack-house or in a glasshouse after picking, allowing the flowers to develop and producing a deeper colour in the corona. Floret opening is minimal at 1°C, takes 38 days at 4°C, and four days at 16°C.[23] 'Sols' develop deeper coloured coronas when stored at 1°C for a few days than when stored at higher temperatures, so they benefit from cool-chain distribution.[24] From the 1970s, these practices were displaced. Growers now bunch the flowers immediately after picking, and despatch them with minimum delay, resulting in longer vase-life. If necessary to store the flowers, this is done in the bud stage in water at 2-4°C for up to a week: this allows a better colour to develop, without appreciable loss of vase-life.

18.2 Flowers and pot-plants under glass

Tazetta cut-flowers

Tazetta cultivars can be successfully advanced in the glasshouse, using protocols adapted from standard bulb forcing.[25] For some markets, the taller cultivars may require a growth regulator treatment. The following summarises recommendations resulting from some Dutch trials:[26,27]

- Use Israeli-raised bulbs of 'Paper White' cultivars such as 'Ziva', 'Galilee' and 'Sheleg'.
- For best flower development and a short glasshouse period, store bulbs first at 25°C, and then at 17°C for four weeks before planting.
- Schedule these treatments to give forcing periods from November (this gives long stems suitable for picking) to March (giving shorter stems for pot-plants).
- Plant bulbs at a density of 250/m^2.
- Force at a glasshouse temperature of 18°C.

In trials in China, *N. tazetta* var. *chinensis* was reported to respond to well to the growth regulator paclobutrazol, less so to chlormequat and daminozide.[28] However, tazetta cultivars grown for cut-flowers in the UK are unlikely to need a growth regulator treatment. In Egypt, growing *Narcissus tazetta* for commercial production has involving storing the bulbs at ambient temperatures; trials showed that the optimum storage temperature was 30°C for 12 weeks.[29]

Tazetta pot-plants and other formats

Tazetta cultivars can also be grown as pot-plants, generally following the recommendations for producing early cut-flowers. Israeli research showed that, for 'Sols', the quality of pot-plants could be improved by the following:[30]

- Using heat-retarded bulbs.
- Storing for six to eight weeks at 9°C before planting.
- Treating with a growth regulator (including paclobutrazol), either as a pre-planting 15-minute bulb soak, or by drenching the growing medium when the shoots were 4 to 5 cm-long.

The latest UK approvals information should be consulted before considering the use of growth regulators.

In the USA and elsewhere, bulbs of tazetta 'Ziva' are often grown in other formats, for example, hydroponically in a shallow dish with pebbles or glass beads. Once planted, the bulbs may flower within three weeks, but can become tall, weak and unattractive. Starting with anecdotal information, 'root-zone' alcohol was investigated and confirmed as an effective growth retardant.[31] At 1 to 5% (v/v), ethanol reduced height effectively, without visible phytotoxicity.

In HDC project BOF 23[32] 'Tête-à-Tête' was evaluated as a chipped crop. Penicillium rots were a problem, with 14 to 40% of chips rotting during incubation. When chipped in late-July, bulb yields were similar to those when incubated before planting or when planted directly after chipping. The results were poor if chipping and planting was delayed until mid-August. A planting rate of 5 t/ha (measured as the weight of bulbs that were chipped) gave satisfactory bulb yields. Using a straw mulch did not increase yields, though leaving half of the straw in place after shoot emergence usefully suppressed weeds.

Optimised production in the field

Standard bulb production is designed to give the most cost-effective production of bulbs and (or) flowers, but in the case of valuable bulb stocks it may be more important to maximise bulb yields. This can be achieved by reducing planting density and by adopting one-year-down growing. Planting density should be reduced so that inter-plant competition is minimised, provided there is no wind damage. In a trial of optimised bulb production, low planting densities and annual planting and lifting were effective, but there was little additional benefit of using combinations of foliar feeding, top-dressing, de-heading, irrigation or fungicidal sprays.[33] However, all these methods might be considered beneficial in specific circumstances where it is desired to maximise bulb yields.

Future growing systems

In time, it is likely that the UK narcissus industry will need a structured programme to ensure the availability of the highest quality stocks and the rapid commercialisation of new, improved cultivars.[31] This might begin with micropropagation, continue with a low-cost macro-propagation method such as chipping, and end with optimised field growing.

The Dutch crop economist de Vroomen identified three growing systems currently used in Dutch bulb growing:[34]

- Combined production of commercial-sized bulbs and planting stocks with natural multiplication, the system currently used for narcissus and many other flower-bulbs, such as tulip and Dutch iris.
- Growing commercial-sized bulbs in two- to four-year cycles from planting stock that is produced by an artificial multiplication process, for example, the system used with hyacinths where new planting stock is obtained from 'scooped' hyacinth bulbs.
- Separate production of the planting stock and the commercial-sized bulbs, the system used for gladiolus.

With the development of optimised narcissus chipping and growing-on, it would be possible to envisage a hyacinth-type system being used. This would allow for the continuous production of high-health propagation material to be fed into the industry, with all bulbs produced from them in the field being sold (or used to produce flowers and then disposed of); this would eliminate the continuous recycling of pests and disease.

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19.0 Specialist types of narcissus production

19.1 Growing narcissus for galanthamine production

Preparations from narcissus have been used in herbal medicines and folk remedies from antiquity. In the 20th Century another bulb, the snowdrop, was used for medicinal purposes, particularly in Eastern Europe, and its active ingredient, galanthamine, was isolated and named in 1947. Subsequently, galanthamine was found to be present in many other Amaryllid species. By the 1990s this information had come to the attention of Western Europe, and, when the potential for using galanthamine in the treatment of Alzheimer's-type dementia was discovered, narcissus cultivars, by virtue of their bulk and easy availability, were the obvious choice as a source for large-scale extraction.

To optimise galanthamine extraction, information on the yields from different cultivars and from plants grown under different conditions is important. Some cultivar comparisons have been carried out to assess relative galanthamine concentrations.

