Chapter 15

Cultural control and other non-chemical methods

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15.1 Introduction

Cultural control is the manipulation of an agroecosystem that makes the cropping system less friendly to the establishment and proliferation of pest populations (Dufour, 2001).

The potato *Solanum tuberosum* L. is one of the principal food crops, and a high level of production must be maintained to meet the growing demand of the world population. Unfortunately, spatial and temporal potato intensification drives insecticide resistance in the specialist herbivores (Huseth et al., 2015; see Chapter 24 for more details). Additionally, climate change is likely to affect agricultural pest management (Strand, 2000; Haverkort and Ver Hagen, 2008). Global warming favors the development of certain insects on potato fields, especially those that develop in the soil and cause damage to underground parts of potatoes: high temperatures and periods of dry weather that occur during the growing season accelerate the development of Elateridae (Coleoptera), Noctuidae (Lepidoptera), and the Colorado potato beetle, *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). As a result, more generations can develop per year than in the past (Kapsa, 2008).

The development of insect pest management strategies for potato has long been based on the substitution of insecticides by alternative methods (Boiteau, 2010; see also Chapter 27 for further discussion). In a theoretical model of environmentally- and human-friendly crop production, four phases of pest management can be distinguished (Wyss et al., 2005; Kühne, 2008). The first two basic phases are cultural practices and vegetation management to enhance natural enemy impact and exert direct effects on pest populations. The third phase requires the release of biological control agents, and the fourth, last-resort phase requires the use of approved insecticides and the use of mating disruption (Wyss et al., 2005; Boiteau, 2010). The first and the second phases correspond to the primary strategy of contemporary cultural control, which is maintaining and increasing the biological diversity in the farm system by the management of abiotic and biotic environment of the crop. The manipulation of abiotic conditions includes site selection, soil practices including irrigation and fertilizer management, and the use of mulches, row covers, physical control methods, etc. The manipulation of biotic environment embraces various aspects of crop rotation, intercropping, trap crops, companion planting, and the use of semiochemicals, including antifeedants.

15.2 Management of abiotic conditions

Abiotic factors are all non-living chemical and physical components of the environment that affect survival or reproductive success of living organisms. Abiotic factors that have bearing on potato growth include temperature, solar radiation, day length, moisture availability, and soil nutrients (MacKerron and Waister, 1985; Haverkort and Ver Hagen, 2008; see also Chapter 2). Potato crop development, including sprout growth rate, emergence, and leaf area development, depends on temperature and dry matter accumulation, the latter being a function of the amount of solar radiation intercepted by the crop and dry matter distribution between the various organs. For example, short days and low temperatures reduce branching and the number of leaves per stem, but increase the size of individual leaves; high temperatures increase specific leaf area

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but reduce photosynthesis; long days and high temperatures delay stolon and tuber initiation, and delay and reduce partitioning of dry matter to the tubers, which results in low harvest indices. However, a delay of tuber formation may stimulate final yield, provided that the growing season is sufficiently long to profit from the increased duration of ground cover (Struik and Ewing, 1995). If water stress occurs (i.e., there is less water available than needed for optimal growth), the plants are lower in height and the canopy coverage of soil is reduced due to the diminished leaf area and foliage (Ojala et al., 1990). Tuber yields can be reduced by water stress imposed at any time during the growing season (Adams and Stevenson, 1990; Jeffries, 1995).

Potato is best grown at places where daily temperatures are above 5°C and below 21°C, with sufficient availability of water (Vos and Haverkort, 2007). The variability in meteorological conditions influences the long-term effect of different soil tillage and fertilization regimes on potato yields, with the fertilization-induced yield differences manifested most noticeably in years with favorable growing conditions. A warm spring brings higher yields but precipitation during the same period is negatively correlated with the crop, whereas the positive influence of precipitation is expressed after flowering (Saue et al., 2010).

Abiotic conditions that are associated with the climate in a particular region of the world are difficult to manipulate in the open field environment. Nevertheless, human activities associated with the farming system of potatoes may contribute to the economic optimization of the potato yield not only by improving the plant growth but also by eliminating or restraining the populations of insect pests. For example, farm site selection, crop isolation, manipulation of planting or harvest time, or the use of mulches may make the crop unavailable to pests in space and time, and the enhancement of soil quality and fertility may alter the crop's susceptibility to pests (Zehnder et al., 2007).

15.2.1 Site selection, planting and harvest time

The location of the potato field should be as unsuitable as possible to insect pests (Boiteau, 2010). This can be accomplished by simply modifying the location of the crop in space and in time. The spatial separation of the crop may be gained by increasing the distance between crops and sources of colonizing pests or separating them by various barriers (vegetational or physical) or by avoiding the cultivation in areas where a given pest species occurred in abundance the previous season. Temporal isolation can be achieved by selecting the planting and harvest dates to escape heavy losses due to the pest feeding.

The setting of the potato field is especially important to prevent the aphid-borne virus spread. The minimum separation from virus sources depends on local conditions and the virus species involved. A distance of 400 m to 5 km is probably sufficient for the reduction of potato virus Y (PVY) spread, but much greater distance (ca. 32 km) may be required in the case of potato leaf roll virus (PLRV), as PVY is a short-lived non-persistent virus easily discharged by the vector during probing while PLRV is a persistent, circulative one and remains in the vector organism for all its life (Radcliffe and Ragsdale, 2002; Radcliffe et al., 2007) (for more details on aphid-borne viruses see Chapter 5).

The development and feeding habits of herbivorous insects are synchronized with the development of their host plants, which is one of the aspects of plant-herbivore co-evolution. Therefore, if the planting and harvest time can be modified in relation to the natural situation, the damage to the crops may be reduced. However, the potato planting time depends on local climatic and agronomic conditions, and economic factors, which may limit the use of this method (Alyokhin, 2009).

In the case of potato tuber worm *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), foliar damage to the potato crop usually does not result in significant yield losses, although the tuber worm larvae prefer green foliage to tubers for feeding and oviposition. However, when foliage starts to decline, the caterpillars are forced to go into the ground. Therefore, the greatest risk of tuber damage occurs immediately before harvest while the crop is left in the field prior to digging, and the longer the potatoes are left in the field after the vines die, the greater the likelihood of tuber infestation (Rondon et al., 2007; see also Chapter 8).

