Fungal disease management

Most of vegetables are grown from seeds

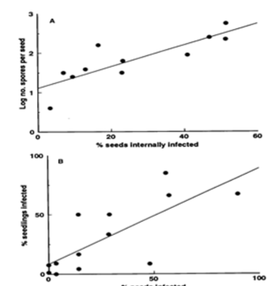
Significance of seed-borne diseases

- Prolonged transmissibility
- Maximum infection
- Dissemination over long distance
- Introduction to new area
- Infected new soil
- Random infection foci in production field

Viability of seedborne fungal pathogens after storage at −20°C

Fungus	Host	No. of samples	Storage period (years)	Seeds infected (%) Start	End
Ascochyta pisi	Pea	8	8–11	18	14
Ascochyta fabae	Vicia bean*	5	9–13	14	14
Pleospora betae	Sugarbeet	2	14	30	23
Leptosphaeria nodorum	Wheat	9	9–14	50	39
Micronectriella nivalis	Wheat, rye, barley	5	9–12	19	19
Cochliobolus sativus	Wheat, barley	9	8–12	43	33
Pyrenophora teres	Barley	5	8–12	24	16
Pyrenophora graminea	Barley	4	11–12	47	44
Colletotrichum lindemuthianum	Phaseolus bean†	1	12	99	93
Ascochyta boltshauseri	Phaseolus bean	1	12	52	41
Leptosphaeria maculans	Cabbage	1	11–13	13	12
Alternaria dauci	Carrot	4	9–14	22	21
Alternaria radicina	Carrot	3	14	37	28

* *Vicia faba.*
† *Phaseolus vulgaris.*



Seed infection relationships of *Alternaria brassicicola*. (A) Relationship between superficial conidia and internal infection of seeds. (B) Relationship between internally infected seeds and diseases seedlings.

Seed transmission relationships.

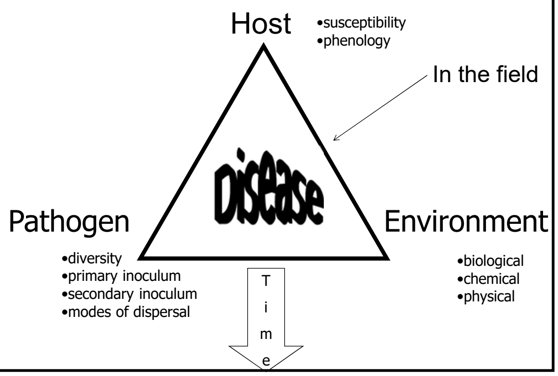
Pathogen	% infection in Lab/glhse	Field soil	Transmission ratio	Crop	Reference
Polyspora lini	15.0	1.7	9:1	Flax	Henry and Campbell, 1938
Colletotrichum lini	66.3	17.0	4:1	Flax	Henry and Campbell, 1938
Pyrenophora graminea and *P. teres*	50–75	5–10	10:1 to 7.5:1	Barley	Jorgensen, 1977
	50–65	0–11	0:0 to 6.0:1	Barley	Jorgensen, 1977
Ascochyta pisi	11.2	3.3	4:1	Peas	Maude and Kyle, 1970
	6.3	0.4	16:1	Peas	Maude and Kyle, 1970
	34.0	6.5	5:1	Peas	Maude and Kyle, 1970
Alternaria brassicicola	62.0	11.0	6:1	Cabbage	Maude and Humpherson-Jones, 1980b
	11.5	1.2	10:1	Kale	Maude and Humpherson-Jones, 1980b
	1.5	0.0	0:0	Kale	Maude and Humpherson-Jones, 1980b
Alternaria brassicae	28.0	9.3	3:1	Cabbage	R.B. Maude, pers. comm., 1991
	10.5	1.2	9:1	Oilseed rape	R.B. Maude, pers. comm., 1991
	14.0	1.2	12:1	Oilseed rape	R.B. Maude, pers. comm., 1991
Pseudomonas syringae pv. *phaseolicola*	9.2	0.84	11.0:1	Phaseolus bean	Taylor, 1970b
	3.5	0.37	9.5:1	Phaseolus bean	Taylor, 1970b
	1.4	0.15	9.3:1	Phaseolus bean	Taylor, 1970b
	0.1	0.0	0:0	Phaseolus bean	Taylor, 1970b
Pseudomonas syringae pv. *phaseolicola*	16.1	1.80	8.9:1	Phaseolus bean	Taylor *etal.*, 1979b
	1.1	0.13	8.5:1	Phaseolus bean	Taylor et al., 1979b
	2.4	0.22	10.9:1	Phaseolus bean	Taylor *et al.*, 1979b
	2.4	0.42	5.7:1	Phaseolus bean	Taylor *et al.*, 1979b
	5.4	0.57	9.5:1	Phaseolus bean	Taylor *et al.*, 1979b

Lab/glhse, laboratory/glasshouse tests

Inoculum thresholds and crop losses.