- In a screen in Germany of bulbs of 20 popular cultivars, 'Carlton' was found to have the highest level of galanthamine (0.07% of fresh weight), 'Gigantic Star', 'Ice Follies' and 'Fortune' were relatively rich in galanthamine (0.02-0.03%), and 'Broughshane', 'Dick Wilden', 'Dutch Master', 'Golden Harvest', 'Minnow' and 'Unsurpassable' relatively low (<0.001%).[1] This finding, and the easy availability of 'Carlton', has led to the use of this cultivar in processing.

- In trials in Mississippi, 'Mount Hood' and 'Ice Follies' had higher galanthamine levels (50 and 65 mg/100 gDW, respectively) than 'Cheerfulness' or 'Geranium' (5 and 7 mg/100 gDW, respectively).[2]

- In a Spanish survey of over 80 taxa of narcissus, the highest galanthamine content was found in 'Inglescombe'. The variation in alkaloid content appeared to be genotypically fixed.[3,4]

It has been suggested that cultural or environmental factors may be of relevance to galanthamine levels, though none of the published data appears to be based on replicated studies.

- There may be differences in galanthamine content between narcissus growing on different soil or at different locations. In a trial in Germany, 'Carlton' bulbs were grown in plots treated with either nitrogen or potassium-magnesium fertiliser, and both showed increased galanthamine content compared with non-fertilised plots.[1]

- In trials in Mississippi, it appeared that neither planting depth, bulb size, planting density or flower bud removal influenced galanthamine levels, though of course they did influence crop yield, showing that what is needed is a combination of high yield and high galanthamine levels.[2]

- In trials in Wales, galanthamine levels were reportedly doubled in narcissus when grown at an altitude over 425 m, compared with growing at sea level.[5]

Differences in galanthamine content within the narcissus plant or throughout the year might also be relevant:

- In separate studies, either the bulb scales generally, or specifically the base plate, were reported to contain the highest levels of galanthamine[1,2]

- Galanthamine levels were found to be maximal around flowering time, decreasing significantly at other times[1,2]

- In *Narcissus confusus*, alkaloids, including galanthamine, occurred in all parts of the plant, with the highest levels at the emergence stage, when galanthamine was present at the high concentration of 2.5% of dry weight.[6]

Clearly, the requirement for growing narcissus for extraction and processing are quite distinct to the usual considerations of flower and bulb production.[7] When grown for processing, for example, the plants are required simply as a source of raw material, so there is no imperative to produce bulbs with a good 'finish', of particular grades, or with a high flower count. There would be no market reason for applying the usual deadlines of the bulb business, so bulb-growing for extraction might allow the grower some relaxation of the usual requirements.

In growing bulbs for pharmaceutical or other industrial uses, essentially what is required are reliably heavy yields of bulbs that can be lifted as and when required and stored, without significant dry-weight loss or lowering of galanthamine content, until processing facilities are available. For ethical reasons customers might wish to have plants grown without significant pest or disease attacks, but with only well justified use of pesticides and, of course, with a low environmental effect.

Growing narcissus for galanthamine extraction could lead to a conflict of interest with 'regular' growers producing dry bulbs and picking flowers, if the additional area grown for processing also has its flowers picked, which could over-supply the market and affect prices. On the other hand, processors may wish to utilise all parts of the plant, and flower picking could result in yield-reducing fungal infections as well as loss of photosynthetic area. Perhaps fortunately, 'Carlton' has a quite short cropping period, so it would be unlikely that all flowers could be cropped.[8]

In the case of bulb supplies, it would be desirable to have in place arrangements such that large, additional quantities of dry bulbs would not be placed on the regular bulb markets in the case of over-production for processing.

19.2 Growing virus-tested (VT) narcissus

The origin of virus-tested (VT) stocks

Propagation schemes for VT bulbs started in the UK in the 1960s, following the finding that loss of vigour in Scillonian 'Grand Soleil d'Or' was due to widespread infestation by viruses.[9] Virus infestation was also found to be the reason for the widespread, if more sporadic, loss of vigour found in standard narcissus cultivars on the mainland, so the scheme was extended to cover a wide range of cultivars.[10,11,12] At the time the quality and yield advantages of these VT bulbs were widely appreciated – for example, the flowers of VT 'Fortune' were described as "unrecognisable against commercial stock" (Image 71).[13]

71 The bright colours of VT 'Fortune' (three years after twin-scaling)

Photo: Warwick HRI and predecessors

A propagation scheme involving VT stocks appeared to be the best way to manage viral plant diseases.[12] In UK two approaches were used to obtain the 'virus-free' nuclear stocks needed to start the scheme.

Meristem-tip culture at Glasshouse Crops Research Institute

When the growing point (meristem) of a narcissus bulb is excised and grown-on in tissue culture, some of the plantlets obtained appeared 'virus-free' and these were propagated by chipping and grown under vector-proof conditions.[9,14,15,16,17] For 'Grand Soleil d'Or', four years of multiplication and five years of cultivation produced 2,000 bulbs from five starter bulbs, and it was calculated that, by this scheme, the Isles of Scilly stocks could be replaced in 10 years.[9]

Virus-indexing at Scottish Crops Research Institute

Stocks of several cultivars were 'indexed' for viruses to identify apparently 'virus-free' plants, which were then multiplied by twin-scaling and grown under vector-proof conditions.[18,19,20] Surveying Scottish stocks, 'Golden Harvest', 'King Alfred' and 'Rembrandt' were found to be totally infected, while 'Carlton', 'Sempre Avanti', 'Corinthian' and 'Fortune' yielded some apparently 'virus-free' plants. In 'Dutch Master' not all plants were infected with any one virus.

There have also been schemes to produce VT narcissus bulbs in other countries:

- In the Netherlands work towards producing VT bulbs was started using tissue-cultured bulbs.[17]
- In New Zealand, VT plants were reported to make earlier growth and give 10 to 20% higher bulb yields, more in some cases.[21]
- In Poland, potyvirus-free narcissus plants were obtained from adventitious buds regenerated in vitro on explants of bulbs from naturally infested plants.[22] The buds were multiplied in vitro, acclimatised ex vitro, and tested using enzyme-linked immunosorbent assay (ELISA) at various growth stages. Of the adventitious buds produced from infected plants, 77% were potyvirus-free. From this population, 74% were free at the acclimatisation stage. After the second and third growing seasons (in insect-free tunnels), 97 and 98% of the plants remained potyvirus-free.