Late, as well as early planting is considered in management of Colorado potato beetle. Late planting causes late plant emergence, so the early emerging beetles are forced to migrate from the field because of food unavailability. Early planting and harvest might also reduce the impact of the second generation because the crop can be removed before the emergence of larvae. In addition, late-planted fields may act as sinks for beetles emigrating from earlier harvested fields looking for feeding and overwintering sites (Baker et al., 2001). The harvest date and tillage at different times between crop production seasons do not affect the overwintering Colorado potato beetle survival significantly (Nault et al., 1997).

Bringing forward tuber-lifting dates to the middle of August results in significantly lower wireworm- (the larval stages of click beetles (Coleoptera: Elateridae)) induced tuber losses compared with middle of September. This is probably due to the fact that the incidence of tuber damage increases in the second half of August, irrespective of wireworm abundance

(Erlichowski, 2010). Indeed, Schepl and Paffrath (2005) found that 4-week acceleration of the harvest may cause the 31%−64% reduction in tuber damage. Early harvesting can be recommended if tuber skin is sufficiently suberized and if cooling facilities are available for the tubers (Neuhoff et al., 2007).

Planting dates may appear very important in management of aphid (Hemiptera: Aphididae) infestation and especially the incidence of aphid-borne viruses. Early planting can be a useful strategy if vector species do not begin colonization until late in the growing season (Radcliffe and Ragsdale, 2002). Saucke and Döring (2004) found that the incidence of PVY decreased when the phase of early crop emergence coincided with low aphid spring flight activity. However, this method of prevention must be considered in relation to local fluctuation in the aphid (mainly the peach potato aphid *Myzus persicae* (Sulz.)) population, especially aphid flight activity (Wratten et al., 2007). Moreover, in many northern temperate production areas, the duration of the growing season is the limiting factor.

The combination of spatial and temporal isolation of potato crops can be achieved by crop rotation. This routine practice of growing a series of dissimilar types of crops in the same area in sequential seasons has traditionally been used to maintain and improve soil health and fertility (Nelson et al., 2009; Boiteau, 2010; Mohr et al., 2011). Nowadays, crop rotation is also used for the cultural management of pests and diseases that become established in the soil over time. For example, crop rotation is crucial to the control of the Colorado potato beetle, which overwinters as adults in potato field margins or surrounding woodlands; this was shown by Wright (1984), who found that rotation for 1 year to a non-host grain crop (rye or wheat) was sufficient to reduce adult *L. decemlineata* densities by 70%−95% in the following year's potato crop. The timing of adult beetle colonization, population densities, and early-season defoliation were related closely to how isolated the fields were from the previous year planting. Even short distances of 0.3−0.9 km between rotated locations were sufficient to reduce Colorado potato beetle densities and the necessity to apply insecticides by 50% (Weisz et al., 1994). Weisz et al. (1996) concluded that beetle infestation of a new potato planting is negatively correlated with distance to all potato fields from the previous growing season. Rotation may delay the colonization of fields by spring-emerging Colorado potato beetle from 1 to 3 weeks, due to the time needed for the beetles to locate fields after emerging and leaving remote overwintering sites (Baker et al., 2001). "Risk maps" can be drawn to show which potato fields should be rotated out of the area where potatoes were normally grown to substantially reduce the risk of infestation (Hoy et al., 2000). Finally, rotated fields also require fewer insecticide applications, which delays the evolution of resistance in Colorado potato beetle (Baker et al., 2001). Crop rotation has an important effect on patterns of genetic variation in Colorado potato beetle population (Crossley et al., 2019). The reduced genetic connectivity observed between Colorado potato beetle populations separated by low potato land cover in Columbia Basin (USA) suggests that increasing rotation distances (in space and time) could reduce rates of adaptive gene flow and levels of genetic diversity and could limit the long-term viability of *L. decemlineata* populations (Crossley et al., 2019).

Crop rotation is an important tool in controlling wireworms. Wireworms tend to increase rapidly in red and sweet clover, and small grains (particularly barley and wheat). As a result, the populations of wireworms affecting potatoes tend to increase following clover or small grains (Hills et al., 2020). To the contrary, a clean stand of alfalfa that is maintained for 3−4 years tends to reduce wireworm numbers, because extreme dryness of soil is harmful to most wireworms, and alfalfa serves as a soil-drying crop. Moreover, if alfalfa fields are allowed to dry during the season in which they are out of production, further reduction in wireworm populations can be expected (Berry et al., 2000).

The cotton whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) damage in potato crop depends, among other factors, on the nature of preceding crops and the crops growing along with potato in the same locality. In India, the whitefly incidence was higher at locations where potato is preceded by crops preferred by whitefly such as cotton, broad beans, groundnut, etc. (Shah et al., 2019).

Crop rotation affects also non-pest soil mesofauna. The study conducted in Poland focused on the response of soil fauna to 90 years of potato cultivation in monoculture (Twardowski et al., 2016). The abundance and diversity of soil-dwelling springtails were investigated, considering changes in the soil environment in relation to five-crop rotation. Soil springtails feed on decaying organic matter and fungi. The study demonstrated that although there were greater numbers of Collembola in the long-term monoculture of potatoes, the species diversity was lower in comparison to a five-field crop rotation, which indicated better biological soil quality in the five-field rotation system compared to monoculture (Twardowski et al., 2016).

15.2.2 Soil tillage

The conventional approach to potato farming system uses autumn plowing *ca*. 20 cm deep. The potato crop is usually grown in rows *ca*. 75 cm apart and on ridges about 20−25 cm above soil surface. One of the main objectives of tillage is to keep and maintain a high level of clod in soil, so that the roots could penetrate and develop better (Carter and Sanderson, 2001; Ghazavi et al., 2010). Soil surface configuration such as ridge tillage may allow manipulation of soil water content. For example, ridge till technology can not only overcome the constraints of water logging but can also capture and store water in the furrows during periods of low rainfall. Soil and nutrient losses are reported to be as much as 68% less under ridge tillage than conventional tillage, and ridge tillage in the fall may increase soil temperature early in the growing season and accelerate crop emergence (Essah and Honeycutt, 2004). Due to the form of the ridge and the spatial variation of root distribution, both vertical and horizontal movement of water and nutrients occurs in the soil. It was shown that for identical environmental conditions, nitrogen uptake by potatoes was higher in sandy clay loam than in loamy sand, as sandy clay loam has higher water content at the same pressure head (De Willigen et al., 1995).

