BIOLOGY AND MANAGEMENT OF WIREWORMS IN WESTERN WASHINGTON

Introduction

Wireworms cause damage to a wide range of agricultural crops, including potatoes, cereal grains, corn, carrots, lettuce, and other annual vegetables. In western Washington there are two genera of wireworms that are considered significant economic pests, *Agriotes* and *Limonius*. Currently, the three most economically important species in western Washington are *Agriotes lineatus*, *Agriotes obscurus*, and *Limonius canus*. The former two species were introduced from Europe and were first detected in Washington State in 1997 (Vernon and Pats 1997). Surveying by LaGasa et al. (2006) and Brouwer et al. (2020) found a distribution of different species of *Agriotes* ranging from Cowlitz County north to Whatcom County (Figure 1). It is likely that these species have spread through transportation of larvae-infested soil, compost, and nursery stock, as well as adult flights to new fields. The third wireworm of concern (*L. canus*), known commonly as the Pacific coast wireworm, is a native species and commonly encountered in irrigated vegetable fields across the Pacific Northwest.

Some other wireworm genera found in western Washington that may cause damage to vegetable or cereal crops include *Aeolus*, *Campylomorphus*, *Ctenicera*, and *Hypolithus* (Hatch 1971). It is possible for larvae of multiple species to be present in a single field. Understanding wireworm species composition and ecology in western Washington is still a major work in progress, with most available data coming from research in British Columbia and information on taxa sourced from east of the Cascade Mountains.

Identification

Wireworms are the immature stage of beetles belonging to the family Elateridae. Adults are commonly known as click beetles due to their habit of "clicking" to right themselves if they land on their back, an action made possible by a spine and groove mechanism found on the ventral side of the thorax. In North America, click beetles range in size from 0.04 to 2.4 in., but most pest species in western Washington are closer to 0.5 in. in length. Adults are elongate and usually uniformly light or dark brown. *Agriotes lineatus* is brown with lighter colored stripes running parallel along the length of the wing covers (Figure 2, bottom photo). Adults are capable of flight, are often attracted to light, and generally do not cause crop damage. Their mobility enables egg distribution and thereby population dispersal, resulting in the threat of expanding crop infestations.

Wireworms are generally long and slender with a shiny and hardened exoskeleton (Figure 2, top photo). Their bodies are most often a toasted caramel color with a darker reddish-brown head. *Agriotes* larvae have two "eye spots" on the top of the ninth abdominal segment, and the tip of this segment is bluntly pointed (Figure 3, top photo). In *Limonius*, there are no "eye spots" and the tip of the ninth abdominal segment has a small "key-hole" opening (Figure 3, bottom photo). As with adult click beetles, wireworms have three pairs of legs located on several segments behind the head and possess chewing mouthparts.

Figure 1. Documented distribution of *Agriotes lineatus* and *A. obscurus* in Washington State based on adult pheromone trapping and larva identification (adapted from LaGasa et al. [2006] and Brouwer et al. [2020]). Image: T. Alexander.

For identification of species commonly found in eastern Washington, see *Identifying Wireworms in Cereal Crops* (Milosavljevic et al. 2015).

Depending on the species, wireworm larvae grow to as long as approximately 1.6 in. and are often longer than adults when mature. Fully grown *Agriotes* larvae are more typically between 0.6 to 0.9 in. long. These insects undergo complete metamorphosis, meaning the immature (larval) and adult (flying beetle) growth stages exhibit distinctively different forms. The stages of development include egg, larva, pupa, and adult.

Figure 2. *Agriotes* sp. larvae (top photo) and *Agriotes lineatus* click beetles (bottom photo). Photos: B. Brouwer.

Life Cycle

Overwintering adults emerge in spring and mate during a flight period that typically begins (for *Agriotes* spp.) in March, peaks in May, and tapers off by the end of June. During this time adults mate and females lay eggs. Adult dispersal is limited as they are generally poor flyers, with reports of male beetles moving approximately 100 ft per day (Traugott et al. 2015). Females are highly attracted to grass, pasture, or grains to lay eggs, of which they can lay up to 350 during their lifetime (Andrews et al. 2008). Eggs are deposited in clusters at a depth of one to six inches in soil, often in multiple burrows, resulting in spotty infestations throughout a field. Eggs usually hatch within four weeks.