Crop	Pathogen	No. of affected seeds/ seedlings causing economic loss
Lettuce	Lettuce mosaic virus	1/30,000
Bean	*Pseudomonas syringae* pv. *phaseolicola*	1/10,000 to 1/16,000
Cabbage	*Leptosphaeria maculans*	1/10,000
Celery	*Septoria apiicola*	1/7000
Onion	*Botrytis allii*	1/100
Peas	*Ascochyta pisi*	> 5/100
Field bean	*Didymella fabae*	> 2/100

Disease Triangle



Disease will occur

- Susceptible plant
- Pathogen that can cause disease
- Environmental conditions favourable for disease development

Plant Disease Epidemiology

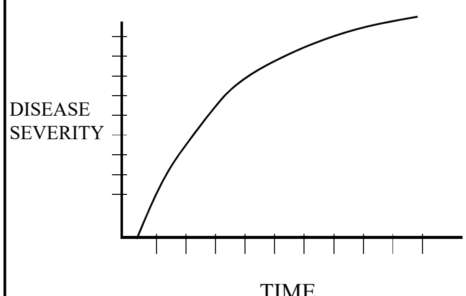
- Components of an Epidemic:
  - (1) Susceptible Host
  - (2) Virulent Pathogen
  - (3) Conducive Environment
  - (4) Favorable Time
  - (5) Extensive Space
  - (6) Favorable Human Activity

A monocyclic pathogen completes just one disease cycle per season. There are no secondary disease cycles

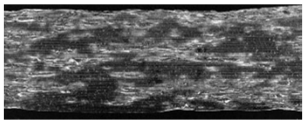
Soilborne pathogens are usually monocyclic due to physical constraints--inoculum is not dispersed within the growing season.

Verticillium wilt of strawberry

Disease progress curve for a typical monocyclic pathogen



Polycyclic pathogens have several secondary disease cycles each season.

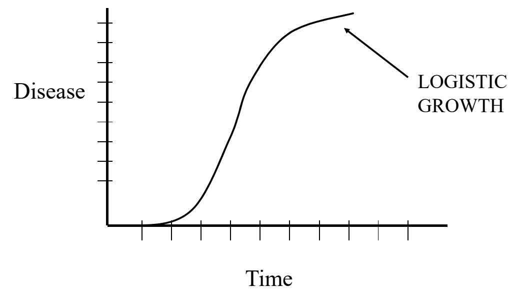


Oat stem rust

Halo blight

Soybean mosaic

Disease progress curve for a typical polycyclic pathogen is an S-shaped curve.



Natural vs “Cultivated” Systems

- “Natural” Systems
  - Genetically Diverse
  - Many plant species
  - Factors of genetics, spatial separation
  - Pathogens (usually) have evolved with their hosts

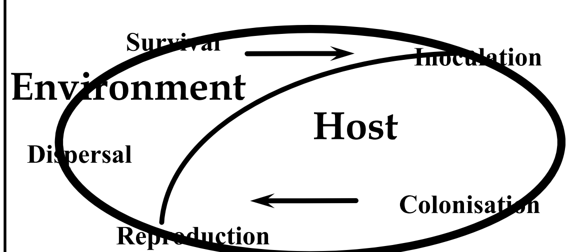
Cultivated Systems

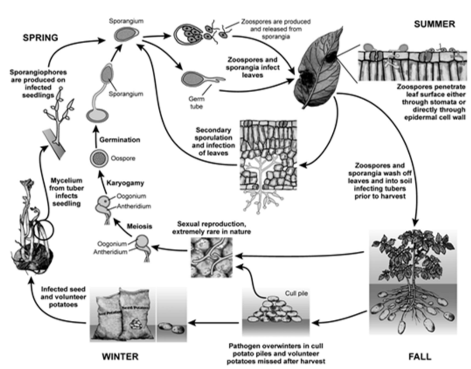
- Economics of production
- Productivity
- Quality control

All require genetically homogenous crops that are:

- Prime targets for epidemics

Chain of Events in Disease Cycles



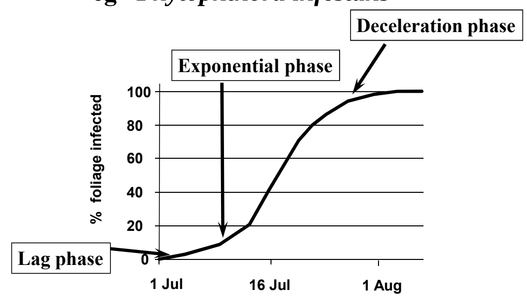


Epidemic

- Natural consequence of introducing a virulent pathogen into a relatively homogeneous susceptible host population

Disease Progress Curve

eg ***Phytophthora infestans***



PLANT DISEASE MANAGEMENT

General Concepts

Disease Triangle

Host
Total of all properties that affect susceptibility

Pathogen
Total of all properties of pathogen (virulence, abundance, etc.)

Environment
Total of all conditions that affect disease

All three factors are necessary components of disease

If components could be quantified, Area of triangle would represent amount of disease.

Vanderplank's Equivalence Theorem

"Effects of host, pathogen and environment can be translated into terms of the rate parameter of an epidemic"

Change in any component has an equivalent effect on disease

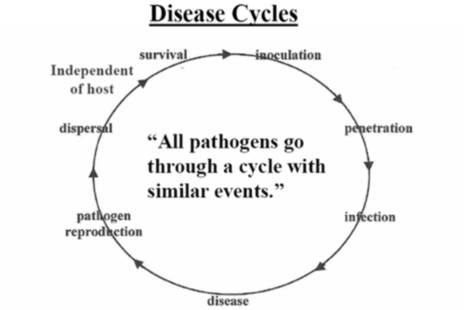
- More-less susceptible host
- More-less aggressive pathogen
- More-less favorable environment

} All affect amount of disease

Therefore, disease management principles and practices are often centered around the concept of the Disease Triangle.

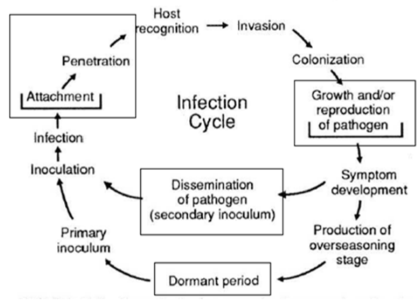
Management tactics often seek to manipulate one or more of the components of the disease triangle.