In terms of plant protection, tillage can be beneficial because it may disrupt the life cycle of insect pests and can expose the soil-living stages to predators and the physical environmental factors. However, different tillage practices may have different effects depending on the specificity of the insect biology.

In the case of wireworms that spend their life as much as 0.3−1.5 m below ground level for 2−5 years (Andrews et al., 2008), repeated disturbance of the soil decreases their populations both by direct injury and by exposure to desiccation or attack by birds (Seal et al., 1992). Wireworms are very sensitive to soil moisture: drying of the upper soil layers in combination with high temperatures causes the downsoil migration. Therefore, cultivation is likely to be most effective when wireworms are active in the upper layers of the soil profile (i.e., 10−20 cm), which occurs at *ca*. 13°C. In the U.K., for example, this means that autumn plowing followed by disking will have more effect on reducing wireworm populations than the cultivation in February or March (Parker and Howard, 2001).

In the case of the Colorado potato beetle, the conventionally tilled crop (tomato *Lycopersicon esculentum* Mill.) had a more abundant beetle population than non-tilled one in both rotated and non-rotated fields, probably because of the earlier colonization of overwintered adults. In conventionally tilled plots, this resulted in higher egg mass densities and subsequent infestation of first-generation larvae and adults. Moreover, in treatments where fenvalerate was applied to control Colorado potato beetle populations above economic thresholds, four spray applications were required in conventionally tilled plots, compared with two applications in non-tilled tomatoes (Zehnder and Linduska, 1987). In another experiment, where tomatoes were grown in a reduced tillage system utilizing rye (*Secale cereale* (L.)) as a cover crop, colonization by newly emerged adult Colorado potato beetles in the spring was significantly more rapid in conventionally tilled than in reduced-tillage plots. Conventionally tilled plots had significantly higher densities of egg masses, larvae, and second-generation adult Colorado potato beetles, which was attributed to the presence of rye residue in the reduced-tillage plots. Eventually, the reduced-tillage plots sustained less defoliation than conventionally tilled plots and had higher yields of ripe fruit (Hunt, 1998).

The soil provides the environment to a wide diversity of predatory arthropods, mainly the ground beetles (Coleoptera: Carabidae) and spiders (Arachnida). Plowing the soil may affect their survival directly by causing mortality and may also have indirect effects by modifying habitat and the availability of prey. Generally, the larger species are more vulnerable to soil cultivations than the smaller ones. However, the response of individual species varies due to their species-specific characteristics, so the overall abundance of soil predators may not differ in consequence of plowing but the species spectrum of this group may change (Holland, 2004).

15.2.3 Soil moisture

Soil moisture management (soil drying, soil flooding, or alternation of these) is the most frequently considered technique among the preventive cultural methods that are carried out before potato is planted, especially against wireworms. Wireworms are highly responsive to soil moisture and temperature (Parker and Howard, 2001). However, the effect of these practices depends on the wireworm species, soil type, and temperature. Continuous or alternate flooding appears effective for control of *Melanotus communis* (Gyllenhal) and *Conoderus* sp. with the minimal effective continuous flooding period 6 weeks (Genung, 1970). The dusky wireworm *Agriotes obscurus* (L.) and the lined click beetle *A. lineatus* (L.), submerged at high temperatures died more quickly than those submerged at low temperatures, and wireworms in flooded Delta soil died more quickly than those in flooded Agassiz soil. Soil analysis suggests that soil salinity may affect the effectiveness of flooding as a control strategy. Flooding in fall or summer (higher temperatures) would likely provide more effective control of wireworm populations than flooding in winter (van Herk and Vernon, 2006). However, it must be kept in mind that potato responds negatively to variations in water supply. Over-irrigation favors disease, leads to nitrate leaching, and to sediment and nutrient losses (Shock et al., 2007). Too much water may cause reduced root development and rotting of the newly formed tubers, and infection with late blight *Phytophthora infestans* (Mont) De Bary; excessive variation in soil moisture, especially water after a prolonged drought, may affect tuber quality due to ‘second growth’ (Haverkort, 1982).

Soil moisture is also important for potato tuber moth infestation. Female moths prefer dry soil for oviposition, and the survival of larvae increase with decreasing soil moisture content. The density of adults is higher in relatively dry sandy soil than in moist loess soil. Also, tuber moth larvae on foliage in the field margins are more abundant than in the center, probably because plants on the edges of the field are more exposed to wind and solar radiation, leading to drier conditions than in the field center. Moreover, infested tubers in loess may support more larvae than those in sand, possibly because cracks in loess soil make the tubers accessible to more larvae (Coll et al., 2000).

15.2.4 Mulches

In the crop rotation systems, potato farming generally uses intensive tillage throughout the cropping period and produces low levels of crop residue in the potato year, both of which are associated with soil degradation processes: erosion and leaching of nitrates (Carter et al., 2005). The application of mulches is one of the most effective soil erosion prevention methods. Essentially, a mulch is a protective cover placed over the soil to retain moisture, reduce erosion, provide nutrients, and suppress weed growth. Different materials are applied: organic residues such as straw of various origins, compost, plastic, gravel, etc. Organic mulches are used especially in organic farming to add organic matter to the soil and to increase soil-moisture-holding capacity and reduce soil temperature (Jabran, 2019). A number of studies have investigated the effect of different mulches on soil properties, potato harvest, and the occurrence of diseases. Zehnder and Hough-Goldstein (1990) found that soil temperature and moisture conditions were more favorable for potato plant growth in Virginia under straw mulch than in bare ground (no mulch) plots. Final tuber yields were significantly greater in mulched plots (with and without insecticides) compared with plots without mulch. The use of organic mulches after the potato harvest presented a practical form of conservation tillage for potato rotations (Carter and Sanderson, 2001). The risk of undesirable post-harvest nitrogen leaching was significantly reduced due to the immobilization of nitrate after harvest, and soil erosion was reduced by more than 97% in a rain simulation experiment (Döring et al., 2005). When soil temperature is insufficient, plastic and straw mulches enhance tuber yield (Kar and Kumar, 2007; Wang et al., 2011a). During a fallow period, a mulch can reduce the soil desiccation (Wang et al., 2011b). Plots with straw mulch generally have lower soil temperatures and higher soil moisture than control (weedy, no straw) plots. Moreover, when straw was applied at planting the weeds were suppressed, whereas straw applied 4 weeks after planting had less effect on weeds (Johnson et al., 2004).