The duration of the larval stage depends on the species, soil temperature, and food availability, and can extend up to five years for complete development. Wireworm larvae pass through approximately seven to nine instars (phase between molting) prior to pupating, depending on the species and environmental conditions (Traugott et al. 2015). After hatching, larvae disperse in the soil profile, where individual larva have been found to burrow to a depth of at least five feet, and range laterally approximately three to five feet (Traugott et al. 2015). They migrate to the soil surface in the spring as soil temperatures increase. This vertical movement typically coincides with spring planting. In western Washington, pupation typically occurs in August and September. The adults remain in the soil to hibernate during the winter and emerge the following spring. Figures 4–9 and Figure 16 show the stages of the wireworm life cycle.

Figure 3. The tail of *Agriotes* spp. are bluntly pointed (top photo), while the tail of the Pacific coast wireworm (*Limonius* spp.) is key-hole shaped (bottom photo). Top photo: B. Diehl; bottom photo: S. Bramwell.

Figure 4. Adult preparing to overwinter in soil at approximately six inches in depth. Photo: B. Brouwer.

Figure 5. Mating behavior in spring. Photo: B. Brouwer.

Figure 6. Neonate larva. Photo: S. Bramwell.

Figure 7. Multiple generations and sizes of larvae present in a field. Photo: B. Brouwer.

Figure 8. Wireworm molting. Photo: B. Brouwer.

Figure 9. Pupae found in soil in early fall. Photo: B. Brouwer.

Damage

Wireworms feed on seeds, young seedlings, transplants, as well as roots and tubers, resulting in seedling mortality and damage that reduces marketable yield (Figure 10). It is believed that wireworms are attracted to the carbon dioxide produced by germinating seeds and growing roots. Damaged root systems cause plants to wilt and sometimes die due to reduced capacity for water uptake. Resulting crop stands are thin and lack vigor (Figure 11). In a heavy infestation, bare spots may appear in the field and replanting is necessary. Damage to seedlings often occurs in the crown portion where larvae bore distinct holes and are themselves sometimes found in the damaged portion. Feeding on roots, tubers, and bulbs is unlikely to kill the plant; however, even cosmetic damage is likely to reduce marketable yield (Figure 12). Wireworms are most active in spring and late summer when soil temperatures are between 50°F and 77°F, though damage has been observed throughout the summer in western Washington.

Figure 10. Young lettuce (*Lactuca sativa*) seedling damaged by wireworm (left photo). Close-up of wireworm on lettuce seedling roots (right photo). Photos: B. Diehl.

Figure 11. Corn (*Zea mas*) stand thinned by wireworm. Photo: B. Gerdeman.

Figure 12. Wireworm emerging from a potato (*Solanum tuberosum*). Photo: S. Bramwell.

Monitoring

Wireworms are a challenging pest to monitor because they are mobile in the soil, they can live for multiple years, and populations can regularly increase from annual egg laying. Oftentimes it takes several years of management to reduce an established larvae population. Monitoring for larva should be done prior to planting when wireworms are active near the soil surface. Avoid sampling immediately following cultivation.

There are two general methods to determine if a field is infested. The first method is soil sampling, which can be done with a shovel or large diameter soil corer. Soil sampling can be broken down into three steps: (1) dig down approximately six to ten inches and lift the shovel or core for inspection, (2) round excess soil off the shovel to create an approximately six-inch diameter column, (3) count the number of wireworms present (Figure 13). Repeat this process at a minimum of 20 additional locations per field and calculate the average per shovel (Esser 2006).

The second method for monitoring wireworms is bait trapping (Figure 14). Bait traps are more effective at detecting low levels of wireworms than random soil samples. To deploy bait traps, bury a mesh bag of flour or germinating seed (e.g., wheat or corn) in the soil, which releases carbon dioxide and attracts wireworms. Dig up the bag after seven days and inspect the surface and contents for wireworms. The effectiveness of baiting can be reduced if a poor bait is chosen, too few samples are taken, sampling is done during inclement weather, a field was recently tilled, or bait is left in the soil too long. For large-scale production, a minimum of one bait trap per acre is recommended, while for smaller scales (less than one acre up to approximately five acres), five to ten traps per field are recommended. There may be variation in wireworm species preference for different bait types, but this is not well documented. See *Wireworm Scouting: The Shovel Method and the Modified Wireworm Solar Bait Trap* (Esser 2006) and *Wireworms: A Pest of Monumental Proportions* (Rondon et al. 2017) for more details on soil sampling and bait traps.

