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Profile

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Developing Insect Pest Management Systems for Hemp in the United States: A Work in Progress

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Abstract

Hemp (*Cannabis sativa* L.) is now being grown within the United States over a much broader geographic area and for different uses than during its last period of significant production that ended after World War II. Within the past 3 yr, a large number of arthropod species have been documented to feed on hemp in the United States. Among key pest species, corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), has demonstrated greatest potential for crop injury, being particularly damaging to flower buds. Hemp russet mite, *Aculops cannibicola* (Farkas), and cannabis aphid, *Phorodon cannabis* Passerini, are the two species observed most damaging among those that suck plant fluids. Eurasian hemp borer, *Grapholita delineana* Walker, is widely present east of the Rocky Mountains and appears to have potential to significantly damage both flower buds and developing seeds. Numerous species of caterpillars, grasshoppers, and beetles chew hemp foliage; the severity of these defoliation injuries appears to be minimal, but needs further study. Similarly, numerous seed feeding hemipterans, most notably stink bugs and Lygus bugs, are regularly found in the crop but injury potential remains unclear. Some preliminary efforts have been made to develop integrated pest management strategies for these insects, particularly for corn earworm. Future research can be expected to rapidly resolve many of the data gaps that presently restrict advancing pest management on the crop. However, a major confounding issue involves the use of pesticides on hemp. Federal agencies have not yet provided clear direction on this issue, and regulatory decisions have subsequently devolved to the states.

Key words: *Cannabis sativa*, hemp, arthropod pest, corn earworm, integrated pest management

The cultivation of hemp (*Cannabis sativa* L.) in the United States has a long, but very peculiar history (Deitch 2003). Historically grown for fiber, production peaked in 1943 when it was grown on 146,200 acres (59,805 ha) in six Midwestern states as a crop to support the war effort. However, prior to this point, growing the crop became greatly complicated by passage of the 1937 Marihuana Tax Act, which classified all *C. sativa* materials as being marijuana and thus subject to new tax and drug enforcement laws. Following World War II, hemp production in the United States sharply declined; by the late 1950s, all U.S. production had ceased due to a combination of restrictions related to drug laws and competition with other fibers.

With the passage of the 2014 Farm Bill (U.S. H.R. 2642 – Agricultural Act of 2014 113th Congress [2013–2014]), this situation changed in some important respects. Within it, Section 7606 (Legitimacy of Industrial Hemp Research) provided a formal definition of the crop as 'the plant *C. sativa* L. and any part of such plant, whether growing or not, with a delta-9 tetrahydrocannabinol (THC) concentration of not more than 0.3% on a dry weight basis'. It also provided a means for universities to research the crop, and for it to be commercially grown where state laws allowed it to be produced. As of 2018, 38 states have passed laws that define industrial hemp as a distinct crop (from marijuana), and most have removed barriers to its production. In 2017, there were seven states (Colorado, Kentucky, Oregon, North Dakota, Minnesota, New York, North Carolina) with over 1,000 licensed acres (405 ha; Anonymous 2018a). Many areas saw substantial increases in acreage in 2018; Colorado went from 12,042 licensed acres (4,873 ha; 346 growers) in 2017 to 30,950 (12,525 ha; 835 growers) in 2018.

In the 62 yr since hemp was last grown in the United States (Rens 1995), many things have changed that affect its production as a crop today (Fike 2016). Probably most important is an expansion of products that are in present demand. Formerly, hemp grown in the United States was almost entirely produced for bast fiber, and this continues to represent a market. However, there are also markets for the seed, either whole or as oilseeds (Fig. 1). More recently, cultivars have been developed that produce compounds of potential pharmaceutical value, most notably cannabidiol (CBD). CBD has a wide range of purported uses including antiemetic, neuroprotective, antiepileptic, antipsychotic, and anti-inflammatory (Grotenhermen and Müller-Vahl 2016), and one formulation (Epidiolex) was recently approved by the FDA for use in treating severe forms of epilepsy.

Presently, there are efforts around the country to develop improved cultivars for production of one or more of all of these commodities, and these different forms of hemp often have very different features (Fike 2016). For example, cultivars grown to maximize oilseed yield will be grown from seed and require pollination. Cultivars grown for pharmaceutical purpose are typically all-female plants, often cloned, from which nonfertilized, but enlarged, flower buds are the primary harvested plant part (Fig. 2). The latter are being grown both in fields (in summer) and in indoor facilities (in winter). However, multiuse hemp cultivars (e.g., seed/fiber, CBD/seed) are also being grown.

The arthropod pests associated with the production of hemp in this new era have been essentially undescribed, as are the associated pest management needs. There are reviews of pest arthropods of hemp, most notably by McPartland et al. (2000). Nearly 300 species, worldwide, are reported to colonize the crop (McPartland 1996), although only a small percentage of reports from worldwide compilations of hemp insects involve North American observations (Smith and Haney 1973, Miller 1982, Lago and Stanford 1989, McPartland 2002, McPartland and Hillig 2003, Small et al. 2007).

With the current renaissance of hemp as a crop in the United States, there are new production areas with new crop products to be cultured—and new associated pests that will affect production. At this early stage, several steps need to be met before effective pest management plans can be provided to assist growers. This article summarizes the situation with hemp insect pest management at the end of 2018, drawing on experiences primarily from three states where recent research projects have involved defining insect issues on hemp—Colorado, Virginia, and Tennessee. Clearly, in the near future, this topic will need to be revisited, but enough information is now known to provide a base for the subject of arthropods associated with industrial hemp as it is presently produced in the United States.