Studies have shown that the application of mulches can suppress some insect pests (mainly Colorado potato beetle and aphids), probably through a combination of effects involving migration, overwintering, host-finding ability, and increased predation from natural enemies (Alyokhin et al., 2020). In the case of the Colorado potato beetle, the use of mulches has a detrimental effect on various aspects of its biology, especially on survival during the vegetative period and at overwintering sites. In potato fields where wheat straw mulch was placed, the numbers of second, third, and fourth instars of first-generation and all instars of second-generation *L. decemlineata* were significantly lower than in non-mulched plots. This was attributed to a significant increase in the number of soil predators, mainly coccinellids and chrysopids, that began in mulch plots approximately 2—3 weeks after straw was placed in the field. As a result of heavy predation, mulched plots suffered 2.5 times less defoliation than non-mulched plots and, consequently, tuber yield was approximately 35% greater in mulched plots than in the non-mulched ones (Brust, 1994). Straw mulch reduced the density per square meter of adults and large larvae in plots without beetle management, so defoliation was lower and leaf area and ground cover were increased in mulched subplots (Stoner et al., 1996). Mulching with wheat or rye straw may reduce the Colorado potato beetle's ability to locate potato fields, and the mulch creates a microenvironment that favors its predators. In the first half of the season, soil predators — mostly ground beetles — climb potato plants to feed on second- and third-instar larvae of the Colorado potato beetle. In the second half of the season, lady beetles and green lacewings are the predominant predators, feeding on eggs and on first and second instars. Mulched plots supported greater numbers of predators in comparison to non-mulched plots, resulting in significantly less defoliation by Colorado potato beetle; in consequence, the tuber yields were increased by a third (Brust, 1994). Barley straw mulch is significantly preferred to birch sawdust, milled peat, and black plastic mulches by the generalist predators *Pterostichus vulgaris* (L.), *P. niger* (Bonelli), *Carabus nemoralis* (Müll.), and *Harpalus pubescens* (Müll.) (Coleoptera: Carabidae) (Arus et al., 2011). The application of organic mulches (hay and leaf litter mulch) significantly increased the number and diversity of carabid beetles in potato plots in Hungary (Dudas et al., 2016). Wheat straw mulch also caused an indirect negative impact on the Colorado potato beetle population due to an increased predation by *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Coleomegilla maculata* (DeGeer) (Coleoptera: Coccinellidae), and *Perillus bioculatus* (Fabr.) (Hemiptera: Pentatomidae) (Jabran, 2019).

Interestingly, potatoes with straw at planting had more colonizing Colorado potato beetle adults than non-mulched potatoes but the subsequent Colorado potato beetle egg masses and larval numbers were not higher in this treatment, possibly because of the higher numbers of predators in these plots as assessed by pitfall trapping (Johnson et al., 2004). However, the impact of predators in mulched versus non-mulched potatoes depends on the predator species. Szendrei and Weber (2009) studied the effect of *Lebia grandis* (Hentz) (Coleoptera: Carabidae) and *C. maculata* on Colorado potato beetle in potato fields with and without rye mulch. They found that the two predator species responded in opposing manner to the habitat manipulation treatment in potato fields: on average, 35% of all *C. maculata* but 85% of all *L. grandis* collected over two field seasons were found in tilled plots versus rye mulched plots but neither predator was influenced significantly by the presence of rye mulch in the field cage experiment. Nevertheless, *C. maculata* eliminated more (but not significantly more) prey in the rye-mulched than in the tilled treatment. *C. maculata* was frequently observed scurrying along rye stalks, so the presence of stalks might have had a positive behavioral or physiological effect (Szendrei and Weber, 2009).

Mulching has no significant effect on adult Colorado potato beetle migration within the potato field either during the vegetative period or before overwintering (Brust, 1994; Hoy et al., 1996). Generally, the numbers of overwintered adult beetles, egg masses, and larvae are significantly lower in plots with straw mulch compared with those without (Zehnder and Hough-Goldstein, 1990), but the mulch depth has no impact on overwintering depth of beetles in the soil or average date of emergence in the spring (Hoy et al., 1996). However, what happens to a mulch during winter is important. The removal of mulch covers or snow over a mulch rapidly depresses soil temperatures at all depths. In the 0−15 cm soil strata, where most of the adults overwinter, temperatures may drop from 0°C to −11.7°C, whereas in undisturbed plots, the temperature may remain close to 0°C. As a result, adult survival may be significantly higher in snow-covered, non-mulched plots and mulched habitats (26%) than in disturbed habitats 7%. Apparently, thermal shock may increase the overwintering mortality of Colorado potato beetle; direct disturbance of overwintering habitats could be achieved with mulching/unmulching (Milner et al., 1992).

Finally, in the fields where mulches are used, it is possible to reduce the number of insecticide applications, which was the case in the study by Zehnder and Hough-Goldstein (1990): in plots treated with insecticides, six spray applications were required to control Colorado potato beetle populations above economic thresholds in plots without mulch, compared with two applications in plots with mulch.