Figure 13. Soil sampling for wireworms using a shovel: sample six to ten inches deep (left photo); round soil off shovel to approximately a six-inch diameter (second from left photo); count wireworms in sample (second from right photo); plastic tray can help catch wireworms as you sift through sample (right photo). Photos: B. Brouwer.

Figure 14. Setting a bait trap: soak grain seed for 12 to 24 hr (left photo); bury mesh bag 6 to 12 inches (second from left photo); flag location of trap (second from right photo); dig up trap after one week (right photo). Photos: B. Brouwer.

In addition to sampling for wireworms, one can also monitor for adult click beetles. Pheromones are commercially available for *A. lineatus* and *A. obscurus* and will attract males from an approximately 26,000 square-foot area (Hicks and Blackshaw 2008). Pheromones for additional species are in development. These chemical lures are placed in a pitfall trap (e.g., Vernon Pitfall Trap) and draw reproducing adult beetles to them (Figure 15). To determine adult flight time and abundance, monitor weekly from late March through late June. If traps are left unattended, predatory ground beetles may eat click beetles and impact the accuracy of counts.

Damage thresholds for crops in western Washington are not well established. Trials with lettuce suggest that crop damage is likely to occur if there is an average of one or more wireworms per bait trap (Brouwer, unpublished data). At greater than five wireworms per trap, potential exists for severe damage (over 80% crop loss). In other regions, the presence of one to two wireworms per bait trap has been found to indicate probable damage to potatoes and wheat (Esser 2006; Andrews et al. 2008). The abundance of adult click beetles is difficult to correlate directly to potential crop damage in a given year; however, monitoring adults can help identify species present, egg laying potential, and the need for management strategies to reduce damage in subsequent years.

Site Selection

If wireworms are detected or suspected on your farm, site selection for planting may help mitigate damage. Conditions that have been identified as contributing factors to damage include crop and tillage history, field weediness, vegetation type in field margins, soil bulk density, tillage history, and irrigation (Poggi et al. 2021). The impact of these conditions on wireworms is described in depth below.

Planting history may indicate a potential significant risk for wireworm damage, especially if cereal or grass crops present considerable risk for wireworm damage. Grass cover provides a stable physical habitat for wireworms, and population levels have been observed to increase to very high levels under long-term grass and pasture for multiple species in N. America and Europe (Poggi et al. 2021; Vernon and van Herk 2013). Female wireworms also utilize cereal crops for depositing eggs. As a result, these crops, in rotation with horticultural crops such as potatoes, can lead to damage. Additionally, growing wireworm-susceptible annual crops year after year, or even two times per year (double-cropping) can increase wireworm populations by consistently providing a food source (Furlan et al. 2017).

Selecting fields that have been managed for low weed populations is also important. Patchy weeds and grassy areas provide good conditions in which females will deposit eggs, as they specifically lay eggs in these patches to decrease the chances that the eggs will dry out (Benefer et al. 2012). In contrast to the stable environment provided by long-term perennial grass cover, tillage disrupts wireworm larval populations, causing desiccation and predation, eventually reducing wireworm food availability (Vernon and van Herk 2013).

Figure 15. Monitoring for click beetles using a species-specific pheromone lure and a Vernon Pitfall Trap. Trap is located at edge of grassy field (left photo). Contents of trap after one week using *Agriotes lineatus* lure (right photo). Photos: B. Brouwer.

Vegetative field margins, specifically grass margins, provide habitat for dispersing male and female wireworms and have been positively related to crop damage (Hermann et al. 2013; Blackshaw and Vernon 2006; Blackshaw et al. 2018). Damage may be higher in sandy soils with grassy field margins due to the susceptibility of these soils to dry out and drive wireworms to seek refuge in moist tubers (Hermann et al. 2013). In contrast to grassy margins, hedges at field borders have been correlated with decreased wireworm damage in some situations and thereby are promising as an agroecological landscape approach for pest management (Saussure et al. 2015).