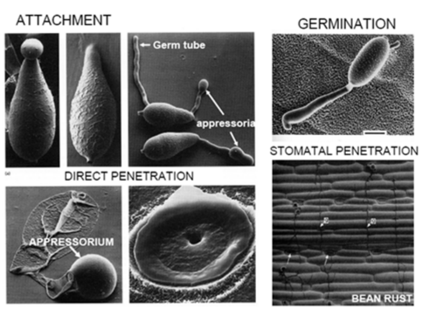
Disease Cycles

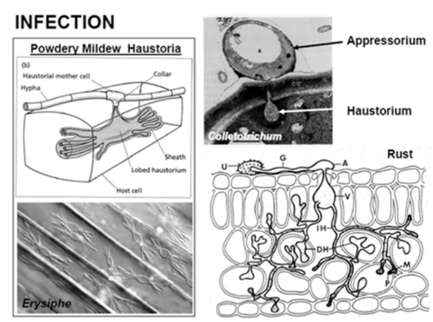


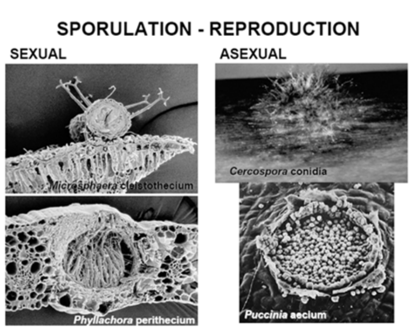
Knowing how particular pathogens go through their disease cycle is important in developing management strategies.

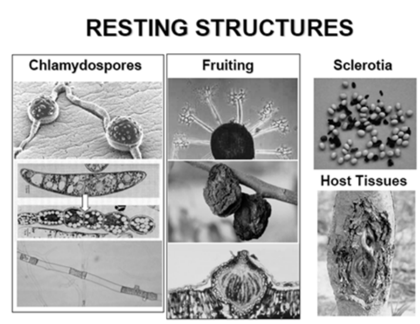
Fungal Infection

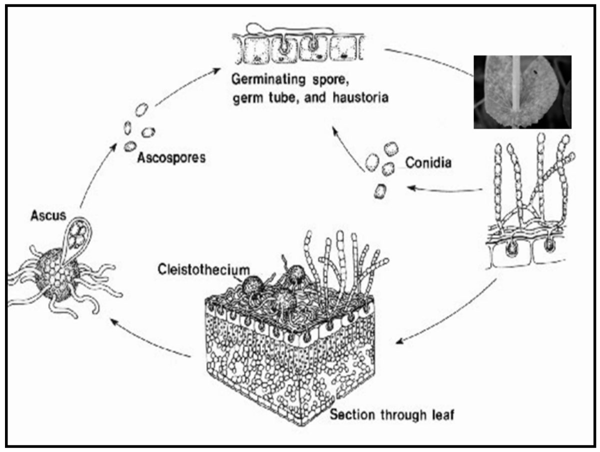












A central concept to epidemiology is that different pathogen populations have different disease cycles.

I. Pathogens that complete one or even part of one disease cycle/year are called <u>monocyclic.</u>

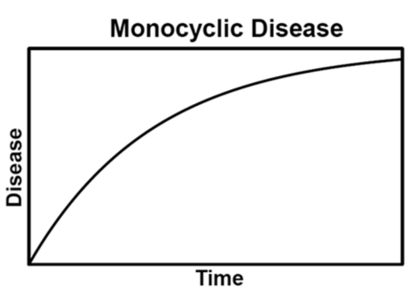
In monocyclic pathogens the primary inoculum is the only inoculum available for the entire season. There is no secondary inoculum and no secondary infection.

The amount of inoculum produced at the end of the season, however, is greater than at the start of the season so the amount of inoculum may increase steadily from year to year.

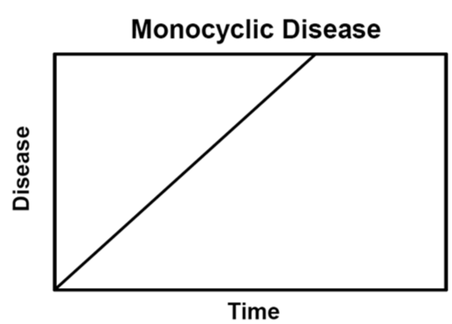
Verticillium wilt of strawberry

This representation of plant disease over time is referred to as a "Disease Progress Curve"

Graphically, disease caused by monocyclic pathogens looks like a saturation curve.



Rate of increase of disease over time can be represented by a simple interest function.



Examples of Monocyclic Diseases

Blackleg of potato (*Erwinia caratovora*)
Verticillium wilt
Cereal Cyst Nematode

II. Polycyclic = multiple cycles/year (compound interest)
Most pathogens go through more than one (2-30) disease cycles in a growing season and are referred to as polycyclic.

Only a small number of sexual spores or other hardy structures survive as primary inoculum that cause initial infections.

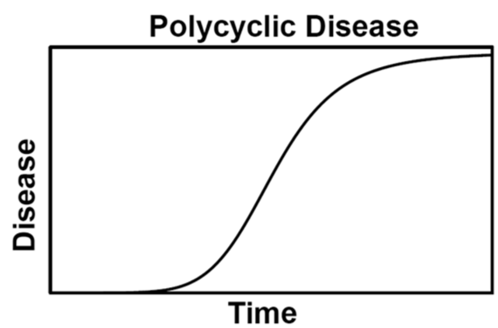
Once infection takes place, large numbers of asexual spores are produced as secondary inoculum at each infection site.

These spores can produce new (secondary) infections that produce more asexual spores and so on.