The Pest Complex

A great many species of phytophagous arthropods have been observed from hemp over the past 3 yr. Those found feeding on leaves, flowers, and seeds have been most easily observed and are presently best known. Stem/stalk feeding insects and, particularly, root feeders remain more poorly described. Greatest injuries seem to be associated with species that affect female flower buds and developing seeds.

Defoliators

Perhaps the most conspicuous insects on the crop have been various defoliators, although serious defoliation has only rarely been seen. Among lepidopterans, woollybear caterpillars (Erebidae), both yellow woollybear, *Spilosoma virginica* (Fabr.), and saltmarsh caterpillar, *Estigmene acrea* (Drury), are among the most consistently encountered species east of the Rockies (Fig. 3). Noctuids observed to feed on foliage include beet armyworm, *Spodoptera exigua* (Hübner), variegated cutworm, *Peridroma saucia* (Hübner), yellowstriped armyworm, *Spodoptera ornithigalli* (Guenée), and zebra caterpillar, *Melanchra picta* (Harris), although the latter two species appear primarily associated with flowers and developing seeds. Other lepidopterans confirmed from hemp in Colorado include beet webworm, *Loxostege sticticalis* (L.) (Pyralidae) and the butterflies painted lady, *Vanessa cardui* (L.) (Nympalidae), and cotton square borer, *Strymon melinus* (Hübner) (Lycaenidae). Bertha armyworm, *Mamestra configurata* Walker (Noctuidae), has been reported to skeletonize hemp in areas in Manitoba (McPartland et al. 2000).

Among the coleopterans, the southern corn rootworm/spotted cucumber beetle, *Diabrotica undecimpunctata howardi* Barber

Fig. 1. Maturing seed head of a hemp plant.

Fig. 2. Hemp being grown primarily for production of cannabidiol.

(Chrysomelidae), is the species with the widest geographic range and is very frequently observed in hemp growing east of the Rockies. It feeds on leaves, but appears to prefer flowers. Japanese beetle, *Popillia japonica* Newman (Scarabaeidae), is a highly visible and potentially significant defoliator east of the Mississippi; this species also feeds readily on hemp flowers (Fig. 4). Very minor injury has been observed by flea beetles (Chrysomelidae): western black flea beetle, *Phyllotreta pusilla* Horn, and palestriped flea beetle, *Systena blanda* Melsheimer, are regularly present in Colorado hemp. The latter species has been commonly observed in Tennessee and elongate flea beetle, *Systena elongata* (Fabr.), was reported to be abundant on cultivated marijuana in Northern Mississippi by Lago and Stanford (1989).

The most important defoliators in eastern Colorado have been grasshoppers (Orthoptera: Acrididae), with localized outbreaks reported in 2016 and 2017. At least four species have been observed to feed on hemp: differential grasshopper, *Melanoplus differentialis* (Thomas); twostriped grasshopper, *M. bivittatus* (Say); redlegged grasshopper, *M. femurrubrum* (De Geer); and *M. lakinus* (Scudder). McPartland et al. (2000) provide accounts of two additional North American species from hemp: clearwinged grasshopper, *Camnula pellucida* (Scudder), and *Chloealtis conspersa* (Scudder). Unlike other defoliators of the crop, grasshoppers may also cause extensive damage to twigs, producing flagging of small branches (Fig. 5).

Fig. 3. Several caterpillars, such as yellow woollybear, chew hemp foliage.

Fig. 4. Japanese beetle can be a significant defoliator of hemp and readily feeds on flowers.

Separating out the grasshopper species that feed on hemp from those that limit feeding to weeds associated with the crop needs further study. For example, the chenopod specialist *Aeoloplides turnbulli* (Thomas) can be common along field edges where Russian thistle (*Salsola* spp.) is abundant, and the grasshoppers can cause unwarranted grower alarm. Likely only a small percentage of North American grasshopper species will use hemp as a host plant.

Other orthopterans have occasionally been encountered in hemp fields, notably tree crickets, *Oecanthus* spp. (Gryllidae), and bush katydids, *Scudderia* spp. (Tettigoniidae). These are likely incidental migrants, breeding on plants outside hemp fields, and have only been observed to cause very minor leaf feeding.

Agromyzid leafminers (Diptera: Agromyzidae) also develop in leaves of hemp, but have only been observed in low numbers and causing little leaf injury. The North American species in hemp have not been characterized; McPartland et al. (2000) list six species that have been reported elsewhere.

To better understand the significance of the defoliator complex, experiments are needed that will define the relationship of defoliation to hemp growth and yield. Because of the diverse nature of the various hemp crops, defoliation studies probably will need to be done to separate effects of leaf loss on seed production (on cultivars grown for seed), on fiber production (on cultivars grown for fiber production), and for production of CBD (on cultivars grown for CBD production). Furthermore, because the threshold concentration of 0.3% THC cannot be exceeded on this crop, studies also need to be done to determine whether defoliators may cause changes in plant production for either THC or CBD.

Sucking Insects and Mites on Leaves

During the course of this new evaluation of hemp insect pests in the United States, one common species present constitutes a new record for North America, cannabis aphid, *Phorodon cannabis* Passerini (Hemiptera: Aphididae) (Cranshaw et al. 2018; Fig. 6). In Colorado, this insect has been observed to produce high populations in late summer in some fields every season since 2016. Outdoors, the aphid is holocyclic on the crop and sexual forms (winged males, apterous oviparae) appear beginning by early September. Overwintering eggs

Fig. 5. Grasshoppers chew leaves but will often chew and weaken stems of hemp plants.

survive on crop debris and volunteer seedlings present the following spring are colonized after egg hatch; incidence of this insect can be expected to increase in areas where volunteer seedlings are common in and around fields. Cannabis aphid can also be a common pest if there is an indoor production phase (e.g., propagation through cuttings, seedling production of transplants) and may sustain asexual reproduction year round in plantings with adequate lighting.