There are some other ways 'virus-free' bulbs have been obtained:

- In further trials in Scotland a small proportion of plantlets obtained from twin-scaled, infested bulbs was found to be apparently 'virus-free' (1% of twin-scales from narcissus tip necrosis virus-infested 'Golden Harvest').[23]
- New hybrids can produce 'virus-free' plants, since most narcissus viruses are not seed-borne, but they would need to be maintained in vector-proof conditions.
- Heat-treatment of twin-scales (but not of bulbs) was found to eliminate arabis mosaic virus but not other viruses. A daily cycle of 40°C for eight hours, followed by 22°C for 16 hours, was effective when continued for 10 weeks, though propagule mortality was high.[24,25] Storage of twin-scales at 30 to 36°C for eight weeks also yielded some apparently 'virus-free' plants.
- Following meristem-tip culture, the use of anti-viral agents, such as vidarabine, suppressed virus replication initially, though by the second year virus levels had increased.[26] Another antiviral, ribavirine, was used successfully to produce a small number of virus-free plants of a stock almost totally infected by narcissus mosaic virus.[27]

What does 'VT' mean?

VT bulbs are sometimes referred to as 'virus-free' bulbs, but the use of this term is discouraged because complete virus-freedom is difficult to achieve for a number of reasons. In practice, confirmation of true virus freedom is hardly possible, given that the knowledge of narcissus viruses is increasing and improvements are being made in virus detection, such that any one-off indexing could be misleading. Bulbs once deemed 'virus-free' might later be shown to be infected through using more sensitive techniques or by testing for additional viruses.[28,29,30,31,32,33]

The ELISA technique has been used to investigate narcissus potyviruses such as narcissus late season yellow virus, but the results were cultivar-dependent and neither ELISA nor electronmicroscopy were able to detect all viruses.[20,21,34] cDNA clones to some viruses have been produced in the Netherlands.[23] Improved detection of viruses has shown that some – arabis mosaic virus (AMV), narcissus mosaic virus (NMV), narcissus Q virus (NQV), narcissus tip necrosis virus (NTNV) and tobacco rattle virus (TRV) - were difficult to eliminate by meristem-tip culture. Although commercial ELISA testing services were made available,[35] antisera are available only for six of the important aphid-borne viruses of narcissus, so other viruses would still need to be detected by inoculation to test plants or by electron microscopy, both laborious methods.

VT stocks and certification schemes

In the UK the VT bulbs were multiplied and maintained by the Nuclear Stock Association (Bulbs) Ltd and the Nuclear Stock Association (Scotland) Ltd, and were sold to their members. There were two distinct propagation schemes, in England and Wales and in Scotland.

Plant Health and Seeds Inspectorate (PHSI) Plant Health Propagation Scheme (England and Wales)

VT bulbs were inspected and certified by PHSI under its Plant Health Propagation Scheme. There were growing season inspections at green-bud stage and after flowering (but before senescence) and, if the bulbs were to be marketed or moved-on, a dry bulb inspection (DBI). The scheme recognised three grades of VT bulbs,[36] and only bulbs certified at the same or higher grade in the previous year were eligible to be certified at a given grade.

- VT Mother Stocks were the highest grade, originating from a Defra-approved source and maintained in strict isolation in soil-free or sterilised soil-based growing media, free of virus-vector nematodes, in vector-proof conditions (e.g. aphid-proof mesh tunnels). In the case of VT Mother Stocks there was zero tolerance for pests, diseases, rogues and undesirable variations, and (at the DBI) for soil.

- Foundation Grade bulbs were field stocks grown in isolation (50 m from narcissus not being entered at the same grade) in soil free of *Trichodorus* and *Paratrichodorus* nematodes; there was zero tolerance for stem nematode, bulb aphid, large narcissus fly and bulb-scale mite and tolerances of 0.05% for severe virus symptoms, 0.02% for rogues and undesirable variations, 0.5% for mild virus symptoms, smoulder, basal, neck, Fusarium or Penicillium rots or small narcissus fly, 4.5% for bulbs with three or more large sclerotia, reasonable freedom from other pests and diseases, and substantial freedom from soil.

- Elite Grade bulbs were field-grown stocks, grown with 2 m separation from stocks not entered for certification. There was zero tolerance of stem nematode, bulb aphid and large narcissus fly but with less exacting other tolerances (2% for severe virus symptoms and small narcissus fly, 0.5% for rogues and undesirable variations, 1.5% for basal or neck rot (or 2% combined), 2% for smoulder, 4.5% for bulb-scale mite or bulbs with three or more large sclerotia, and substantial soil freedom). Sufficient flowers were to be left un-picked for inspection, and mixtures were to be reported, and any roguing was to be properly recorded.

Although there was initially some uptake by the industry, the high cost of maintaining VT stocks, and the lack of clear financial returns for the better quality (narcissus flowers are marketed in a 'tight pencil' stage so any benefits would not be obvious), led to VT stocks being abandoned. The Plant Health Propagation Scheme became rarely used and appears no longer to be used. Sometimes stocks originating from VT stocks have acquired a dubious 'ex-VT status', but this was no guarantee of quality. The introduction of VT stocks, therefore, contributed little to the overall health of bulb stocks, though in the Isles of Scilly a high proportion of the current 'Grand Soleil d'Or' stocks has originated from the nuclear stock scheme.

Scottish Governments Rural Payments and Inspection Directorate (SGRPID) Narcissus Certification Scheme (Scotland)

In Scotland, VT bulbs were propagated by twin-scaling, grown in vector-proof gauze houses for three years, and then transferred to field sites that had not previously grown narcissus and that were at least 500 m from other narcissus stocks. The sites were first sterilised and tested for vector nematodes.[15,10,37,38] Bulbs from this 'Foundation Stock', when tested after five years in the field situation, demonstrated good prospects for maintaining its high-health status, and were sold on for certification under a voluntary certification scheme set up in 1970 and now operated by SGRPID. There is now no remaining commercially grown Foundation Stock maintained under protected conditions. The certification scheme was based on the seed potato scheme, with a growing season inspection (GSI) and a DBI. There are three grades of VT stocks, 'Super Elite' (the highest grade), 'Elite' and 'A Grade' (the lowest grade), and the tolerances and other main requirements of the scheme are listed in Table 52. One key to the success of the scheme is that all narcissus must be planted in potato cyst nematode (PCN)-free ground, allowing the lifted crop to be exported worldwide. The bulking-up of these stocks in Scotland has continued, with commercial quantities of bulbs now being reached, and it is anticipated that they will in due course replace standard non-VT stocks.[39]

The Scottish scheme may have succeeded (where the PHSI scheme did not) because of its more realistic requirements for eligibility and a more realistic setting of tolerance levels.