Many of the plastic mulches can deflect or repel insect pests such as whiteflies, thrips, or aphids through their color, odor, or surface characteristics (Diaz and Fereres, 2007; Jabran, 2019). In the case of aphids, mainly the peach potato aphid *M. persicae*, the direct effect of mulches is manifested primarily in the disruption of host plant location by the winged morphs, especially early in the season (Wratten et al., 2007). The effectiveness of mulches depends on aphid response to color and light reflectance. According to Žanić et al. (2009), green mulch was found the most attractive to *M. persicae*, black and clear mulches alternated in attractiveness for *M. persicae* during the season, while the overall seasonal number of *M. persicae* was lower on black, brown, and clear mulches than on green and white mulches. According to Adlerz and Everett (1968), yellow and orange mulch attracted *M. persicae*, while aluminum and silver mulches repelled green peach aphids. Aluminum mulch significantly reduced virus transmission by *M. persicae* on tomato, which was attributed to the increased reflectance of UV light by that mulch (Kring and Schuster, 1992). On the other hand, significantly greater aphid fecundity was demonstrated on plants grown through aluminum-coated construction paper than on plants grown on bare soil. Higher temperatures and host-plant physiology were factors modified by the mulch and could have resulted in larger aphid populations on plants grown over a reflective surface as the season progressed (Zalom, 1981). The total number, and especially the number of winged aphids, was reduced and the degree of PVY infection was distinctly lower in potatoes with straw mulch as compared to the crop without mulch (Heimbach et al., 2002). Another potential method to control the transmission of PVY is mulching a potato field with cereal straw after planting: the mode of action is primarily attributed to the manipulation of the host finding behavior of aphids by the visual properties of straw (Kirchner et al., 2014). Straw mulch spread to the field at the time of plant emergence reduced PVY incidence by 50%−70% in the 3-year study in Finland (Kirchner et al., 2014).

The effect of mulches on soil temperature and insect abundance depends on geographical conditions. In Czech Republic, the effectiveness of chopped grass and black textile mulches on soil properties and the abundance of Colorado potato beetle was studied in highlands and lowlands, which differ in the average annual temperatures and rainfall (Dvorak et al., 2012). In the colder highlands, both treatments had a positive effect on increasing soil temperatures. Consequently, higher soil temperatures under both mulches correlated with a slightly higher occurrence of adult Colorado potato beetle. The use of textile mulch also increased the number of eggs. In the warmer lowlands, grass mulches decreased the soil temperatures, while textile mulches increased soil temperatures. In lowlands, the use of textile mulches correlated with an increase in the number of all Colorado potato beetle life stages, while the use of grass mulch reduced the number of larvae (Dvorak et al., 2012).

15.2.5 Fertilizers and other soil amendments

Potato demands high level of soil nutrients due to relative poorly developed and shallow root system in relation to yield (Elbordiny and Gad, 2008). Soil amendments, especially with the use of natural fertilizers, such as manure, results in good plant growth and condition. For example, tuber yields were higher in manure-amended plots as compared to plots receiving full rates of synthetic fertilizers but no manure (Alyokhin et al., 2005).

Organic soil management has been associated with plant characteristics unfavorable for Colorado potato beetle reproduction and development: the beetle population density was lower in plots receiving manure and reduced amounts of synthetic fertilizers compared to plots receiving full doses of synthetic fertilizers, but no manure. The effect was attributed to distinct differences in concentrations of macro- and micro-nutrients in potato leaves from manure- and synthetic fertilizer-treated plots. Of all studied minerals, zinc had a consistently positive effect on beetle populations but boron had a strong negative effect on all beetle stages except for the overwintered adults. Also, concentrations of this element were usually about two-fold higher in the plants grown on manure-amended soil (Alyokhin et al., 2005). Female fecundity was lower in manure-amended plots early in the season, although it later became comparable to that on potatoes grown in synthetically fertilized soil. Fewer larvae survived past the first instar, and development of immature stages was slowed down on manure-amended plots. Moreover, in the laboratory, first instars consumed less foliage from plants grown in manure-amended soils (Alyokhin and Atlihan, 2005).

An interesting option for soil insect pest control is the application of allelopathic plant products to the soil. Allelopathy is a natural ecological phenomenon that occurs through the release, by one plant species, of chemicals which affect other species in its vicinity (Kruse et al., 2000; Bogatek and Gniazdowska, 2007). The term allelopathy is generally used to describe inhibitory and stimulatory effects of one plant on another plant, but the effects of secondary compounds on plant-insect interactions are also included (Kruse et al., 2000). In field crops, allelopathy can be used following rotation, using cover crops or mulching (Farooq et al., 2011). The allelopathic products can be administered either in the form of green manures or plant extracts. For example, brassica (*Brassica nigra* (L.) and *Sinapis alba* (L.)) green manures, used before the planting of potatoes, can produce a trend for lower levels of wireworm damage to potato tubers. The effect is caused possibly by toxic brassica green-manure breakdown products (McCaffrey et al., 1995; Frost et al., 2002). Similar effects can be gained by the application of wheat, turnip, vetch and mustard green manures, which are the most effective when plowed in autumn (Schepl and Paffrath, 2005). Nevertheless, consideration must be given to whether allelochemicals affect non-target organisms, and whether the allelopathic plant itself has adverse effects in the cultivated field or in natural environments (Kruse et al., 2000).

15.2.6 Physical control methods

Physical control refers to mechanical or hand controls where the pest is removed or destroyed. Physical control methods aim also to prevent or reduce pest colonization by various physical means that function either as a barrrier or by passively or actively affecting insects' behavior (Berlinger and Lebiush-Mordechi, 2004; Weintraub, 2013). Passive methods that refer to pest control in open spaces are mainly mechanical and include fences or insect exclusion screens, inorganic mulches, sticky barriers, traps, and trenches. Active methods in agricultural environment can be divided according to the mode of energy that they use into mechanical (contact removal), pneumatic (vacuuming, blowing), electromagnetic (microwaves, electricity), and thermal (burning, flaming, solarization or solar heating, steaming) (Panneton et al., 2001; Vincent et al., 2009; Vincent and Boiteau, 2001).

A physical barrier may be defined as a structure made up of wood, metal, plastic or any other material (including living barriers) used to obstruct or close a passage or to fence in a space (Boiteau and Vernon, 2001). Growers conventionally isolate seed potato fields with cultivated fallow borders, creating a green plant/dark soil border that is attractive to flying aphids potentially carrying PVY (Boiteau and Vernon, 2001). The use of barriers like plastic-lined trenches to manage the Colorado potato beetle is one of the more effective control opportunities. The immigrating beetles fall into the trench and while trying to climb out, they cover their tarsae, or footpads, with the dust, which worsens their ability to escape from the trench. The beetles are also unable to fly out of the trap and die (Boiteau and Vernon, 2001). In New Zealand, the mesh covers caused a reduction in the numbers of tomato potato psyllid *Bactericera cockerelli* (Šulc) (Hemiptera: Triozidae) nymphs and adults, which resulted in an increase in tuber size and in the overall yield (Merfield et al., 2015). The incidence of *B. cockerelli* foliage damage and the development of blight were lowest when the passage of ambient ultraviolet radiation through the crop cover was reduced. Additionally, potatoes grown under mesh covers exhibited increased yield and produced fewer smaller tubers (Merfield et al., 2019).