McPartland et al. (2000) mention several other aphids that are reported associated with hemp. Of these, only bean aphid, *Aphis fabae* Scopoli, has yet been observed from hemp in North America, and this involved a single field in eastern Colorado. However, cotton/melon aphid, *Aphis gossypii* Glover, has been recovered from greenhouse hemp in Virginia and is found abundant in indoor production of marijuana in the southeastern United States. (S. Wainwright-Evans, personal communication to WC, 2018). Lago and Stanford (1989) only recorded one aphid species, rusty plum aphid, *Hysteroneura setariae* (Thomas), from cultivated marijuana in northern Mississippi.

Leafhoppers (Hemiptera: Cicadellidae) are often the most species-rich insect family associated with hemp, although few appear to reproduce on the crop. Lago and Stanford (1989) cataloged 19 species in fields of cultivated marijuana in Mississippi, but only two species were abundant, *Graphocephala versuta* (Say) and *Agallia constricta* (Van Duzee). Fourteen species have been identified so far from Colorado, but breeding in the crop only appears to occur with three or four of these. Most of the leafhoppers found on foliage appear to be transient adults, perhaps associated with weeds in the crop.

Very little, if any, damage appears to be associated with the leafhoppers found in hemp. To date, there are no published records of leafhopper vectored plant pathogens of the crop (e.g., beet curly top, aster yellows). No visible evidence of leaf injury has yet been observed associated from leafhoppers, aside from a modest stippling produced by an *Empoasca* species in eastern Colorado. However, the related potato leafhopper, *Empoasca fabae* Harris, may be more significant in eastern North America. Dudley (1920) reported hemp as a host for this insect and stated that the injury to hemp resembled 'hopperburn' on potato. Potato leafhopper also causes hopperburn to hops (Calderwood et al. 2015), a close relative to hemp. In Tennessee and Virginia, potato leafhopper is recorded from hemp, but to date, no signs of hopperburn have been observed.

Fig. 6. Cannabis aphid is the most common aphid found on the crop. Decreasing day length, results in production of sexual forms in late September and early October, shown here, that lay overwintering eggs on the maturing plants.

A few treehoppers (Hemiptera: Membracidae) also occur in hemp. In both Mississippi (Lago and Stanford 1989) and Colorado, *Micrutalis calva* (Say) and threecorned alfalfa treehopper, *Spissistilus festinus* (Say), have been recorded from hemp and nymphs have been observed, indicating that these species can breed on the crop.

No whiteflies (Hemiptera: Aleyrodidae) have yet been observed developing in hemp fields. However, sweetpotato whitefly, *Bemisia tabaci* (Gennadius), has been observed to be a serious pest on indoor grown marijuana in the southeastern United States (S. Wainwright-Evans, personal communication to WC, 2018).

Insects from at least four families of true bugs (suborder Heteroptera) have been confirmed to feed on hemp: Pentatomidae, Miridae, Rhopalidae, and Lygaeidae. Most of these appear to feed on flowers, stems, and seeds of the crop.

Lygus spp. (Hemiptera: Miridae) are often among the most commonly encountered insects on hemp and breeding does occur on plants in vegetative growth (Fig. 7); tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is common throughout the duration of the growing season wherever hemp is grown and is the most consistently observed phytophagous species in hemp grown in Tennessee and Virginia. This species is also common in Colorado, where a related species, pale legume bug, *Lygus elisus* Van Duzee, is often the dominant *Lygus* species. No visible leaf injuries by *Lygus* spp. have yet been noted on hemp, and they are more likely to feed and damage developing seeds, as they do on other crops such as oilseed rape (Butts and Lamb 1990). Lago and Stanford (1989) reported garden fleahopper, *Microtechnites bractatus* (Say), to be abundant, and this species produces leaf spotting on host plants. Another common mirid in many eastern Colorado fields is ragweed plant bug, *Chlamydatus associatus* (Uhler), a species that is primarily predatory.

Thrips are regularly found on hemp but remain largely uncharacterized. Onion thrips, *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae), is the only species found commonly on hemp foliage in eastern Colorado. During indoor phases of hemp production, onion thrips can cause serious foliage damage. However, during outdoor production, where plants grow rapidly, onion thrips fail to reach damaging population levels. Western flower thrips, *Frankliniella occidentalis* (Pergande), has also been identified in hemp in Colorado, although it appears to be mostly associated with flowers and pollen. Lago and Stanford (1989) reported tobacco thrips, *Frankliniella fusca* Hinds, as being common on young plants but appeared to disappear as plants grew older.

Fig. 7. Various kinds of *Lygus* spp. are among the most commonly observed phytophagous insects in hemp.

Twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is a key pest of *C. sativa* crops wherever there is an indoor/greenhouse phase of production. In hemp, serious pest problems can involve mother plants used for clonal propagation and their progeny during indoor growth prior to transplanting. However, high spider mite populations do not appear to be sustained once plants are transplanted to fields. Broad mite, *Polyphagotarsonemus latus* (Banks) (Acari: Tarsenomidae), is also known as a pest of indoor grown *Cannabis* crops in the United States (Wainwright-Evans 2017).

The eriophyid hemp russet mite, *Aculops cannibicola* (Farkas) (Acari: Eriophyidae), can be a serious pest of hemp in both indoor and outdoor production. Indoors, extremely high populations can develop on plants to the point where the mites sometimes completely cover areas of the leaf, becoming visible as a fine powdery material. Outdoors, sustained population increases can occur; in one field monitored in Colorado in 2018, russet mite numbers increased steadily from about 50 per leaf to about 450 per leaf between early June and early September (MS, unpublished data). In Tennessee, ca. 18% of growers reported serious problems with hemp russet mite in 2018; several growers reported destroying and burning their fields due to this pest.