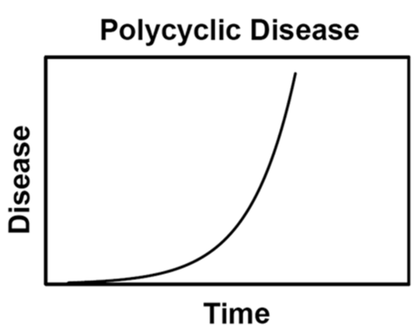
With each cycle the amount of inoculum is multiplied many fold.

Downy mildew of grape

Graphically this type of population growth is represented as a sigmoid curve



Rate of increase of disease over time can be represented by a compound interest function.



Many of these pathogens are disseminated primarily by air
Or air-borne vectors and are responsible for of the explosive epidemics in most crops

Examples of Polycyclic Diseases
Downy mildews
Powdery mildews
Late blight of potato
Leaf spots
Blights
Grain rusts
Aphid borne viruses
Root-knot nematodes

Implications for Disease Management Strategies

Monocyclic Diseases
Reduce the <u>amount of primary inoculum</u>, or affect the efficiency of invasion by the primary inoculum

Polycyclic Diseases
Reducing the amount of primary inoculum has less impact.
Reducing the <u>rate of increase</u> of the pathogen more beneficial.

Stay tuned….

Other Concepts Related to Disease Cycles

Successful Infections => symptoms
Before symptoms:
Incubation period = time between infection and appearance of the disease symptom.

The **<u>length of the incubation period</u>** of different pathogens/diseases varies with:

1. the **<u>particular pathogen-host combination</u>**
2. the **<u>stage of development</u>** of the host
3. the **<u>temperature</u>** in the environment.

Can make disease assessments misleading
If infections are presymptomatic during scouting.

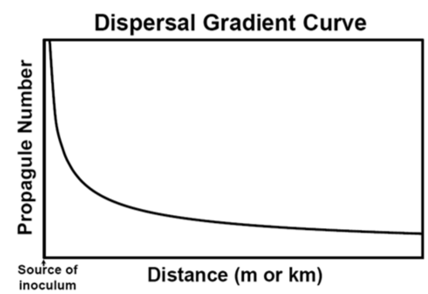
Latent period = time from infection until production of new inoculum (reproduction).

Duration can have a large effect on the <u>rate</u> of the epidemic.

Affected by characteristics of the host (stage of development, age of tissue, physiological condition), the pathogen, and the environment (temperature, moisture).

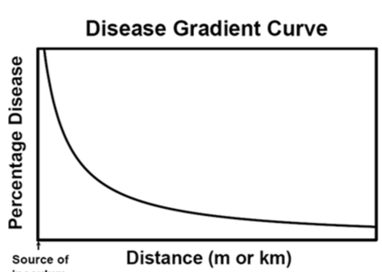
Gradients in pathogen densities and disease are frequently observed.

Factors that affect spatial variation in the amount of incoming inoculum lead to dispersal gradients.



Gradients in pathogen propagule density can result in

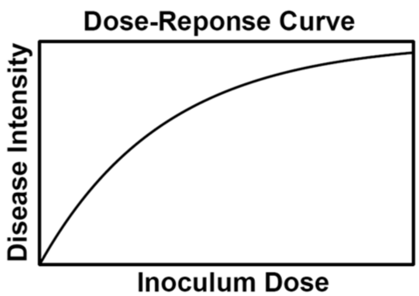
Disease gradients = change in disease severity along a straight line away from the source of inoculum.



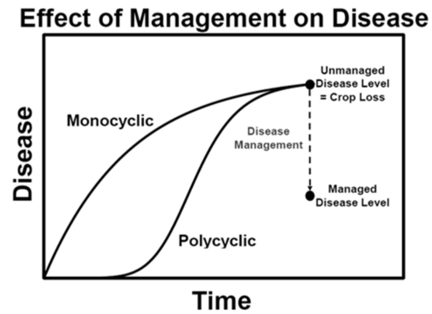
The <u>percentage of disease</u> and the <u>scale for distance</u> vary with the type of pathogen or its method of dispersal, being small for soilborne pathogens or vectors and larger for airborne pathogens.

Disease gradients can also be caused by environmental gradients such as, variations in <u>soil type</u>, <u>fertility</u>, or gradual changes in <u>microclimate</u>.

Variations in pathogen density as the result of dispersal gradients or other causes are important relative to the impact of a Dose Response on disease.

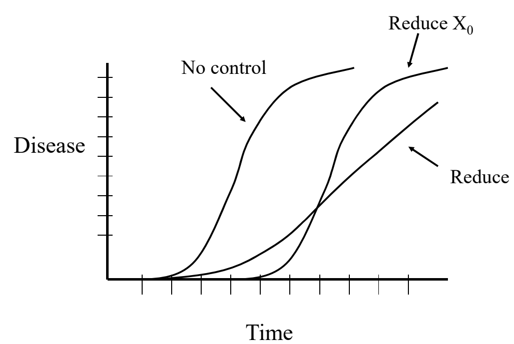


Purpose of disease management is to prevent disease from exceeding some level where profit or yield is significantly diminished.



Principles of epidemiology indicate that control measures can do this in only two ways:

1. They may reduce (or delay) disease at the beginning of the season (x_0) <u>or</u>
2. They may decrease the <u>rate</u> of disease development (*r*) during the growing period.



Ways to reduce disease (inoculum) at beginning (x_0)
Affects monocyclic and polycylic diseases

Fumigation	Certified seed
Sanitation	Seed treatments
Quarantine	Host plant resistance

Ways to decrease the rate of disease development (infection rate) (*r*)
- Change the environment
- Fertilizer application
- Host plant resistance

Ways to change t (see "b" on figure)
- Harvest early before disease becomes severe
- Plant early (cereal cyst nematode)

Control of different diseases requires different strategies.