Comparisons between VT and ordinary stocks

Surprisingly few critical comparisons of the relative performance and appearance of VT and ordinary stocks have been made. This is probably because of the difficulties in designing experimentation, obtaining enough VT bulbs for destructive testing, preventing re-infection under field conditions, eliminating persisting effects due to previous history and husbandry (e.g. twin-scaling of the VT stock produces a different size and shape of bulb). However, some comparative trials were carried out at Kirton and Rosewarne, in the Isles of Scilly, and in Scotland.

Comparisons using 'Sols'

VT bulbs of 'Grand Soleil d'Or' had more and larger flowers with brighter coronas than plants with AMV and narcissus degeneration virus (NDV).[9] The critical bulb weight for flowering was 25 and 40 g, respectively. Differences between VT bulbs and others with only arabis mosaic virus were less marked.

Table 52 Requirements for certification under the three grades of the SGRPID Narcissus Certification Scheme 2010

Requirement	Super Elite (SE)	Elite	A Grade
Bulbs eligible	Certified at Foundation or Super Elite Grade in previous two years	Certified at Foundation, Super Elite or Elite Grade in previous two years	All commercial cultivars
Site	Tested and free of soil-borne virus infection and PCN	No requirement	No requirement
Separation	1 m gap from other SE cultivars 100 m gap from all other narcissus or tulip crops	1 m gap from other SE varieties 50 m gap from all other narcissus or tulip crops	1 m gap from other narcissus stocks Reasonable gap from any other stock obviously infected with virus
Stem nematode*	Zero tolerance	Zero tolerance	Free from visible symptoms
Visible symptoms of virus disease	0.1% tolerance	0.5% tolerance	3.0% tolerance for plants with obvious virus disease symptoms
Rogues	0.1% tolerance	Substantially free of rogues	Not accepted if obviously not true to cultivar
Other tolerances	Substantially free of all other pests and diseases including smoulder and narcissus fly Must be true to type and free from unsatisfactory plants	Substantially free of all other pests and diseases Must be true to type and free from unsatisfactory plants	Reasonably free of all other pests and diseases
Flower picking	All flowers must be left un-picked	Sufficient flowers must be left un-picked to determine purity	Sufficient flowers must be left un-picked to determine purity
Roguing	No prior roguing allowed	No requirement	No requirement

* All tolerances refer to inspections in the second growing season.

Comparisons in gauze houses between VT 'Sols' and indigenous Scillonian 'Sols' were started in 1971.[40] VT bulbs showed advantages in terms of numbers of stems and florets, flower and leaf size, and bulb yields, over ordinary stocks. There were similar responses to burning-over, but VT stocks showed more advantage in non-burnt stocks. VT stocks gave better yields when twin-scaled. However, in further trials six years later, the yield advantage of VT stocks was only modest, and crop appearance similar: it was suggested that improvements in husbandry, especially the use of more effective fungicide spray programmes, might have been responsible for this change.

Comparisons using standard cultivars

The growth of symptomless plants, plants infected with narcissus mosaic virus, and plants infected with both narcissus yellow stripe virus and tobacco rattle virus, was investigated earlier, using 'Minister Talma'.[41] These plants had been sourced by virus-indexing and had been propagated separately in isolation, and bulbs of the same size were selected for the work. Infection did not affect flower number or size, but flower quality and stem length were reduced in the infected plants. Early on, symptomless plants were taller with a larger leaf area, but this was due to the infected plants having a leaf area curve shifted backwards by about two weeks. Total yields were similar in all three cases, so any loss of vigour due to infection may have been countered by the delay in senescence. The losses obtained as a result of virus infection were relatively small, contradicting some earlier estimates.

In a study in Scotland, adjacent plantings of VT stocks (at least five years from twin-scaling, then field-acclimatised for a further three years) and visually healthy commercial stocks (with a significant proportion of plants with mild symptoms due to narcissus mosaic virus and narcissus tip necrosis virus) were compared.[42,43] In the first year, stocks emerged in geographical order, southern-most first. Thereafter, VT stocks were the first to emergence, flower and senesce, and out-yielded ordinary stocks by 15 to 20%. There were differences between stocks in the number of leaves per bulb, suggesting difference in the numbers of growing points. When the data were adjusted for leaf number differences and the different origins, the VT stocks still maintained their yield advantage of 9 to 20% due to the production of heavier bulbs. There were no consistent differences between flower size and stem length in the two stocks. When the trials were conducted under protection, the yield differences were not significant.

A series of trials with VT and commercial stocks of 'Carlton', 'Fortune' and 'Ice Follies' was carried out at Rosewarne and Kirton, some under HDC funding (HDC Project BOF 2 and 2a).[44,45] These showed there was a consistent yield advantage for the VT stocks in Cornwall, but a variable one at Kirton. When VT and ordinary stocks were grown for two years at Rosewarne, and then moved to Kirton and grown-on for a further two years, the differences between the stocks became less. This suggested that VT bulbs were able to take advantage of the earlier, milder conditions in the South-West.[46,47] This may suggest that, when growing VT stocks, cultural practices may need to be adjusted to take account of their greater vigour (by using lower planting densities).

Bulbs of ‘Carlton’, ‘Dutch Master’ and ‘Unsurpassable’ from English VTES were compared with local, commercial Polish stocks. Though bulb multiplication rates were similar between the two stocks, the VTES bulbs produced the higher yields of flowers and longer flower stems.[48]

Re-infection rates for VT stocks

The acceptability of VT stocks depends partly on how quickly they might be re-infested, and some studies of re-infestation rates were made.