Damage by hemp russet mite is more subtle than that produced by twospotted spider mite and has not been well characterized. Heavily infested leaves often have a slight grayish or bronzed color change and some growers have reported that the mites have killed plants during indoor propagation. In some cultivars, a slight upward rolling of the leaf edge may occur; this symptom is not universally produced and some hemp cultivars normally will produce similar leaf curling in the absence of the mite. More clearly damaging effects occur when hemp russet mite infests developing flower buds of cultivars grown for CBD production. High populations can reduce the size of flower buds and resin production, which can result in reduced yield of extractable cannabinoids (McPartland and Hillig 2003; Fig. 8).

There are more important information gaps involving hemp russet mite than for any of the other species that have potential to be key pests of the crop. Fundamental information is almost completely lacking on the life history of this species. Studies on overwintering biology, and the possibility of alternate host plants would provide information that could address important questions needed to help better manage hemp russet mite.

Fig. 8. Injury by hemp russet mite can produce a range of symptoms that often can be subtle. In this plant there is some off-color and reduction in leaf size, but the primary effect has been to retard bud development, which can greatly affect yield of cannabidiol cultivars.

Biological controls need to be evaluated for this species; populations of potential natural enemies of hemp russet mite (e.g., predatory mites, anthocorids) have been very low in fields in Colorado even with very high hemp russet mite populations. Currently, none of the commercially available predatory mites used for greenhouse pests have yet been clearly demonstrated to be effective for hemp russet mite and predatory mites are often limited by the low humidity conditions that normally are associated with hemp being produced in arid areas, such as Colorado. Limited trials have indicated that mineral oils appear promising for suppression of hemp russet mite (WC, unpublished data).

Stem and Stalk Borers

European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae), is reported to tunnel into larger stems and stalks of hemp and has the potential to weaken plants to the extent that they are prone to breakage (Anonymous 2018b). The potential importance of this injury was briefly noted by Willsie et al. (1942) who later stated 'hemp is exceptionally resistant to lodging and usually is not affected by ordinary storms'. This suggests plant damage of the type produced by European corn borer injuries (structural weakening of stalks) may be well tolerated by hemp. Further evidence of this was indicated by Small et al. (2007) who reported increased branching and increased seed yields following European corn borer tunneling. An increased bushiness of growth habit can be desirable in production of CBD cultivars because it can lead to an increase in resin-rich buds. Region-wide population suppression of this insect species has occurred in the central and eastern United States due to the widespread planting of Bt transgenic corn (Hutchison et al. 2010, Dively et al. 2018). At the time of this manuscript submission, the only reliable record of European corn borer damage to hemp known by the authors involved a single specimen discovered by a grower in North Carolina in 2018 tunneling into the stem at ground level of a young hemp plant (TK).

Eurasian hemp borer, *Grapholita delineana* (Walker) (Lepidoptera: Tortricidae), is a much smaller species of stem/stalk borer but may have more potential to cause significant stem and stalk injuries to the crop than European corn borer in some production areas. It appears capable of producing three to four generations per year, allowing rapid rates of population increase.

There is minimal external evidence of stalk tunneling produced by Eurasian hemp borer. A slight swelling of the stalk may occur, and leaf flagging may occur adjacent to the wounds. Whether these injuries significantly affect yield needs to be studied. Far more damage is caused by this insect late in the season when stem tunneling destroys buds and developing seeds are consumed.

Sucking Insects Associated with Flowers and Seeds

Several types of true bugs become abundant in hemp after flowering, feeding primarily on flowers, and developing seeds. The largest and most conspicuous are various stink bugs (Hemiptera: Pentatomidae), and hemp appears to attract many species. Redshouldered stink bug, *Thyanta custator* (Fabr.), and brown stink bug, *Euschistus servus* (Say), occur on hemp throughout the continental United States (Fig. 9). In the western states, *Chlorochroa* species appear to be the most common stink bugs in hemp, particularly the conchuela stink bug, *C. ligata* (Say), and Uhler stink bug, *C. uhleri* (Stål). In the eastern United States, green stink bug, *Chinavia hilaris* (Say) is common and was observed to readily breed on the crop by Lago and Stanford (1989). In Virginia, in areas where the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), is established, it is consistently present on hemp, clearly breeds on the crop, and is viewed as a suspected pest. In outdoor crops, adults appear when plants become fragrant and have developed inflorescences. Eggs have been found on plants and nymphs are able to successfully complete development to adulthood on a diet of hemp alone (Britt et al. 2019). Adults of rice stink bug, *Oebalus pugnax* Fabr. and *Cosmopepla lintneriana* (Kirkaldy), have been observed on hemp in Tennessee. Southern green stink bug, *Nezara viridula* L., was reported to occur on feral hemp in Illinois (McPartland et al. 2000).

Plant bugs of the genus *Lygus* are also extremely common residents of hemp, and at least two species breed on the crop (tarnished plant bug, pale legume bug). These insects can be found on hemp plants throughout the growing season, but occur in higher numbers after flowering. In Virginia, tarnished plant bug is present in hemp soon after plants emerge from seeds until harvest.

Both stink bugs and *Lygus* spp. plant bugs feed on flowers, developing fruit, and seeds of a great many plants, and several of the species on hemp are important pests in other crops. Flower bud abscission, seed abortion, and seed deformities are common effects produced on other crops, which could have implications for hemp produced for seed. However, data are presently absent to determine whether any of these seed feeding bugs are significant pests affecting hemp seed production or quality.