Some pathosystems, monocyclic and polyetic diseases can be affected by use of an x_0-reducing practice only.

However, for most diseases more than one control procedure is used and these are often chosen to reduce x_0 <u>and</u> *r*.

These integrated control measures use a combination

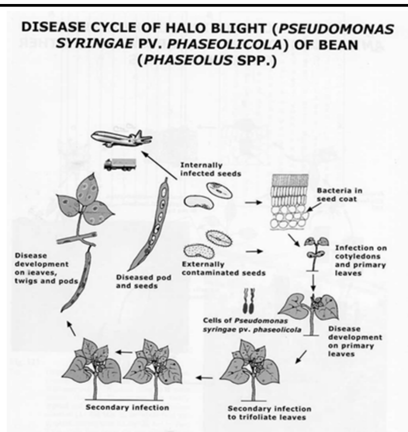
cultural methods,	resistance breeding
regulatory actions,	chemical control measures

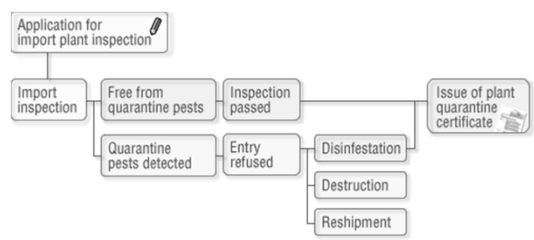
Disease Control Measures

- Quarantine and other exclusion mechanisms
- Cultural practices
- Crop protection chemicals
  - fumigants, fungicides
- Resistant cultivars
- Biological control

Pathogen exclusion -Quarantine & Sanitation

- Sanitation - a matter of common sense
  - machinery, boots etc should be cleaned between fields (soil-borne diseases)
  - recycle run-off irrigation water within same field (*Phytophthora, Pythium, Fusarium*)
    - in nurseries, use chlorinated water

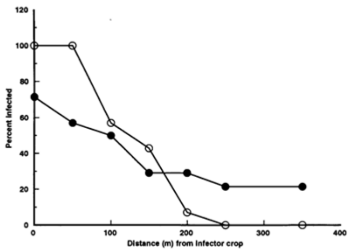




Strategies:
- Prohibition
  - Quarantine & Embargo
- Intercept
  - Inspection
- Elimination
  - Treatment

Sanitation

- Avoid growing crops in fields near (downwind of) inoculum sources
- Avoid sequential cropping
- Destroy stubble. (Foliar diseases)
- Disease-free, or “pathogen tested” planting materials
- Eliminate alternate and reservoir hosts



Cross infection study of *Alternaria brassicicola*. ○, incidence of infected plants in a vegetative brassica crop, August 1978; ●, incidence of infected seeds from the same crop in July 1979. (Redrawn from Humpherson-Jones and Maude, 1982.)

Cultural Practices

- Removal or destruction of inoculum
  - direct removal
  - stubble destruction
  - weed control
- Cultivation
- Heat
- Crop rotation
- Mulching

Soilborne pathogens, inoculum is not dispersed within the growing season but possible dispersed by irrigation, worker

Verticillium wilt of strawberry

Table 3. Effect of soil solarization on subsequent development of Fusarium wilt on lettuce in 2004 to 2007 field trials

Year, solarization period (days)	Soil temperature (°C)[y]	Beds shaped	Disease incidence (%)[z]
2004			
0	37	No	50 a
41	41	No	29 b
2005			
0	41	Yes	92 a
28	47	Yes	9 b
56	46	Yes	8 b
2006			
0	38	No	100 a
0	38	Yes	100 a
30	45	No	84 ab
27	49	Yes	52 b
69	44	No	79 ab
66	48	Yes	44 b
2007			
0	41	Yes	67 a
33	44	Yes	25 b

[y] Mean soil temperature at a depth of 5 cm during solarization period.
[z] Percentage of plants that were dead or diseased and displayed typical symptoms of Fusarium wilt at crop maturity. Values for each year followed by a different letter are significantly different according to the *t* test ($P = 0.13$ in 2004 and $P < 0.001$ in 2007) or the Tukey Test ($P < 0.05$ in 2005 and 2006).

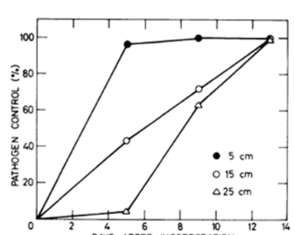


Fig. 1. Effect of solar heating of soil on control of *Verticillium dahliae*. Microsclerotia were incorporated at three depths in either polyethylene-mulched or nonmulched soil and were removed after various periods. Results are expressed as percent control of the pathogen at each layer in the mulching treatment.

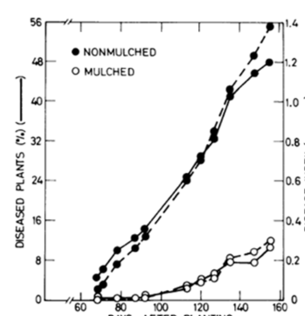


Fig. 2. Effect of solar heating of soil on Verticillium wilt of eggplant. Disease index: scale of 0–4, with 0 = healthy.

Crop Rotation

- The most important cultural measure for disease control
- Breaks disease-cycle of pathogens
- Works best on pathogens with:
  - limited host range
  - low competitive saprophytic ability
  - no survival structures produced during the “non-host” phase
  - short period of viability of survival structures (1-2 years).