Thermal control of insects is generally aimed at inducing internal injuries that will lead to death over a short period of time, and three different techniques may be used to expose pests to high temperatures: direct exposure to flames, use of infrared radiation, or steam projection (Lague et al., 2001). The thermal technique could be used to simultaneously control weeds and Colorado potato beetle (adults and eggs) in the spring, but it is only efficient against weeds and pests that are present during the treatments. In the spring, thermal control could be applied to the whole field or to its sections (border rows, trap crops) that are rapidly colonized by Colorado potato beetle adults. The control of larvae by making passages during the appearance of floral buds and at blooming may also be considered (Duchesne et al., 2001). Using flamers on plants 10 cm tall or less can eliminate roughly 90% of adult Colorado potato beetle in spring and reduce hatching of egg masses by 30%, without reducing crop yields (Lacasse et al., 2001).

In pneumatic control, insects can be dislodged from plants with air pressure, then killed by a system of turbines or collected and killed upstream in a dedicated system of the blower (Weintraub, 2012). Pneumatic control systems are often referred to as vacuums (Khellfi et al., 2001). In potato, pneumatic control is considered mainly to remove the Colorado potato beetle adults and larvae by suction, blowing, or a combination of both (Khellfi et al., 2001; Lacasse et al., 2001). It can be assumed that pneumatic control eliminates all the insects present on foliage indiscriminately. However, the number of the adult parasitoids was reduced only immediately after vacuuming melon, and there was no significant difference between the number of parasitoids in vacuum-, insecticide- and nontreated plots (Weintraub and Horowitz, 2001). This technique is successfully used to control insects that easily fly as soon as they are disturbed in their environment. However, the Colorado potato beetle adults hold onto the plants firmly (Khelifi et al., 2001; Weintraub and Horowitz, 2001). Furthermore, the foliage of the host potato plants becomes denser as growth advances and the generated vacuuming force rapidly dissipates. It is, therefore, very difficult to suck up beetles that are deep in the plants or those that are firmly gripping to the foliage (Khellfi et al., 2001). Forces up to 0.04, 0.03, and 0.01N were necessary to detach from potato plant leaves adults, fourth instar larvae, and second or third instar larvae, respectively. However, those results were highly related to the position of the Colorado potato beetles within plant canopy, in particular the adults (Misener and Boiteau, 1991). Horizontal airstreams moving across the plants at a mean velocity of 27.5 mL/s at the foliage level yielded the best removal rate (100%) of adult Colorado potato beetles from potato plants and neither beetle sex nor their degree of previous exposure to airflow had an effect on the removal rate (Khelifi et al., 1995a). Young potato plants, 0.4m tall or less (less than 12 leaves), can tolerate airflows of up to 27.5 m/s without suffering any visual injury (Khelifi et al., 1995b). A number of pneumatic machines for the removal of insects were described by Boiteau et al. (1992), Khelifi et al. (2001), Weintraub and Horowitz (2001), and Lacasse et al. (2001).

Soil solarization is a technique of raising soil temperature by clear plastic sheets which allows shorter wavelength solar radiation to enter into soil and heat it up while restricting the longer wavelength radiation during night time (Panwar et al., 2019). Thus, soil solarization keeps soil temperature continuously above lethal range (up to 60°C) for many soilborne plant pathogens, nematodes, weeds, and hibernating stages of insect pests (Panwar et al., 2019). Solarization is a chemical-free way of controlling pests and weeds in the soil before planting crops. However, this pre-plant method involves soil heating by capturing solar radiation for 4—6 weeks during the summer time when the soil receives the maximum sunlight (Gill et al., 2017), which may not always be practical for commercial growers.

15.3 Management of biotic conditions

Biotic factors are the living parts of ecosystems. In agroecosystems, the crop, being the producer in the food chain, interacts with other biotic components — directly with phytophagous organisms, and indirectly with predators and parasites (see Chapter 25 for a more detailed discussion). At the same time, the crop is a member of a biological network of interactions, which means that its welfare depends not only on interactions with other trophic levels but also on indirect effects of other biotic components, such as neighboring vegetation, accompanying vegetation (e.g., weeds), history of vegetation (e.g., preceding crops, cover crops), etc. Considering these facts, various strategies of biotic environment manipulation are applied in potato culture to prevent or avoid agricultural pests and pathogens. The crop may be made unacceptable to pests by interfering with oviposition preferences, host-plant discrimination, or host location by intercropping, trap cropping, the use of living mulches, etc. Additionally, pest survival may be reduced by enhancing natural enemies through an increase in crop ecosystem diversity (Zehnder et al., 2007; Powell and Pickett, 2003). Finally, the use of behavior-modifying chemicals (semiochemicals) is a promising strategy supplementing other cultural methods of pest management (Norin, 2007). Semiochemicals, which are discussed in more detail in Chapter 13 are natural products that act as signals and regulate interactions between organisms, e.g., plants and insects (Pickett et al., 2000). Semiochemicals are divided into pheromones (functioning in intraspecific interactions) and allelochemicals (functioning in interspecific interactions) (Norin, 2007). In pest management, semiochemicals are applied mainly in monitoring insect pest populations and preventing agricultural damage by interfering with insect behavior (Raman, 1988). Various chemical stimuli may be used alone or in combinations, which may give different behavioral outputs and often lead to the disorientation of the insects (Cook et al., 2007).

15.3.1 Intercropping

Intercropping is the practice of simultaneously growing two or more crops in close proximity. Intercropping has a long history in traditional agriculture (Roder et al., 1992; Bhanu and Yadav, 2019; Jamshidia et al., 2008). In certain areas, such as Bhutan, up to 40% of the potato was grown in intercropping systems (Roder et al., 1992). The idea of intercropping is to choose two or more crops that vary in time of planting and harvesting as well as in manner of growth and development, which means that they should be complementary to, and not competing with, each other in terms of used resources such as light, water, and nutrients (Jamshidia et al., 2008). There are several ways to arrange the crops: (1) in strip intercropping, two or more crops are grown in strips wide enough to permit separate crop production but close enough for the crops to interact, (2) in row intercropping, at least one crop is planted in rows, (3) in mixed intercropping, there is no distinct row or strip arrangement; and (4) in relay intercropping, the crops are planted in succession with a second crop planted into a standing crop at the reproductive stage before harvesting (Knorzer et al., 2009).