A few species of rhopalids (Hemiptera: Rhopalidae) can be found on hemp. Hyaline grass bug, *Liorhyssus hyalinus* (Fabr.), has been observed breeding in seeds and flowers of hemp in Colorado and eastern Virginia. In Colorado, high populations were found in a seed/fiber hemp field that had produced the crop for two consecutive years. In eastern Virginia, all life stages were found in seed/fiber hemp. Adults of various *Arhyssus* spp. also occur in the crop. There is no evidence yet that any will breed on hemp, but many *Arhyssus* species are associated with various weeds common in agricultural areas. Most common on hemp flowers in eastern Colorado is false chinch bug, *Nysius raphanus* Howard (Hemiptera: Lygaeidae), a ubiquitous insect that can be found on most any plant in the region. This insect primarily breeds on cruciferous plants and nymphs have not been found in hemp collections.

Cannabis aphid has often been observed to infest maturing flowers and associated leaflets late in the season and into harvest in Colorado. Effects on yield are unknown, but large numbers of these insects, and their eggs, can be incorporated into harvested floral parts and it can produce abundant amounts of honeydew.

Fig. 9. Several kinds of stink bugs have been observed in hemp, usually appearing after plants begin flowering and seeds develop. Redshouldered stink bug is one of the most common species that has been found on hemp and is the one with the widest geographic range.

Chewing Insects that Damage Flower Buds and Seeds

Eurasian hemp borer was the only insect reported by Haney and Kuscheid (1975) to seriously damage seeds of feral hemp in central Illinois. A subsequent publication on the establishment of this species in North America (Miller 1982) indicated that it was present in at least seven states (Illinois, Iowa, Kentucky, Minnesota, Missouri, New York, and Wisconsin). Presently, there are records for this insect from a majority of the states east of the Mississippi, and Eurasian hemp borer was observed to be present in fields throughout eastern Colorado in 2017–2018.

Eurasian hemp borer spends almost its entire larval stage within stems of hemp, with only a brief period of leaf feeding done by the first-instar larvae (McPartland 2002). Late in the season, tunneling is concentrated in upper stems, producing girdling wounds that damage and often kill terminal buds (Fig. 10). The general appearance of bud injury can superficially resemble that produced by corn earworm; splitting the stem below the injury site can expose larval tunneling that would indicate Eurasian hemp borer. Larvae may also tunnel amongst developing seeds and the last-instar larvae, which are orange or a bit pinkish, have been reported in large numbers at harvest by some Colorado producers.

McPartland (2002) provided information on the life history Eurasian hemp borer and its damage potential to the crop, but several information gaps need further research in order for effective

Fig. 10. Eurasian hemp borer can develop in stems, buds, and developing seeds. In the last instar, larvae turn bright orange.

pest management plans to be developed. These include methods to monitor the insect so that incipient outbreaks can be detected, identification of natural controls, and aspects of its life history including the use of alternate host plants. The suddenness with which this insect has become prominent in some eastern Colorado hemp fields, in areas where no *Cannabis* plants were present prior to 2016, strongly suggests nonhemp wild hosts support this insect. Gilligan and Epstein (2014) mention *Humulus* spp. and *Polygonum* spp. as reported hosts in Europe.

Management of Eurasian hemp borer could be particularly challenging in crops grown for seed. Most injury occurs after plants have begun to flower, and pollinators actively visit the crop where male plants are present; this can greatly limit insecticide options. All presently allowable insecticides (in some states) for use on hemp have very short persistence (pyrethrins, azadirachtin) or are stomach poisons (*Bacillus thuringiensis*). These are unlikely to be satisfactory for control of this insect, given its very short period when larvae are exposed on the plant surface.

The insect that has caused the most damage to hemp grown in Colorado is corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) (Figs 11 and 12). This insect is widely distributed in North America and has been observed feeding on buds and seed heads of hemp in Illinois, Indiana, Kentucky, Nevada, North Carolina, Tennessee, Vermont, Virginia, and Wisconsin. Outbreaks can occur irregularly but serious damage occurred from this insect in southeastern Colorado in both 2016 and 2018; one grower estimated a loss of over $0.5 million to a hemp crop grown for CBD during the 2016 outbreak.

Corn earworm becomes attracted to hemp after plants begin to flower and is rarely seen at earlier stages of plant growth. This often happens late in summer after corn has largely passed the green silk period and is no longer attractive for egg laying; during this time, hemp may be one of the most attractive plants available to this insect. Some leaf feeding occurs, but the caterpillars primarily chew into flower buds and developing seed heads. Corn earworms are particularly damaging to hemp cultivars grown for production of CBD, as larvae can destroy several of the resin-rich buds as they develop. Significant feeding injuries can occur on hemp grown for seed, and a North Carolina grower estimated a 30% crop loss of grain hemp due to a late-season corn earworm infestation during 2017.

Fig. 11. Corn earworm is often the insect that is most damaging to hemp, tunneling into maturing flower buds and developing seeds. Injury is greatest on cannabidiol cultivars where large flower buds are produced.

Pheromone trap-based monitoring systems for corn earworm exist and are commonly used for other crops, notably sweet corn (Olmstead et al. 2016). These can help identify periods when high numbers of corn earworm moths are active, which may be associated with intensity of egg laying. Combined with information on what stages of hemp are attractive to female moths for egg laying, insecticide treatments can be timed to control the damage. Recommendations for control of corn earworm used in Colorado during 2018 included formulations of *B. thuringiensis* var. *aizawi* (Agree WG, XenTari Biological Insecticide) or the *Helicoverpa armigera* nucleopolyhedrovirus/HearNPV (Helicovex), which are allowable for use in the state under the regulatory guidelines developed by the Colorado Department of Agriculture (2016). In hemp, corn earworm feeds more on the surface of the plant than it does with some other crops (e.g., corn, peppers, tomato), improving the potential of these microbial insecticides to be ingested in sufficient quantities to kill larvae. These products also have the advantage of being selective in their effects, conserving existing natural enemies and being compatible with visiting bees that collect pollen from the crop.