Soil bulk density, or the weight of soil per given volume, has also been related to wireworm pressure. More friable, loosely structured soil aids invertebrate movement while also potentially boosting these populations by reducing waterlogging (Parker and Sweeney 1997). Ease of movement and optimal water regime may also explain potentially higher wireworm damage in coarser textured sandy soils, other factors being equal.

Soil moisture conditions have been shown to influence wireworm populations. Wireworms commonly burrow deeper into the ground during the summer when drier surface conditions prevail, potentially reducing summer crop damage. However, this behavior changes under irrigated conditions, which allows wireworms to feed on crops under otherwise drier soil conditions (Staley et al. 2007). Irrigation has been shown to elevate wireworm populations, potentially by increasing food availability year to year (Milosavljevic et al. 2016). Wireworms have also been reported to cause damage directly to drip tape (Ota 1973).

Control

There is not a single simple solution to wireworm management, and a combination of cultural, mechanical, and chemical control strategies should be considered and timed to the appropriate wireworm life stage throughout the year (Figure 16). Wireworms are also more difficult to kill than other soil-dwelling arthropod pests, due to being highly sclerotized (hardened exoskeleton), which apparently helps them resist mechanical damage. Because of their movement within the soil profile, wireworms can be protected from surface disturbances and some species are tolerant to many commonly used insecticides.

Cultural

The most promising cultural practices to help a susceptible crop grow through the vulnerable seedling stage include promoting vigorous growth through optimized planting times, planting depth, moisture, temperature, and fertility management and amendments. Additionally, firm packing of soil in-rows may deter wireworm movement; for transplanted crops, delaying this operation until plants reach a larger size can reduce loss to wireworm feeding. Early harvest of potatoes, or other root crops, may help escape late season feeding damage by maturing wireworms.

Crop Rotation

Wireworms will feed on a very wide range of plants, so it is difficult to select nonhost crops for rotation. The experience of vegetable farmers in the Pacific Northwest indicate wireworm populations can be sustained by consistent availability of annual crops. These may include potatoes, lettuce, garlic, and beans (Pigman, personal communication). Avoid rotating with perennial grass, grain, or other crops that provide long periods of ground cover as this allows for undisturbed egg laying and larval growth. If converting an established perennial grass area to annual crop production, avoid planting particularly vulnerable crops for one to two years and consider a fallow period. Incorporating buckwheat and mustard cover crops may reduce damage in subsequent crops (Noronha 2017). Till under overwintering cover crops early in the spring to reduce plant cover during peak egg laying (May to June) thereby reducing introduction of new larvae into the field.

Trap Cropping

Trap cropping is a method of distracting wireworms from the market crop with an alternative food source, which allows the market crop to grow to a point where it can resist wireworm damage. This method will not reduce the wireworm population; however, it may be used in combination with other methods to protect a vulnerable crop. For example, wheat planted between rows of transplants has been found to reduce loss of strawberry (Vernon et al. 2000) and lettuce transplants (Figure 17; Brouwer et al. 2019). For best results, the trap crop should be planted one week prior to transplanting.