Re-infection rates in ‘Sols’

In ‘Grand Soleil d’Or’ tested in the Isles of Scilly, seven out of 12 VT plants planted in a commercial situation were found to have NDV after 18 months, suggesting large-scale replacement would be necessary.[9]

In field trials of VT and commercial stocks of ‘Grand Soleil d’Or’, grown in proximity in sterilised media for three years, 62% of VT plants had NDV and 75% had arabis mosaic virus, whether or not in sterilised plots.[32]

Re-infection rates in standard cultivars

Bulbs of four cultivars, free of tobacco ring and strawberry latent ring-spot viruses (TobRSV and SLRV), were grown in Scotland on soil infected with these viruses for two years, after which 10 to 65 and 0 to 10% were infected with the two viruses in the different cultivars, respectively.[49]

In a further trial in Scotland, in a field adjacent to ordinary commercial stocks, VT ‘Carlton’ had 0.8% tests positive for narcissus tip necrosis virus by the third year.[35]

The virus re-infestation of VT Mother Stocks of ‘Carlton’ and ‘Fortune’ was studied over six years at Kirton in HDC Project BOF 2a.[37] The bulbs were grown-on in a vector-proof mesh tunnel, in isolated, soil-sterilised field plots either under a mesh tunnel or in the open, and in the field adjacent to ordinary narcissus stocks. Re-infestation was measured using the ELISA technique and as the appearance of visual symptoms (Table 53). Positive tests and visual symptoms were few and sporadic over this period. narcissus mosaic virus has no known vector, so finding it may have been the result of a previously undetected level in the VT Mother Stock. Narcissus yellow stripe virus and narcissus latent virus are aphid-borne, but were only detected in the plots growing adjacent to ordinary stocks in the field.

The results showed that virus re-infection occurred at a slow rate, particularly where VT stocks were sited in isolation.

Table 53 Rates of virus detection in VTMS narcissus after growing for two, four and six years in different locations; virus recorded as number of positive ELISA tests (out of 20)* and as appearance of visual symptoms

Growing situation	Years down	‘Fortune’		‘Carlton’	
		ELISA	Visual	ELISA	Visual
VTMS vector-proof mesh tunnel	2	0	no	0	no
	4	0	no	0	no
	6	0	no	0	no
Sterilised, isolated plots in mesh tunnel	2	0	no	0	no
	4	0	no	2/20 (NMV)	no
	6	0	no	0	no
Sterilised, isolated plots in open	2	0	no	0	no
	4	0	no	0	no
	6	0	no	0	no
Ordinary field plots	2	0	no	1/20 (NMV)	no
	4	2/20 (NYSV)	no	0	no
	6	0	no	1/20 (NLV)	yes

*NYSV, narcissus yellow stripe virus; NMV, narcissus mosaic virus; NLV, narcissus latent virus.

19.3 Producing small-bulbed cultivars and species (including seed-raised bulbs)

Dwarf and small-bulbed cultivars

Growing small bulbed narcissus such as cyclamineus, jonquilla and triandrus cultivars requires a sandy soil to facilitate bulb lifting and labour-intensive handling. It may be appropriate to modify equipment designed for handling other small bulbs such as freesias or onion sets.

Many of these bulbs are also relatively ‘delicate’ or, like ‘Tête-à-Tête’, prone to diseases such as Penicillium rots, skin diseases and smoulder.[50] Their production therefore requires extra care in disease management – in pesticide use, general handling, drying and storage; these factors have been referred to in the main sections on the production of standard narcissus.

Narcissus species

There is little commercial production of *Narcissus* species, and what there is, is limited to specialist nurseries. In the past, large numbers of bulbs of many species have been exported from Mediterranean countries, especially Portugal.[51] Several *Narcissus* species are considered to be under threat as a result of over-collecting or loss of habitats.[52] Bulb companies are now fully aware of the environmental implications of trading wild-collected bulbs. With rising consumer interest in these fascinating plants, and a voracious interest amongst narcissophiles, there would be scope for niche production if sustainable stocks could be secured and maintained through sustainable husbandry. Production from seed, as well as bulbs, would be important.

Production from seed

Production from seed is obviously used by breeders, but is also important for species that form few offsets or for which bulbs are hard to come by. Appropriate temperatures and other conditions are needed for germination.

- Breeders may sow seed soon after collection, either outdoors or in a cold-frame, and germination occurs somewhat unevenly in spring. Under natural conditions, seed of *N. pseudonarcissus* germinated naturally in November or December.[53] When seed was sown outdoors in early May soon after collection, *Narcissus bulbocodium* types started to germinate in late-August, with germination continuing through the winter, but *N. pseudonarcissus* progeny did not germinate until early spring.[54]

- Under natural conditions, summer drought may induce dormancy in *N. pseudonarcissus*.[55,56]

- *Narcissus* seeds reportedly have a cold requirement of many weeks.[57] Seed of commercial cultivars germinated with a cold treatment of 12 weeks at 12°C.[58]

- In *N. bulbocodium* conditioning imbibed seed for seven weeks at 26°C resulted in rapid germination when the seeds were subsequently moved to 16°C. This suggests that seed should be sown in a warm glasshouse and moved to cooler conditions after two months.[59]

- There is little information on other aspects of the seed physiology of narcissus. Seeds of *N. pseudonarcissus* were reportedly not light sensitive.[53]

The germination of *N. pseudonarcissus* has been studied recently in Belgium.[60] In nature, embryo growth was initiated from the moment the seeds were dispersed in spring, and continued during summer. A sequence of high temperatures followed by lower temperatures was needed to complete embryo growth and initiate germination, which took place in autumn.

Under optimum conditions it takes three years for seed-raised plants of species such as *N. bulbocodium* and *N. triandrus* to reach flowering size, four to five years in other species and seven to eight years in some cultivars.[51,61] Having such long periods to produce saleable bulbs is a strong disincentive to commercial production.

Germination and growing systems for the commercial production of *N. cyclamineus*, *N. bulbocodium* var. *citrinus* and *N. pseudonarcissus* were investigated in HDC Project BOF 34 (Images 72 to 74).[62] The main findings were as follows:

- Rapid, synchronous germination was obtained in all three species after keeping imbibed seed at 25 to 30°C for eight to 12 weeks and then transferring to 15°C.

- Controlling seed-borne fungi by disinfection, HWT or fungicide treatments proved difficult.

- Seedlings could be raised successfully in cellular trays for sale as 'plug plants' or for growing on.