Several of the defoliators seen on the crop appeared to be most abundant during flowering and would readily feed on flowers. These include Japanese beetle, yellowstriped armyworm, and zebra caterpillar.

Root Feeders

The complex of arthropods associated with the root system of hemp plants has received very little attention. Willsie et al. (1942) mention that white grubs could damage young plants in Iowa, and Lago and Stanford (1989) reported collecting several larvae of *Phyllophaga tristis* (Fabr.) (Coleoptera: Scarabaeidae) from roots of cultivated marijuana. It is likely that some leaf beetles of generalist habit with soil-dwelling larval stages may feed on hemp roots (e.g., southern corn rootworm, some flea beetles).

In western Colorado, larvae of a *Prionus* sp. (Coleoptera: Cerambycidae) damaged a limited area of a field that had recently been converted from an area of sagebrush. This is a long-lived insect and, in this situation, the larvae appear to have originated from roots of the sagebrush remaining within the field. Damage to seedlings and small transplants by pavement ant, *Tetramorium caespitum* (L.) (Hymenoptera: Formicidae), also was seen in western Colorado in 2018. Seedlings located near nest entrances were damaged just below the soil line, constricting the stem, which resulted in wilting and death of plants as they got older.

Fig. 12. Flower bud of hemp destroyed by corn earworm.

The most common aphid reported from indoor marijuana production in Colorado is rice root aphid, *Rhopalosiphum abdominalis* (Sasaki) (Hemiptera: Aphididae), and plants supporting large populations can show a significant decline. This species develops almost entirely below ground on *Cannabis*. Most stages found on aboveground parts of plants are winged forms, and these are often observed dead and caught on the leaf surface. Some colonization of foliage occurs, but most progeny produced on foliage by migrant winged forms are observed to migrate to the roots.

Rice root aphid has not yet been recorded from either indoor or outdoor grown hemp. It is unlikely that this is due to differences in host plants, as marijuana and hemp are identical insect hosts in most important respects. It is more likely that the greater incidence of problems on marijuana results from differences in plant culture. Marijuana is often grown in continuous indoor culture and with systems involving live soil often involves use of surface mulches, which has been shown to favor the establishment of rice root aphid (Kindler et al. 2004, Hesler and Kindler 2007). Comparatively, indoor production phases of hemp are typically more limited, with some maintenance of a few mother plants between growing seasons and with a short period when transplants produced from cuttings are produced, prior to field planting.

Rice root aphid is widespread in North America, most often associated with various grain crops. This species may have a holocyclic life cycle in some parts of the world, laying overwintering eggs on *Prunus*. Use of these winter hosts has not been recorded in North America, and the species can survive year round on roots of cereals at least as far north as Illinois (Capinera 2001).

Natural Enemy Species

Hemp fields may support a robust complement of natural enemy species, most of which will reflect the types of species typically present in some other row crops. The incidence of these natural enemies will be affected by the availability of hosts/prey as well as the growth stage and type of hemp being grown.

For example, in fields supporting large numbers of cannabis aphid in Colorado, lady beetles become particularly prominent. Most common are convergent lady beetle, *Hippodamia convergens* Guérin-Méneville, and multicolored Asian lady beetle, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), but at least four other lady beetle species often occur in Colorado hemp (Fig. 13). Three species of green lacewings (Neuroptera: Chrysopidae) can be found, with *Chrysopa oculata* Say and *Chrysoperla plorabunda* (Fitch) being most common. Larvae of at least four species of predaceous syrphids (Diptera: Syrphidae) and *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae) also were observed feeding on cannabis aphids in hemp fields. Parasitism by braconids (Hymenoptera: Braconidae) and infections by entomopathogenic fungi (unidentified) have been observed in fields infrequently. Numerous other generalist predators observed in hemp are probably predaceous on cannabis aphid, including predatory hemipterans—*Orius insidiosus* (Say) (Anthocoridae), *Nabis alternatus* Parshley (Nabidae), *Geocoris punctipes* (Say) (Geocoridae), and *Chlamydatus associatus* (Uhler) (Miridae)—and predatory dipterans—*Platypalpus* sp. Macquart (Diptera: Hybotidae), and *Condylostylus* sp. Bigot (Diptera: Dolichopodidae). In Virginia and Tennessee the most frequently observed natural enemies have been the coccinellids multicolored Asian lady beetle and *Coleomegilla maculata* (De Geer), along with big-eyed bugs, *Geocoris* spp.

A very common species found in almost all eastern Colorado hemp fields has been the chloropid *Thaumatomyia glabra* (Meigan) (Diptera: Chloropidae). This species is unusual among chloropids because it is predaceous on root aphids (Sabrosky 1935). A local species that may support this species is sugarbeet root aphid, *Pemphigus betae* Doane (Hemiptera: Aphididae), which develops on various crops and weeds in the family Amaranthaceae (Pretorius et al. 2016). The near ubiquitous presence of *T. glabra* in hemp fields may also indicate the presence of root-feeding aphids that have not been identified (Fig. 14).

Although hemp is an annual crop, several kinds of spiders have been observed to colonize hemp fields. Most consistently encountered in eastern Colorado fields are crab spiders in the genus *Mecaphasa*, running crab spiders (primarily *Philodromus* sp.), several genera of jumping spiders, and longjawed spiders (*Tetragnatha* sp.).