The effect of intercropping on potato yield depends on many factors, including the species and proportion of the interplanted crop, the location of the field, and the arrangement of the crops. For example, in Bhutan, the variation in planting geometry and maize planting date did not affect potato yield but the location of the fields appeared of importance: in the field located at the elevation of 2700 m above sea level and 720 mm average rainfall, intercropping did not have any effect on the economic output; however at the elevation of 1900 m a.s.l. and 1242 mm average rainfall, it did increase economic benefit by 12%−15%. Moreover, it was suggested that an additional effect of intercropping in the mountainous regions would be a reduction in high erosion risk at the time of potato harvest (Roder et al., 1992). In Iran, a maximum potato yield was obtained from 3:1 potato: maize crop ratio (Jamshidia et al., 2008). In Pakistan, intercropping with maize and faba beans reduced the overall potato yield, and the reduction was higher when strip intercropping was applied than when the mixed intercropping was used. Interestingly, a correlation with the size of tubers was found: maize and bean plant populations were negatively correlated with big tubers and positively with-seed size tubers, depending on the amount of the intercropped maize (Farooq et al., 1996). In Sri Lanka, in relay-cropping combinations using maize or beans (soybean) as companion crops, shading during the first 4 weeks improved tuber yield by 20% whereas shading for up to six or 8 weeks after planting the potato reduced the potato yields by 25% and 35%, respectively (Kuruppuarachchi, 1990). In Peru, when relay-cropped with maize, potato plant population at harvest was superior to that of a sole crop of potato − an effect mediated through faster emergence and achievement of a greater maximum population, and not through differential survival of shaded or sole potato plants (Midmore et al., 1988). In southern England, intercropping potato with cabbage significantly reduced the economic yields of both component crops due to competition for nutrients or light (Opoku-Ameyawi and Harris, 2001).

The described situations show that there is no universal rule on how to apply intercropping to increase the yield of potato or the overall economic effect of this crop arrangement. Conversely, there is ample evidence that the use of an intercropping system helps to control pathogens and insect pest populations. For example, in Germany, the foliar late blight *P. infestans* was significantly reduced in potatoes strip-cropped with cereals or a grass-clover mix compared to pure stands of potato; the most important factors contributing to disease reduction were loss of inoculum outside of the plots and barrier effects of neighboring non-potato hosts (Bouws and Finckh, 2008). In Ethiopia, 75% garlic with 25% potato (3:1) intercropped plots showed significantly lower late blight development and high tuber yield (Kassa and Sommartya, 2006).

In the case of insects, and especially those life stages that are active on the above-ground parts of plants, an intercropping system can contribute to population control by manipulation of their behavior. One of the most sensitive steps in the herbivorous insect life is the host location activity, which has consequences not only for the survival of an individual, but also for the reproduction and survival of the species (Bruce et al., 2005). Host location by herbivores relies mainly on visual and olfactory cues that derive from the habitat of the host plant and the host plant itself, and act over long and short distances. Therefore, many phytophagous insects, especially the oligophagous ones, can find their hosts more efficiently in monocultures, when no other plants are present to interfere (Strong et al., 1984). The olfactory cues are of special importance (Bruce and Pickett, 2011).

For example, studies on Colorado potato beetle showed that subtle alterations in the original ratio of the green leaf volatiles emitted by potato leaves (E)-3-hexen-1-ol, (E)-2-hexen-1-ol, (Z)-2-hexen-1-ol and (E)-2-hexenal had a significant impact on host location, switching off attraction to the host plant when presented in an unnatural ratio (Bruce et al., 2005). It is not surprising then, that the manipulation of the crop accompanying vegetation may prove a successful strategy to disorient the foraging herbivore and reduce the economic loss due to its feeding. Colorado potato beetle can be disoriented by the non-host plant odors. The beetle population on potato plants was reduced by 60%−100% when interplanted with tansy *Tanacetum vulgare* (L.) and 58%−83% when interplanted with catnip *Nepeta cataria* (L.) as compared to monocultural plantings (Panasiuk, 1984). Thiery and Visser (1987) found, in the laboratory, that the attractiveness of potato odor was neutralized by the mixture of potato and the non-host wild tomato *Lycopersicon hirsutum f. glabratum* (C. H. Muell) and suggested that this fact may be used in practical pest control by mixed cropping.

Potato tuber moth infestations were consistently reduced when potatoes were grown in association with certain other crops. Potato-chilli, potato-onion, and potato-pea associations significantly reduced larval infestation compared to potato alone. Similarly, tuber damage was significantly lower in the plots associated with chilli, onion, and pea, being 11%, 11%, and 13% compared, to 27% in potato alone (Lal, 1991).

Significantly fewer aphids *Myzus* spp., leafhoppers *Empoasca* spp., and field crickets *Gryllus* spp. occurred in the potato-berseem *Trifolium alexandrinum* L. and potato-radish mix cropping (Jan et al., 2002). Intercropping the potato crop with onion or garlic reduced populations of *M. persicae, A. gossypii* and *Empoasca* spp. when less than 0.75 m berseem *Trifolium alexandrinum* L. separated the potato plants and *Allium* spp.; leaf damage to potato by *Henosepilachna sparsa* (Herbst) (Coleoptera: Coccinellidae) was also reduced at this spacing, but populations of *Thrips palmi* (Karny) or *T. parvispinus* (Karny) (Thysanoptera: Trypidae) were increased (Potts and Gunadi, 2008).