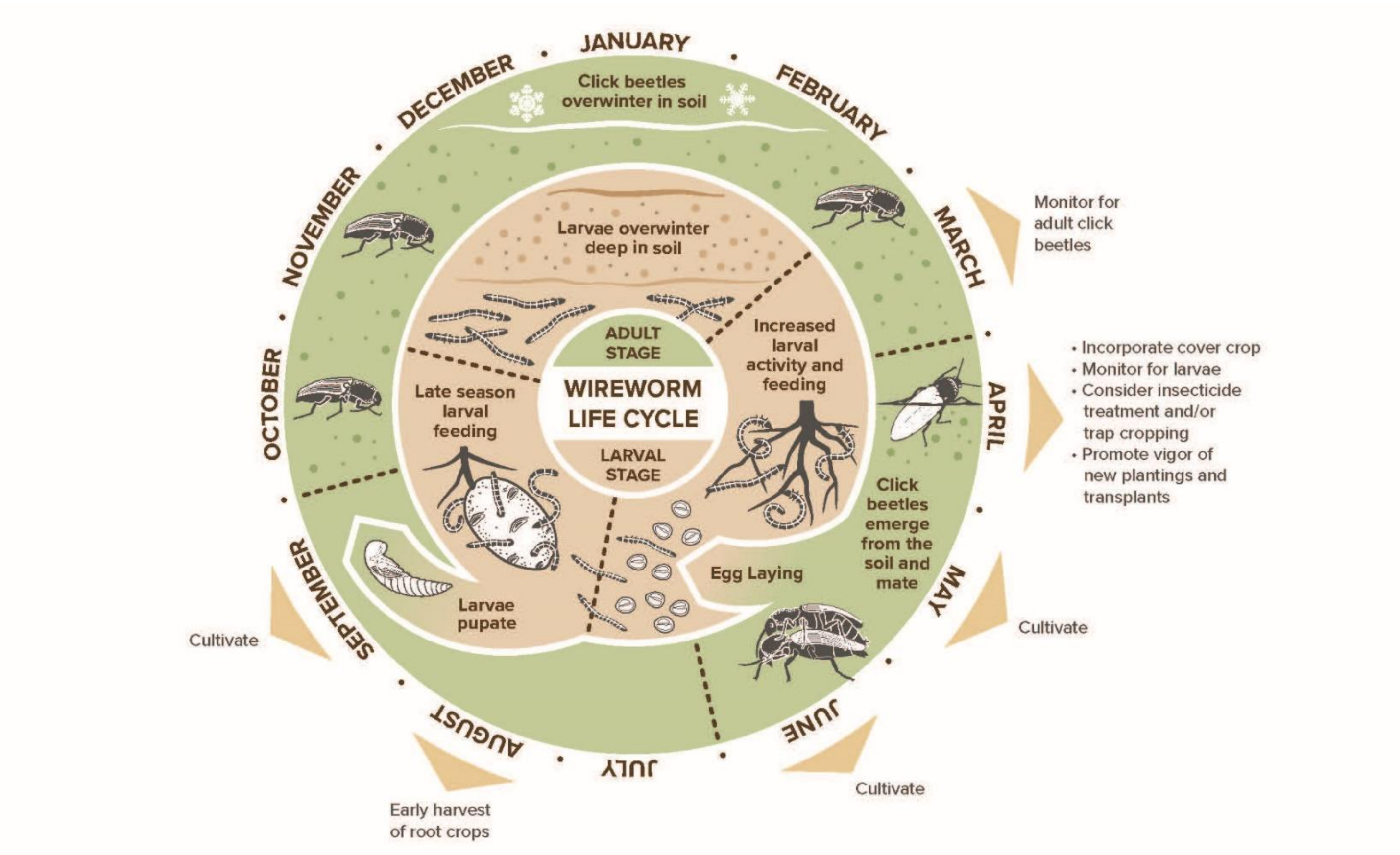

Figure 16. Generalized life cycle and key management timing for wireworms. Please note that exact timing of life stage and management will depend on wireworm species, site conditions, and crop. Inner brown ring indicates key stages of larval growth, outer green ring indicates key stages of adult click beetles. Image created by G. Steffen, CAHNRS Communications.

Mechanical

Repeated cultivation has been found to be effective in reducing wireworm populations over time. Cultivation can kill wireworms directly as well as expose them to predation, desiccation, and food insecurity (Vernon and van Herk 2013). Tillage should be timed when wireworms are active in the upper 3 to 15 inches of soil, particularly in early summer when eggs and early instar larvae are most vulnerable and late summer when pupation is occurring. After converting from pasture, three to five years of annual crop production with breaks of one or more months between crops and frequent cultivation may reduce wireworm levels below an economically damaging level (Furlan et al. 2009; Roebuck 1924).

Chemical

Wireworms are tolerant to a wide range of chemical controls, and species of wireworm differ in their susceptibility to insecticides. It has been hypothesized that wireworm populations and crop damage is increasing because various long-lasting, soil-applied carbamate, organophosphate, and organochlorine insecticides have been phased out of use due to health and environmental concerns (Vernon and van Herk 2013). Neonicotinoid-based seed treatment may act as a deterrent but will not kill wireworms, so damage may continue later in the season or the following year. Similarly, Bifenthrin has not been found to be lethal to wireworms but may have longer lasting repellency. The organophosphate compounds Chloropyrifos and Diazinon have been shown to control wireworms but product labels should be consulted for allowable crop uses. Fipronil, which is currently labeled for use on corn and potato, results in wireworm mortality and can be an effective control (van Herk et al. 2015).