Table 2. Effect of crop rotation (ROT), irrigation and nitrogen rate (INR), and cultivar on incidence of Verticillium wilt during 2008 and 2009

	Incidence of Verticillium wilt (%)[w]				
	Individual rotation wedges				
Variable[x]	**B**	**C**	**D**	**ROT[y]**	**CC[z]**
INR					
0.5	0.7 a	0.2 b	1.3 b	0.8 b	5.6 b
1	3.0 a	3.0 ab	1.3 b	2.6 ab	18.0 ab
1.5	9.5 a	9.0 a	7.3 a	8.8 a	33.8 a
Cultivar					
PR	4.3 a	2.3 a	2.2 b	3.3 a	17.5 a
ST	4.5 a	5.9 a	4.4 a	4.8 a	20.8 a

[w] Analysis was conducted on arcsine(incidence of wilt)$^{1/2}$. Mean estimates are presented in Table 2 but the mean separations were based on the transformed values. Different letters indicate that treatments were significantly different at $P \leq 0.05$, based on the PDIFF test using Proc Mixed in SAS.

[x] ROT is the mean estimate in Proc Mixed using the three rotation wedges (B, C, and D). Wedge B was in cotton in both years, while wedges C and D each had 1 year of cotton over those 2 years.

[y] CC = continuous cotton.

[z] INRs were a base rate (designated as 1) that was designed to replace approximately 80% of the evapotranspiration needs of the crop, and then 50% above and below the base rate. PR stands for partially resistant cultivar and was Paymaster 2140B2RF in 2007 and Deltapine 104B2RF in 2008 and 2009; ST stands for Stoneville 4554B2RF.

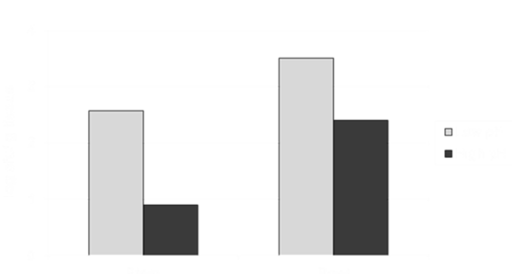
Management of Soil Environment

- Lime, nitrate - increase soil pH
- Sulphur, ammonium - decrease pH
- Sometimes act through direct toxicity
  - eg ammonia vs *Sclerotium, Fusarium, Phytophthora,* nematodes
- Ca in lime can increase Ca pectate formation in roots, which are then less susceptible to attack by *Rhizoctonia solani*

Manipulation of Environment to Modify Inoculum Potential

- Potato scab
- *Streptomyces scabies*
- Modify soil pH (<6.0) to reduce incidence of scabby potato tubers
- General concept that bacteria favor a “basic” environment and fungi an “acidic”” environment

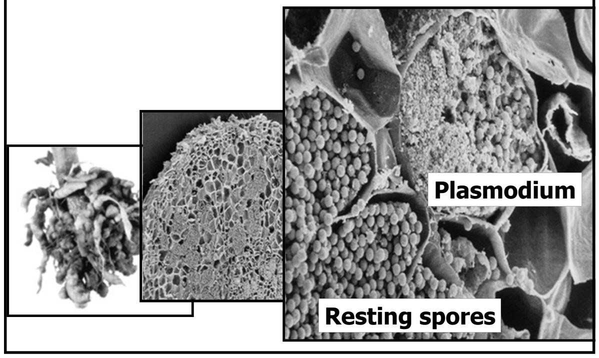
P. gregata detection decreases as soil pH increases in 2000



Clubroot of Crucifers

Clubroot of Crucifers
Plasmodiophora brassicae

Clubroot of Crucifers
Plasmodiophora brassicae



Organic Amendments

- Straw, Lucerne hay, chitinous by-products
- Green manure crops
- Change in nutritional status of soil for micro-organisms
- Complex actions
  - stimulation of antagonists
  - toxic action of breakdown products eg ammonia, saponins

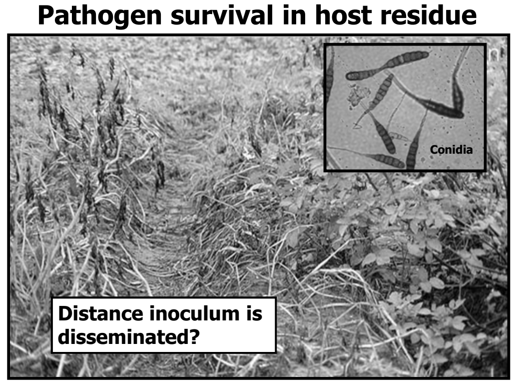
Organic Amendments: Generally incorporated into soil

- ♦Green manure – Grow green manure crop and incorporate living plant material into soil immediately prior to planting.
- Sudan grass – dhurrin (cyanoglucoside) => Hydrogen cyanide
- Species within mustard family – glucosinolates => isothiocynates

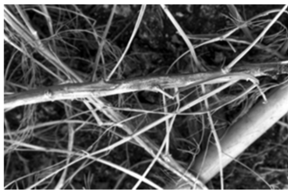
Organic matter – many sources

- Soybean meal
- Meat and bone meal
- Sphagnum peat moss
- Black peat
- Compost-Amended Potting Mixes – Successful in control of root rot pathogens in container systems. (Hoitink et al. 1991. Plant Disease 75:869-873)

Early Blight of Potato
Pathogen survival in host residue



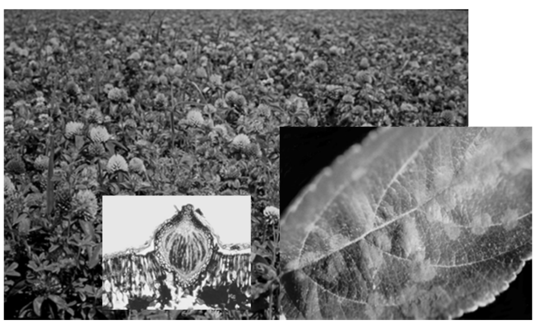
Asparagus plant debris left in the field