The type of hemp being grown may also affect the natural enemy complex. Hemp that flowers and produces pollen may improve food resources for predatory species that also use pollen in their diet. Pollen may also support some primarily phytophagous species (e.g., western flower thrips) that in turn can provide hosts for generalist predators (e.g., *Orius insidiosus*). Conversely, pollen-bearing male flowers are often absent in fields for CBD production. Furthermore, this production system results in large, unfertilized female flower 'buds' that are densely covered with sticky, resin-rich trichomes. The

Fig. 13. Several kinds of lady beetles are common in hemp crops, including convergent lady beetle (above), multicolored Asian lady beetle, and *Coleomegilla maculata*.

Fig. 14. Several kinds of hemipteran predators are present in hemp including damsel bugs (above), big-eyed bugs, and minute pirate bugs.

effects of these sticky trichomes on activity of natural enemy species also need study.

Pollinators and Hemp

Hemp is wind-pollinated, and plants may be either dioecious or monoecious. Very abundant amounts of pollen are produced, typically for a period of several weeks, but the plants do not produce nectar. Fiber/seed cultivars may be visited heavily for pollen by several species of bees.

Flowering hemp can be a significant source of pollen for both honey bees and many kinds of native bees during late summer (Fig. 15). Although honey bee (*Apis mellifera* L.) (Hymenoptera: Apidae) is usually the most noticeable bee, a considerable diversity of species may be found in the crop. Trapping of bees in hemp during 2015 and 2016 in northern Colorado found honey bee to be the most abundant species, but close to half of the total captures involved various longhorned bees (Apidae: Eucerini), particularly *Melissoides* spp. (O' Brien and Arathi 2019). Other Apidae found in high numbers included bumble bees (*Bombus* spp.) and digger bees (*Anthophora* spp.). Solitary bees of other families represented a small percentage of the total captures; five genera of Halictidae were found, and smaller numbers of bees in the Megachilidae and Andrenidae were also collected. In agricultural areas where suitable wild flowering forbs are limited during the period when hemp is in flower (typically August and early September in Colorado), integrating hemp into agricultural systems has the potential to significantly contribute to improving resources for pollinators that collect hemp pollen.

Fig. 15. Flowering hemp produces an abundance of pollen and this may be heavily used by many kinds of bees in areas where alternative pollen sources are not available.

Several conditions can affect the value of hemp as a pollen resource. Regional differences are likely, as in areas of higher rainfall—and greater availability of late summer pollen resources—the potential contribution of hemp will probably diminish. Lago and Stanford (1989) recorded only three species of bees in cultivated marijuana—*A. mellifera*, *Bombus impatiens* Harris, and *Dialictus imitatus* (Smith)—all of which were noted as being either rare or uncommon in the crop.

More fundamentally important is the type of hemp crop being grown. Although hemp being grown for seed and/or fiber will have an abundance of pollen-bearing male flowers, the great majority of hemp currently being grown in Colorado and Tennessee is for the production of the nonpsychoactive pharmacological compound, cannabidiol (CBD), which is one of many plant-produced cannabinoids. In this production system, typically only all-female plants are grown and pollination is undesirable since seed production reduces CBD yield. These types of hemp will have no value as a pollen source.

The use of this crop by pollinators also has potential implications with pesticide use. Many insects, notably seed feeding hemipterans and Eurasian hemp borer, develop highest and most damaging populations during periods when the crop is in flower and being used by bees. This will be a confounding factor to consider in the registration and use of pesticides on hemp during periods when pollen production makes plants attractive to bees.

Pesticide Issues

The situation regarding pesticide use on hemp in the United States has been chaotic, has created enormous confusion, and remains a major impediment to the development of effective pest management on the crop.

At the root of the problem is unresolved tension between the 2014 Farm Bill, which allowed the legal production of hemp, and the Controlled Substance Act of 1970, which continued to define all *C. sativa* crops as a Schedule I drug (Sandler et al. 2019). This has had the effect of paralyzing all federal regulatory action that could enable registration and oversight of pesticides on this new crop.

In the absence of federal action and in response to the very real need for some direction regarding pesticide use, the regulation of pesticides on *Cannabis* crops (marijuana, hemp) has functionally devolved to the states. Predictably, there has been a wide range in how state regulatory agencies have responded to the question of pesticide use on hemp.

To date, the majority of states that have allowed hemp production have not addressed the issue, taking the position that only the federal government can regulate pesticide use on the crop. Extending this reasoning, because federal regulatory agencies do not recognize hemp as a crop site, there can exist no registered pesticides on the crop.

Where this is the position, no registered pesticides are allowed to be used in hemp production within the state. Growers, then, can legally respond in a couple of ways: use no pesticides; use pesticides illegally; use Section 25(b) products that are exempted from FIFRA registration requirements; or use pesticidal products that do not make claims as a pesticide. Examples of the latter would be marketing of neem oil as a 'leaf shine' product, or soap/detergent products as a 'plant wash'.

A different model has evolved in other states, where state regulatory agencies have developed regulations that allow certain registered pesticides to be used. This has happened primarily in states that had previously passed state laws or constitutional amendments allowing production of medical and/or recreational marijuana; these regulations then were applied to all *C. sativa* crops, including hemp.

This involves a finesse of federal regulations, first developed by Washington and released in August 2013; Colorado followed with a similar regulations released in March 2015. In this model, certain pesticide products, registered by the EPA and the state, are allowed if they meet a set of criteria. The first of these is that the active ingredient is exempt from the requirements of a tolerance on all food crops, as established under 40 C.F.R. Part 180 Subparts D and E. This has the effect of limiting the available insect control products largely to certain microbial insecticides (e.g., certain strains of *B. thuringiensis*, *Isaria fumosorosea*), certain plant-derived insecticides (e.g., azadirachtin, pyrethrins), various horticultural oils (e.g., mineral oils, seed-derived oils), and insecticidal soaps.