Soil fumigation may be an option for vegetable crops such as potatoes. Products with the active ingredient 1,3 dichloropropene (e.g., Telone II) have been found to effectively control wireworms (Grove et al. 2000). The soil fumigant sodium N-methyldithiocarbamate (metam sodium), which is used for control of weeds, soilborne disease, nematodes, and symphylans, has been found to kill wireworms. However, metam sodium is not specifically recommended for wireworm control in Washington State, and damage in subsequent potato crops may still occur (Toba 1984). For more information on soil fumigation and insecticides, specifically for potatoes, see the Pesticide Tables for Potato Pests from the *PNW Insect Management Handbook* section on Irish Potato Pests (Blua et al. 2021).

Figure 17. Trap cropping with wheat planted between rows of lettuce transplants (left photo), and a plot in same field without trap crop (right photo). Photos: B. Brouwer.

Currently available options for organic-approved insecticides have not been found to be effective or evaluation has been limited. Specifically, laboratory studies and field trials have found that Spinosad-based products applied as a seed treatment (van Herk et al. 2015) or as a soil-applied bait are not effective for wireworm control (Brouwer et al. 2019). Spinosad has, however, been found to have a synergistic effect with entomopathogenic fungi (*Metarhizium anisopliae*), resulting in higher rates of wireworm mortality when used in combination (Ericsson et al. 2007). See the Hosts and Pests of Vegetable Crops (Green et al. 2021) section of *PNW Insect Management Handbook* for additional crop-specific pesticide recommendations.

Biofumigation

Certain types of mustard cover crops (including *Brassica juncea* and *Brassica carinata*) have been selected for high levels of glucosinolates. When the plant material is incorporated into the soil, it reacts with water to produce isothiocyanate compounds which have a fumigation effect (McGuire 2016). Biofumigant mustard cover crops should be grown to maximize biomass, then chopped finely and incorporated rapidly. Mustard cover crops should be terminated at flowering, prior to setting viable seed.

Defatted mustard seed meal can also be used as a biofumigant and allows for flexibility in application timing. Field and plot studies conducted in Italy have found mustard biofumigants to be effective at killing *Agriotes* spp. and reducing damage to subsequent crops (Furlan et al. 2009; Furlan et al. 2010).

Biological Control

There are a few biocontrol options based on mycoinsecticides and nematodes that show potential for wireworm control. Because study results are often species and strain specific, and local information on efficacy is limited, care should be taken when evaluating products or species for use. Strains of the nematode species *Heterorhabditis bacteriophora* and *Steinernema carpocapsae* have shown potential for control of *A. lineatus* in a laboratory setting, resulting in a significant increase in mortality after three weeks (Ansari et al. 2009). Strains of the entomopathogenic fungi *Metarhizium anisopliae* have been found to cause mortality of *A. lineatus* (Ansari et al. 2009) and to repel and increase mortality of *A. obscurus* under field conditions (Kabaluk et al. 2007). Variable results for *Beauveria bassiana* have been reported, including no infection of *A. lineatus* (Ansari et al. 2009). For both nematodes and fungi, soil temperature, moisture, concentration, and food availability can impact infection (Poggi et al. 2021). Additionally, mortality from infection by these biocontrol agents is often delayed by several weeks so damage to crop during application season is likely to occur. Applying biocontrol agents with a food source (such as grain) to act as an attractant may improve efficacy (Poggi et al. 2021).

Summary

Wireworms are a complex group of soil-inhabiting pests that consist of multiple species which feed on a wide range of crops in western Washington. The damaging larval stage can persist for several years in the soil, and adult females can lay hundreds of eggs over the span of only a few months. The introduced species *Agriotes lineatus* and *Agriotes obscurus* are now widely distributed in western Washington. This expanding range combined with a decline in the use of effective long-term residual soil-applied insecticides could potentially be contributing to recently observed increases in damage attributed to wireworms. The most severe crop loss is reported following rotation out of long-term pasture or following grain production, though wireworms can also persist in annual vegetable cropping systems. Managing wireworms will likely require multiple years of integrated pest management including monitoring, careful planting site selection, and appropriately timed cultural, chemical, biological, and mechanical controls.

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