Manipulation of Environment to Modify Inoculum Potential

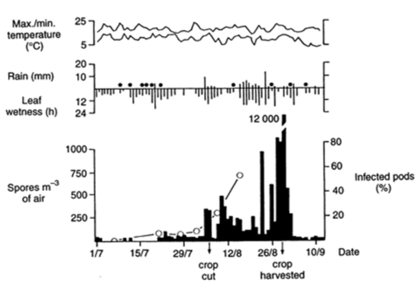
- Application of urea (nitrogen) to orchard litter to enhance microbial decomposition of apple leaves
- Goal to reduce survival of *Venturia inaequalis* in apple leaves
- Reduce primary inoculum

Dense Crop Canopy on Orchard Floor – prevent ascospores from reaching apple buds



Management of Atmospheric Environment/Climate

- Effect of temperatures on disease
- Management of Microclimate -
  - Irrigation
  - Canopy Management
  - Avoid Water stress
- Avoid Heat stress
- Develop forecasting system



Effects of climatic factors and harvesting practices on the mean daily concentration of *Alternaria brassicicola* conidia in the air of a cabbage seed production crop. ●, > 0.2 mm to < 1 mm of rain; ○—○, infected pods.

Protected greenhouse

FUNGICIDES

- Sterilants and Fumigants
- Protectants
- Therapeutics (“systemics”, “eradicants”)

Protectants

- remain on plant surface
- have no effect on established infections
- vary in properties of persistence, redistribution
- broad spectrum
- relatively inexpensive

Therapeutants (systemic)

- compound or a metabolite penetrates host tissue
- may inhibit development of established infections
- often highly specific to certain fungal groups
- vary in “systemicity”, translocation, persistence
- often relatively expensive

Fungicide Application

- Seed treatment
- Soil treatment / “in-furrow”
- Foliar sprays

List of chemicals and commercial products registered

Kinds	Active ingredient
Fungicides	Benomyl,bitertanol, captan,carbendazim, carboxin, difenoconazole, Diniconazole, fenpiconil, iprodione, mancozeb, metalaxyl, metconazole, oxine-copper, pencycuron, quintozene, tebuconazole, thiabendazole, thiram, triadmenol, triazoxide
Bacteriocides	Bronopol, copper hydroxide, kasugamycin, oxolinic acid, streptomyces
Nematicides	Fenitrothion, fenthion, cartap, benomyl
Microorganisms	*Trichoderma, Bacillus subtilis, Pseudomonas cepacia, Rhizobium, Streptomyces griseoviridis*

Major benefits of seed treatment methods

Treatment	Major catagory	Major purpose or application	Horticultural crops
Physical	Irradiation	Sterilization seed-borne diseases	Some crops, if need
	Heat Treatment	Sterilization seed-borne diseases	Many vegetables
	Dry heat treatment	Sterilization seed-borne diseases including tobamovirus and others	Solanaceous & cucurbitaneous vegetables
Chemical	Pesticide treatment	Control of seed-borne diseases and insects in seeds and seedling	Selected vegetables
Biological	Useful microorganism	Trichoderma,Bacillus, Rhizobia, Pseudomonas, and others	Legume and most crops

Seed borne vegetable diseases that can be activatede by heat treatment dry heat treatment, hot water, or other heat-related treatment

Crop	Disease	Seed treatment
Radish	*Alternaria brassicae*	50 C HWT for 10-40 min after 6 hr cold water soaking; 75 C DHT for 72 hr.
Brassica	Black spot (*Alternaria*)	50 C HWT for 30 min after 6 hr cold water soaking; 75 C DHT for 72 hr
	Rhizoctonia root rot	50 C HWT for 30 min after 6 hr cold water soaking
	Xanthomonas campestris	50 C HWT for 15-25 min after 6 hr cold water soaking
	Bacterial leaf spot	50 C HWT for 30 min after 6 hr cold water soaking
Tomato	Stem canker	45-50 C HWT for 30 min
	Bacterial canker	50 C HWT for 1-2 min followed by 55 C for 25 min and washing
	Tobacco Mosaic Virus	70 C DHT for 48 hr.
Cucurbits	Anthracnose	50 C HWT for 15 min.
	Cucumber Green Mottle Mosaic Virus	70 C DHT for 48 hr or a long term storage
	Fusarium root rot	55 C HWT for 15 min.
	Scab (*Cladosporium* sp.)	70 C DHT for 48 hr.

THE OHIO STATE UNIVERSITY EXTENSION

Extension FactSheet

HYG-3085-05

Plant Pathology, 2021 Coffey Road, Columbus, Ohio 43210

Hot Water and Chlorine Treatment of Vegetable Seeds to Eradicate Bacterial Plant Pathogens

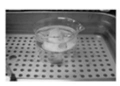
Sally A. Miller
Melanie L. Lewis Ivey

B. How to Hot Water Treat Seed.

Step 1: Wrap seeds loosely in a woven cotton bag (such as cheesecloth) or nylon bag.


Step 2: Pre-warm seed for 10 minutes in 100°F (37°C) water.



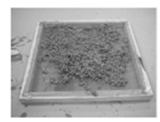


Step 3: Place pre-warmed seed in a water bath that will constantly hold the water at the recommended temperature (see table that follows). **Length of treatment and temperature of water must be exactly as prescribed.**



Step 4: After treatment, place bags in cold tap water for 5 minutes to stop heating action.

Step 5: Spread seed in a single, uniform layer on screen to dry. Do not dry seed in area where fungicides, pesticides, or other chemicals are located.

Step 6: Dust seed with Thiram 75WP (1 tsp/1 lb seed) once the seed is completely dry.