- *N. bulbocodium* var. *citrinus* and *N. cyclamineus* bulbs attained a flowering size (3-5 cm diameter) in two to three years, and *N. pseudonarcissus* (over 5 cm diameter) in three to four years.

72 *N. bulbocodium*: 1-year-old bulb 'plug plants'

Photo: Warwick HRI and predecessors

73 *N. cyclamineus*: 3-year-old bulbs

Photo: Warwick HRI and predecessors

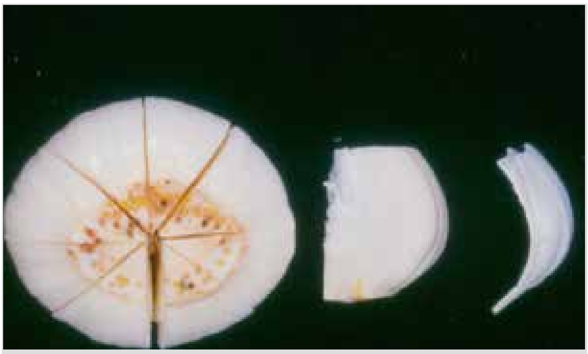
74 *N. bulbocodium* produced from seeds

Photo: Warwick HRI and predecessors

19.4 Propagation – chipping and twin-scaling

Narcissus production is hampered by the prolonged time needed to bulk-up new cultivars to commercial scale quantities of bulbs, starting with a single bulb, that is, around 20 years. Using natural multiplication, with an increase of about 1.6-fold per annum, it takes about 16 years to go from one to 1,000 bulbs.[63] The bulb industry has been cautious to take up micropropagation (tissue culture) on cost grounds and technical issues. Micropropagation is a specialist technique that is beyond the scope of this manual, but several reviews have been published elsewhere.[64,65]

Propagation techniques, where used with narcissus, have been based on the twin-scaling or chipping techniques. Of the simple bulb propagation methods available, scooping and cross-cutting, standard techniques for hyacinths, were found to be ineffective when used on narcissus.[66,67] Leaf cuttings are also unsuccessful.[68,69] However, twin-scaling, and its simpler derivative known as chipping, were successfully adapted to narcissus from methods used with other Amaryllidaceae. The bulb is cut into a number of vertical segments and the segments then divided into single or paired scale-pieces, each with a sector of the base plate attached (Image 75).[70,71,72] Only a small percentage of single scale-pieces, but over 80% of paired scales ('twin-scales') produced bulblets (bulbils). These bulb division methods rely on the destruction of the apical dominance of the existing buds, resulting in adventitious bud formation on the proximal part of the bulb scale adjacent to the base plate.[73,74,75,76]



75 Left to right: Bulb cut to segments, chip and twin-scale

Photo: Warwick HRI and predecessors

Twin-scaling

In twin-scaling flowering-size bulbs are cut into a number of vertical segments (often eight or 16), each with a wedge-shaped piece of base plate. The segments are further divided by, starting at the outside of the segment, cutting off the scales in pairs, each with a conjoining piece of base plate; 60 to 100 twin-scales can be cut from one large bulb. The pieces are incubated in a moist medium (usually damp vermiculite) for three months in the dark at 20°C, during which bulblets develop (Image 76), usually one per 'twin-scale', 80-90% of twin-scales successfully forming bulblets that when grown-on flower in their third or fourth year.[73,75,77,78] Using a wide range of cultivars at Rosewarne, it was shown that one bulb could be multiplied to between seven and 41 flowering-size bulbs in four years, compared with six by natural increase.[79] Twin-scaling was used to multiply VT narcissus stocks in Scotland,[80] and is used elsewhere to propagate valuable material. Practical accounts of twin-scaling are available.[81,82]

76 Incubated twin-scales with bulblets

Photo: Warwick HRI and predecessors

Chipping

Twin-scaling is a simple but labour-intensive, and the propagules are small and delicate. More robust propagules can be obtained by dividing only partly the original bulb segments, giving pieces with a few scales each,[66,72] or by leaving the original eight or 16 segments ('chips') intact (Images 77 and 78).[83] Several practical accounts of chipping are available.[84,85,86,87,88]

As well as being used for on-farm multiplication of select stocks and cultivars, chipping produces attractive round bulbs ideal for sale in pre-packs and with potential for improving predictability, uniformity and mechanised handling.[89] The method has been used extensively with cultivar 'Tête-à-Tête', where 14 to 71% of the bulblets produced flowered in their second year.[89] It was also successful with several *Narcissus* species.[90] Although earlier projections of multiplication rates may have been unduly optimistic,[91] multiplication rates of three or four fold per annum (equivalent to six and a half or five years from one to 1,000 bulbs) are now considered realistic.[92]

77 Incubated chips with bulblets

Photo: Warwick HRI and predecessors

78 The bulbets from one bulb after a year

Photo: Warwick HRI and predecessors

Factors affecting productivity

The factors affecting the productivity of twin-scaling and chipping have been extensively reviewed,[92,93] and the following is a brief account.

Bulbs for chipping should receive HWT about a week before cutting, which improves results and controls bulb-scale mites, but HWT immediately before chipping is harmful.[89]

Bulblet growth is best when propagation takes place using 'dormant' bulbs in July or August,[77,89,94] and this produces propagules ready to plant-out at a convenient time of year.

Cutting many small twin-scales (e.g. 0.5-0.8 g) or chips (16/bulb) maximises multiplication,[88,95] but small propagules take four or more years to produce bulbs of flowering size. It is more pragmatic to sacrifice numbers for bulblet size and a quicker production of flowering-size bulbs: bulbs of 10-12 cm circumference should be cut into eight segments only.[87,89] Cutting rates can be adjusted to initial bulb size to achieve target bulb weights after a year, after which bulb rate increase is independent of cutting method.[96]

Chipping machines are available which can increase throughput to about 0.5 t/day.[97,98]Chipping machines are based on either a star-shaped blade operated by a pneumatic plunger or on arrangements of circular saw blades fed with bulbs or bulb halves on a conveyor.