The second criterion involves the label language associated with the specific product. Label use directions must be broadly written, so that they allow use on unspecified crops, which could be interpreted to include—or at least not to exclude—hemp (or marijuana). For example, language statements that allow use on 'Crops such as…', followed by a long list of crops, among which hemp could be included, would be allowable. Label instructions that more strictly define sites of use would not be allowable. With this interpretation, these allowable pesticides are seen as not being in conflict with the federal label; they are *not* allowed. This can create a bit of a patchwork of allowable products not strictly tied to active ingredient. For example, at present, two *Beauveria bassiana* products that also contain pyrethrins are allowed by the Colorado Department of Agriculture, whereas a similar *B. bassiana* product without pyrethrins, but slightly different label use directions, is not allowed.

Both Colorado and Washington state further limit registered products by requiring that they also either be registered for tobacco (Colorado) or 'data from pyrolysis studies have not led to an exceedance in the level of concern (LOC) or other parameters and have not resulted in EPA denying use of the active ingredient on tobacco' with the product (Washington State Department of Agriculture 2018). Additionally, in the Washington/Colorado model, 25(b) minimum risk products that are exempt from federal registration are allowed if they are registered with the state prior to distribution.

In this model, the state develops and provides a list of specific registered pesticides, regularly updated, that are allowed to be used in production of *Cannabis*-derived crops. The Oregon Department of Agriculture seems to have similarly followed this model, but other states have not. For example, in California, where pesticides are regulated by the Department of Pesticide Regulation, the first criteria for use, exemption from food crop tolerance, is given as guidance on what products are allowed on *Cannabis* crops, and a list of specific allowable pesticides are not provided to growers (California Department of Pesticide Regulation 2018).

The pesticides that are allowed by states that use this model generally provide products that can be used to adequately manage many of the likely arthropod pest problems that develop on this crop, particularly when used with other pest management methods (e.g., crop rotation, elimination of volunteer plants). For other types of pests of the crop—plant pathogens and, particularly, weeds—adequate pesticides are not available.

Language in the recently passed U.S. Farm Bill of 2018 that establishes hemp as a federally recognized crop may provide a path that allows federal agencies to assume the primary role for regulation of pesticide use on hemp. At that point in time, there likely will be several different regulatory paths for different forms of hemp. For example, hemp being grown strictly for seed or fiber may be considered to fall within the Oilseed Group (Crop group 20), which contains crops such as cottonseed, flax seed, and sunflowers. Such a designation could accelerate additional registrations, either through label changes or through Special Local Needs registrations.

Hemp grown for CBD will have a far more difficult path to develop and expand pesticide registrations. Among existing crop groups, it is perhaps closest to the Herbs and Spices Group (Crop group 19), but there are important differences related to how CBD hemp is handled after harvest and used by consumers. Solvents, such as CO_2, butane, or ethanol, are used to extract CBD and other desired plant materials (producing CBD 'oil'), and these extraction methods may concurrently extract certain pesticide residues (Raber et al. 2015). Also, CBD products are consumed in many different forms—ingested, inhaled, or dermally applied. To sufficiently satisfy registration requirements, all of these issues will probably require new studies. Costs of these types of studies will be very large. Given the very small market for pesticides on hemp, it is unlikely that it will be attractive for many, if any, potential pesticide registrants to conduct the studies.

Conclusion

In the few years since the 'new' crop, industrial hemp, has been grown in the United States, most attention involving insect pest management has involved a descriptive phase, where the kinds of arthropods associated with the crop in different regions are described and key species of the crop identified. In this brief period, substantial progress has been made and the broad outlines of pest management needs have emerged. Several potential key pests have already been identified—corn earworm, Eurasian hemp borer, cannabis aphid, hemp russet mite, grasshoppers—and many other phytophagous species may develop into significant pests as the crop becomes more widely established. Furthermore, it appears that present issues with insect/mite pest management on hemp vary in almost every way from what was reported when hemp was last grown widely in the United States over 70 yr ago.

Many studies are now required to address gaps of information that would allow production of pest management plans, the Development Phase. This includes basic information on the life history of several species, assessment of injury potential, identification of monitoring methods, and evaluation of various types of controls (e.g., biological, cultural, chemical). Some work is presently in progress that will answer these questions, but a great deal more is needed. With one insect (corn earworm), in one location (Colorado), on one form of hemp (CBD cultivars), a prototype Implementation Phase project has been started.

Over the past 4 yr, almost everything about production of hemp in the United States, including pest management, has been in a state of enormous flux. Growers have constantly experimented with ways to grow the crop, and many different production systems are being used. Overall, acreage has steadily increased, but the crop is grown for many different markets, all of which are still developing, and crop prices have been very unstable. Some of these problems are related to the uncertainties involving federal laws affecting the crop, and it can be hoped that language in the newly passed 2018 Farm Bill may better resolve many of these issues. Clarity in pesticide regulation involving the crop at the federal level is greatly needed, and that will happen at some point to come.

Changes in pest problems will also result as production systems for hemp evolve. For example, CBD hemp is often asexually propagated through the use of cuttings, which helps sustain continuous populations of some pest species (e.g., hemp russet mite). Breeding and horticultural developments that produce CBD cultivars grown from seed will diminish these challenges. On the other hand, more extensive cultivation of hemp, with more volunteer seedlings in the vicinity of production sites, may increase problems with other pest species, particularly those that are largely restricted to *C. sativa* (e.g., cannabis aphid, Eurasian hemp borer). How this will ultimately play out is unknown, but the entomology of hemp in the United States promises to be an extremely dynamic area in the foreseeable future.

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