Seed	Water temperature		Minutes
	°F	°C	
Brussels sprouts, eggplant, spinach, cabbage, tomato	122	50	25
Broccoli, cauliflower, carrot, collard, kale, kohlrabi, rutabaga, turnip	122	50	20
Mustard, cress, radish	122	50	15
Pepper	125	51	30
Lettuce, celery, celeriac	118	47	30

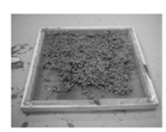
B. How to Chlorine Treat Seed.

Step 1: Agitate seed in a solution of 25 oz Clorox plus 100 oz water with one teaspoon surfactant for 1 minute. Use 1 gallon of disinfectant solution per pound of seed (conversions provided below) and prepare a fresh solution for each batch.



Step 2: Rinse seed thoroughly in cold running tap water for 5 minutes.

Step 3: Spread seed in a single, uniform layer on screen to dry. Do not dry seed in area where fungicides, pesticides, or other chemicals are located.

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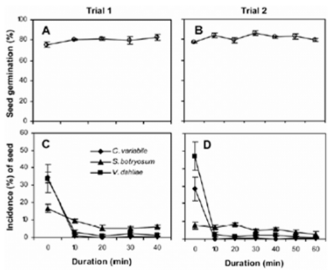

Fig. 1. Efficacy of 0, 10, 20, 30, and 40 min of chlorine (1.2% NaOCl) seed treatment on germination of spinach seed (A and B) and eradication of *Cladosporium variabile*, *Stemphylium botryosum*, and *Verticillium dahliae* from the seed (C and D) in each of two trials (A and C = trial 1, B and D = trial 2). Each data point is the mean of four replications in a randomized complete block design, and each bar is the standard error of the mean.

du Toit, L. J., and Hernandez-Perez, P. 2005. Efficacy of hot water and chlorine for eradication of *Cladosporium variabile*, *Stemphylium botryosum*, and *Verticillium dahliae* from spinach seed. Plant Dis. 89:1305-1312.

TIMING of Control Measures

GOVERNED BY:-

- STAGE OF CROP GROWTH
  - *bud -swell, flowering, ripening*
- SPEED OF CROP GROWTH
  - *emergence of leaves, flowers etc after spraying*
- WEATHER CONDITIONS
  - *rainfall and temperatures following disease*

BIOLOGICAL CONTROL

- Biological Control = applied ecology
  - management of a microbial community to favour the biocontrol agent and disfavour the pathogen
- Biocontrol of soil-borne pathogens
- Biocontrol of foliar pathogens.

Classical Biological control

- "Classical biological control" of insect pests or diseases is the one-time introduction of exotic natural enemies into a region for long-term suppression and regulation of populations of naturalized pests
- Biocontrol agent usually found near centre of origin of pest/disease

Biological Control

- Inundative - "swamping" the system with large numbers of propagules of biocontrol agent
- Augmentative - Repeated introduction of biocontrol agent at critical times

Apply Trichoderma in the field

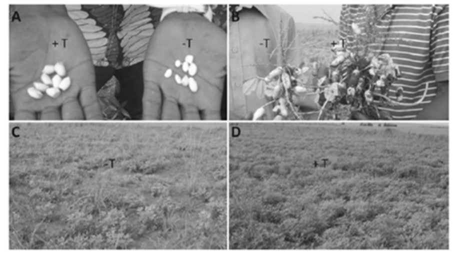

Table 1. Production and delivery of biocontrol systems in commercial agriculture

System	Steps required	Approximate costs/step	Time to significant market penetration
Full-scale registration and production—the chemical pesticide model	1. Identification of good agent 2. Development of production and formulation system 3. Patenting of strain and/or process 4. Toxicology and other testing 5. Registration 6. Building large-scale production system 7. Nationwide or international marketing	1,2. $100,000 3. Up to $200,000 for international coverage, at least $30,000 for one country 4. At least $500,000 5. $100,000 6. Up to $3-4 million 7. $2-3 million Total: up to $8 million	3 to 6 years
Biofertilizer, inoculant, or plant strengthening agent	1. Discovery of a good agent 2. Development of production and formulation system 3. Patenting of strain and/or process 4. Building large-scale production system 5. Nationwide or international marketing	1,2. $100,000 3. Up to $200,000 for international coverage, at least $30,000 for one country 4. Up to $1 million 5. $0.5 million Total: $1.8 million	1 to 2 years
Local production	Discovery of a good strain	$100,000 Total: $100,000 or less	Less than 1 year
Government sponsored or produced agents	Depends upon governmental direction and philosophy	Unknown	Unknown

Recommendation for controlling of Phytophthora blight in USA

1. Select fields with no history of Phytophthora blight.
2. Select fields that did not have cucurbit, eggplant, pepper, or tomato for at least 3 years. No rotation period has been established for effective management of Phytophthora blight of cucurbits.
3. Select fields that are well isolated from fields infested with *P. capsici*.
4. Select well-drained fields, or do not plant the crop in the areas of the field which do not drain well.
5. Clean farm equipment of soil between fields.
6. Plant non-vining crops (i.e., summer squash) on dome-shaped raised beds (approximately 25 cm high).
7. Plant resistant varieties, if available.
8. Avoid excessive irrigation.

9. Do not irrigate from a pond that contains water drained from an infested field.
10. Do not work in wet fields.
11. Scout the field for the Phytophthora symptoms, especially after major rainfall, and particularly in low areas.
12. When symptoms are localized in a small area of the field, disk the area.
13. Discard infected fruit, but not in the field.
14. Do not save seed from a field where Phytophthora blight occurred.
15. Remove healthy fruit from the infested area as soon as possible and check them routinely.

Postharvest handling

- Harvesting
- Transportation
- Precooling and Packing
- Hygiene
- Storage