To avoid spreading pests and disease between bulbs and minimise other contamination, sensible hygiene should be observed, including disinfecting blades.[89]

Immediately following cutting, twin-scales or chips are treated by soaking in a fungicide. In earlier investigations the most effective fungicides included products based on captan and benomyl (often in combination),[87,89,99] but suitable fungicides with approvals for use in bulb dipping are no longer available in the UK. In practice, moulds associated with bulbs may be difficult to control during incubation of the propagules, perhaps because of the presence of fungicide-resistant strains[100] or due to using grossly infected bulb stocks (Image 79).[87]

Bulblet production on twin-scales is inherently variable because of the different properties of bulb scales from different parts of the bulb.[101]

Chips or twin-scales are usually incubated after cutting, usually by mixing with damp vermiculite and holding in trays at 20°C for 12 weeks.[87] These conditions are ideal for fungal growth as well as bulblet production.

Attempts to scale up the treatment of machine-cut chips by using deep crates, or by omitting the medium and controlling humidity, gave promising results.[102]

Immediately after cutting it is important to control chip temperatures which increase as a result of wound respiration and the production of heat by the damped vermiculite, although the exact temperature and duration of incubation is not critical.[87,103]

By the end of incubation, the bulb scales should be largely depleted of reserves: bulblets over 10 mm in length grow well, but smaller ones often remain dormant; these may sprout in the second year, or may become desiccated.[31]

The propagules are planted in the field following the gentle removal of the vermiculite, and in some cases after a pre-planting fungicide soak.[104]

In the case of twin-scales, better growth has been reported following planting in a frost-free glasshouse than in an unheated gauze house.[105]

As an alternative to incubating chips, they may be planted in the field directly after cutting and fungicide treatment ('direct-planting'), but chipping should take place in July so that bulblets are produced before soil temperatures become sub-optimal, or a polythene mulch may be used to raise soil temperatures from planting to emergence.[106,107]

In the field, plant growth should be maximised through careful husbandry, for example controlling weeds by using non-damaging herbicides or a straw mulch, having a prolonged fungicide spray programme, and using a low planting density.[87,104] Planting densities quoted include 0.5 million chips per ha or 1 to 5 t of original bulb weight per ha.

79 Penicillium rots - a problem in chipping

Photo: Warwick HRI and predecessors

In HDC project BOF 23[108] 'Tête-à-Tête' was evaluated as a chipped crop. *Penicillium* rots were a problem, with 14 to 40% of chips rotting during incubation. When chipped in late-July, bulb yields were similar to those when incubated before planting or when planted directly after chipping. The results were poor if chipping and planting was delayed until mid-August. A planting rate of 5 t/ha (measured as the weight of bulbs that were chipped) gave satisfactory bulb yields. Using a straw mulch did not increase yields, though leaving half of the straw in place after shoot emergence usefully suppressed weeds.

Optimised production in the field

Standard bulb production is designed to give the most cost-effective production of bulbs and (or) flowers, but in the case of valuable bulb stocks it may be more important to maximise bulb yields. This can be achieved by reducing planting density and by adopting one-year-down growing. Planting density should be reduced so that inter-plant competition is minimised, provided there is no wind damage. In a trial of optimised bulb production, low planting densities and annual planting and lifting were effective, but there was little additional benefit of using combinations of foliar feeding, top-dressing, de-heading, irrigation or fungicidal sprays.[109] However, all these methods might be considered beneficial in specific circumstances where it is desired to maximise bulb yields.

Future growing systems

In time, it is likely that the UK narcissus industry will need a structured programme to ensure the availability of the highest quality stocks and the rapid commercialisation of new, improved cultivars.[93] This might begin with micropropagation, continue with a low-cost macro-propagation method such as chipping, and end with optimised field growing.

The Dutch crop economist de Vroomen identified three growing systems currently used in Dutch bulb growing.[110]

- Combined production of commercial-sized bulbs and planting stocks with natural multiplication, the system currently used for narcissus and many other flower-bulbs, such as tulip and Dutch iris.
- Growing commercial-sized bulbs in two- to four-year cycles from planting stock that is produced by an artificial multiplication process, for example, the system used with hyacinths where new planting stock is obtained from ‘scooped’ hyacinth bulbs.
- Separate production of the planting stock and the commercial-sized bulbs, the system used for gladiolus.

With the development of optimised narcissus chipping and growing-on, it would be possible to envisage a hyacinth-type system being used. This would allow for the continuous production of high-health propagation material to be fed into the industry, with all bulbs produced from them in the field being sold (or used to produce flowers and then disposed of); this would eliminate the continuous recycling of pests and disease.

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Glossary

Alatae	Winged forms of aphids important for migration
Base (or basal) plate	The solid region of stem tissue at the base of a narcissus bulb
Basal (or base) rot	A rot of the base plate usually caused by *Fusarium oxysporum* f.sp. *narcissi*
Benzimidazole	A class of fungicides including benomyl, carbendazim and thiabendazole (also called MBCs)
Biocide	Disinfectant
Bulb dip	A 'dip' implies a brief (seconds to a few minutes) plunge into a treatment solution, but is often used in narcissus growing for a more prolonged immersion in a treatment solution (better called a bulb soak) or even HWT; the 'dip' also refers to the treatment solution itself
Bulbous crops	Sometimes used loosely in commercial horticulture to refer to corms, tubers, etc., in addition to botanically 'true' bulb crops
Bulb soak	A lengthy (up to three or more hours) immersion of bulbs in a treatment solution, as opposed to a brief (dip) treatment
Bulb unit	In narcissus, a set of bulb scales, leaves and a flower originating from one growing point and growing as a 'unit'
Chipping	A method of bulb propagation in which bulbs are divided into segments called 'chips'
Cluster (bulb)	A narcissus 'bulb' in the general sense, which may have one to several growing points making up one to several bulb units
'Contemporary bulb growing'	Used throughout to refer to practices used from the 1980s, in contrast to more 'traditional' practices used previously
Corona	Horticultural term for the trumpet or cup (also called paracorolla) of a narcissus
Cultivar	A plant variety derived in horticulture
Daffodil	Often used in the UK to refer to trumpet or large-cup narcissus (Division 1 or 2) cultivars, sometimes used as a general term to cover all types of narcissus
Disposable yield	The yield of bulbs from a crop after subtracting the weight required for re-planting (usually the same weight as originally planted): hence, plant 100 t, lift 250 t, disposable yield = 150 t
'Dormant' season	Generally used for the period when bulbs are not showing above ground; in fact, a period of intense growth and development within the bulb
Formaldehyde	The active ingredient of formalin
Formalin	A disinfectant formerly used in bulb growing; also known as commercial formalin
Groundkeeper	Any plant unintentionally left in the ground after harvesting
Hot-water treatment	A standard treatment used to control stem nematode and other pests and diseases in narcissus, often abbreviated as HWT
MBC fungicide	Same as benzimidazole fungicide
Narcissus	Used here to include all types of daffodil and narcissus
Pacific Northwest	The north-western USA, mainly in Washington State, an important horticultural region
Paracorolla	Botanical term for the trumpet or cup (corona) of a narcissus
Percentage increase	A conventional measure of bulb yield: % bulb weight increase = [(weight lifted – weight planted) x 100)] / weight planted. Hence, plant 100 t, lift 250 t, % weight increase = 150%
Perianth	Botanical term for the perianth segments (petals and sepals) collectively
Perianth segment	Botanical term for individual petals or sepals when these are alike (as with narcissus)
Scape	Botanical term for a flower stem which is leafless, as in narcissus
Stem	See scape; in terms of cut-flowers, 'stem' is also used for the stem with its flower
Sterilising	Colloquial term for hot-water treatment
Taxon (plural, taxa)	A level of plant classification (e.g. genus, species or variety)
Tepal	Botanical term to include sepals and petals when they are similar in appearance (as with narcissus)
Volunteer	Same as groundkeeper

Abbreviations and acronyms

ADAS	(The former) Agricultural Development and Advisory Service, part of the former MAFF (later privatised as ADAS, distinguished as 'ADAS Ltd' in this manual)
ADAS Ltd	The privatised 'successor' to ADAS
ADS	American Daffodil Society
AHDB	The Agriculture and Horticulture Development Board
a.i.	Active ingredient (or active substance) of a pesticide, etc.
BKD	*Bloembollenkeuringsdienst* (the Netherlands)
CABGA	Cornwall Area Bulb Growers' Association
CADB	*Consulentschap in Algemene Dienst voor de Bloembollenteelt* (the Netherlands)
ClO_2	Chlorine dioxide (a biocide)
COSHH	The Control of Substances Hazardous to Health Regulations 1988
CSL	(The former) Central Science Laboratories, part of MAFF, now within Fera
Defra	Department for Environment, Food and Rural Affairs, formerly MAFF
DBI	Dry bulb inspection (part of plant health checks)
EHS	(The former) Experimental Horticulture Station (part of ADAS)
ELISA	Enzyme-linked immunosorbent assay
Fera	Food and Environment Research Agency (incorporating the former CSL, PHSI and other agencies)
FYM	Farm-yard manure
GCRI	(The former) Glasshouse Crops Research Institute, Littlehampton, West Sussex
GSI	Growing season inspection (part of plant health checks)
HDC	(The former) Horticultural Development Council, later Horticultural Development Company), now a sector of the Agriculture and Horticulture Development Board
HRI	(The former) Horticulture Research International, later Warwick HRI
HWT	Hot-water treatment of narcissus bulbs (sometimes called 'sterilising')
IACR	Institute of Arable Crop Research, Rothamsted
IFBC	International Flower Bulb Centre, Hillegom, the Netherlands
IKC	*Informatie en Kennis Centrum Landbouw, Laboratorium voor Bloembollenonderzoek*, Lisse (the Netherlands)
Kirton	(The former) Kirton EHS, later the Kirton Research Centre of Warwick HRI, Kirton, Boston, Lincolnshire
LBO	*Laboratorium voor Bloembollenonderzoek*, Lisse (the Netherlands)
MAFF	(The former) Ministry of Agriculture, Fisheries and Food (now Defra)
MLNV	*Ministerie van Landbouw, Natuurbeheer en Visserij* (the Netherlands)
NAAS	(The former) National Agricultural Advisory Service, which became ADAS
NBCC	ADAS Ltd's National Bulbs Consultancy Centre
NV	Neutralizing value (e.g. of lime)
PCN	Potato cyst nematode
PHSI	Plant Health and Seeds Inspectorate, now part of Fera
ppm	(Of a dilution) parts per million, the same as (for example) mg/L or µg/ml
PPPR	Plant Protection Products Regulations
PVS	*Producktschap voor Siergewassen*, Den Haag (the Netherlands)
RHS	Royal Horticultural Society (UK)
Rosewarne	(The former) Rosewarne EHS, Camborne, Cornwall
SBS	Sodium bisulphate (sodium hydrogen sulphate), an acidifier
Starcross	(The former) ADAS Laboratory at Starcross, Exeter, Devon
SGRPID	Scottish Government Rural Payments and Inspections Directorate
USDA	United States Department of Agriculture
VT bulbs	Virus-tested bulbs (often called 'virus-free' bulbs)
Warwick HRI	(A former) department of the University of Warwick concerned with horticultural research, now incorporated in the University's School of Life Sciences which includes the Warwick Crop Centre based at Wellesbourne
Wellesbourne	(The former) Wellesbourne site of HRI and Warwick HRI, once the National Vegetable Research Station, Wellesbourne, Warwickshire, now the base of the Warwick Crop Centre (see Warwick HRI)
WSU	Washington State University

Acknowledgements

I thank all those who have advised me on the contents of the Narcissus Manual, special thanks being due to Adrian Jansen (HDC co-ordinator for the project) who refereed the whole work and gave much helpful advice. A succession of HDC managers brought the manual to the production stage, and special thanks are due to Wayne Brough for supervising its completion and carrying out the final editing.

I thank Malcolm Millar and Roy Willingham, who edited substantial sections of the manual in its early stages, and all those who advised on specialist areas, including: Mark Clark (bulb growing in Scotland), Dr Rosemary Collier (pests), Cathy Knott (herbicides), Dr Clive Rahn (plant nutrition), Lin Secker (hot-water treatment), John Snowden (plant health), Claire Streit (flower conditioners and flower foods) and Mark Vandervliet (bulb growing in Cornwall and the Channel Islands). The photographs are credited individually with the exception of the front cover images, small images left to right courtesy of Secker Welding, HRI Warwick and predecessors and Cathy Knott.

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