Intercropping also promotes the occurrence of natural enemies, which contribute to the reduction of insect pest populations. In Egypt, planting potato under sweet orange *Citrus sinensis* (L.) trees significantly reduced the infestation by the silverleaf whitefly *B. tabaci* (Mousa and Ueno, 2019). Planting systems also had a significant but minor impact on the potato leafhopper *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae) and the green sink bug *Nezara viridula* (L.) (Hemiptera: Pentatomidae). Natural enemies such as ladybeetle *Coccinella undecimpunctata* (L.) (Coleoptera: Coccinellidae) were more abundant on intercropped than on monocropped potato in both winter and summer seasons. To the contrary, the insidious flower bug *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) was less abundant in intercropped systems (Mousa and Ueno, 2019). In Yunnan Province, China, intercropping of potato with maize reduced adult and larva *P. operculella* populations, and reduced its damage by enhancing the number of parasitoids and the level of parasitism. The greatest population density of parasitoids and parasitism rate were in the intercropping pattern of two rows of potatoes with three rows of maize (Zheng et al., 2020). With the development of the crops and the parasitoids, the maximum populations and parasitism rates appeared in the 12th week after the emergence of potato, which was presumably caused by the appearance of the blooming of maize that provided food resource for the parasitoids (Zheng et al., 2020).

Flowering strips are a variation of intercropping, which also promotes the occurrence of natural enemies of insect pests. In Switzerland, the 3 m wide tailored flower strips composed of 11 annual plant species specifically designed to promote natural enemies of aphids were sown adjacent to potato crops. The abundance of major natural enemies of aphids (hoverflies, lacewings and ladybirds) and hoverfly species richness were greatly enhanced in tailored flower strips compared with potato control strips, which resulted in an average increase in the number of eggs deposited by hover-flies and lacewings by 127% and 48%, respectively, and a reduction in the number of aphids by 75% in adjacent potato crops (Tschumi et al., 2016).

15.3.2 Trap crops and barrier crops

Andow (1991) reported that although pest injury is less likely to exceed economic damage levels in polycultures than in mono cultures, in vegetationally diverse agroecosystems absolute yield benefits occur only rarely − and only when the arthropod pests cause severe yield losses in monocultures, and only if polycultures have lower pest populations than monocultures; even then, it occurs intermittently. Considering this, and the fact that the cultivation of two or more plant species in the same agricultural field simultaneously can reduce the yield of the main crop due to plant competition, it is disputable whether this method is a prospective pest management strategy in agricultural production (Szendrei and Weber, 2009). Instead, a similar, alternative approach has been developed, the so called “push-pull strategy” (stimulo-deterrent diversionary strategy). A push-pull strategy means that the pests are repelled or deterred from the crop (the “push” part) and simultaneously attracted (the “pull” part) to other areas such as trap crops or barrier crops (Cook et al., 2007; Khan et al., 2008). Trap crops are plants grown to attract insects or other organisms to protect target crops from pest attack, preventing the pests from reaching the crop or concentrating them in a certain part of the field where they can be economically destroyed (Shelton and Badenes-Perez, 2006). Barrier crops are a type of trap crops used as a border to protect another crop from virus diseases by acting either as “sink” for non-persistent viruses (infective virus vectors, mainly aphids, lose the viruses while probing on plants of the barrier crop) or mechanical obstacle that impedes the colonization of the protected crop (Fereres, 2000).

The use of trap crops should be preceded by analysis of the pest species' characteristics, including its biology and behavior. Migratory, host-finding, and reproduction behaviors are especially important, so that the behavior-modifying stimuli for use in push-pull strategies may include visual and chemical cues or signals from the crops, which respond to mechanisms underlying differential pest preferences (Cook et al., 2007). In addition to the natural characteristics of a particular plant used as a trap crop, insect preference can be altered in time and space to further enhance the effectiveness of a trap crop — for example, by the use of behavior-modifying chemicals, such as non-host or host-derived volatiles or other chemicals, pheromones, antifeedants, etc (Shelton and Badenes-Perez, 2006; Cook et al., 2007).

Below, there are examples of various approaches to habitat management targeted at various sensitive phases of the potato pest insect biology and ecology.

15.4 Examples of habitat management

15.4.1 Push-pull and trap crop strategies

In the case of Colorado potato beetle, the push-pull or trap crop strategies explored a variety of possibilities and were aimed mainly against overwintered adult beetles colonizing potatoes, and adult beetles dispersing within the field later in the season. Weisz et al. (1994) reported that winter wheat and hay buffers significantly delayed overwintered adult colonization. Hoy et al. (2000) investigated the effectiveness of spring trap crops, which were the host plants placed between the overwintering site and a new potato field, and barriers beyond them that were intended to retain and concentrate overwintered adult beetles and keep them out of the field. They found that planting date affects the pattern of potato beetle infestation by enhancing and maintaining adult Colorado potato beetle at the edges of potato fields. Physical barriers (dense interplanting of rye) had a greater impact than chemical barriers (tansy *T. vulgare* oil, wormwood *Artemisia absinthium* (L.) oil, piperonyl butoxide applied to outer rows of potatoes) on adult beetle movement from a potato trap crop to the protected potatoes beyond the barrier. Barrier treatments reduced beetle numbers in and just beyond the barrier, but the effects were localized and no significant reduction of beetles was observed further into the field, probably due to increased flight from trap or barrier areas or decreased sensitivity to host plants by walking beetles after passing through the barrier (Hoy et al., 2000). Martel et al. (2005) found that more postdiapausing, colonizing adults, egg masses, and small larvae were present in synthetic host volatile attractant-treated trap crops than in untreated trap crops, and although the yields for conventionally managed plots and plots bordered by attractant treated trap crops did not differ, 44% less insecticide was applied to plots bordered by attractant-treated trap crops. Additionally, the traditional application of pheromones for monitoring purposes may be broadened for a more general field use. The male aggregation pheromone of Colorado potato beetle [(S)-3,7-dimethyl-2-oxo-oct-6-ene-1,3-diol] may increase the preventative role of trap crops: more colonizing adults were present in pheromone-treated peripheral rows of potatoes compared with untreated middle rows, and significantly fewer egg masses and larvae were found in potato plots that were bordered by pheromone-treated rows (Kuhar et al., 2006). Host plant chemicals may alter the response of insects to semiochemicals: orientation of the Colorado potato beetle males can be disrupted by a combination of male-produced aggregation pheromone, (*S*)-3,7-dimethyl-2-oxo-oct-6-ene-1,3-diol and the three-component plant attractant blend (comprised of (*Z*)-3-hexenyl acetate + (±)-linalool + methyl salicylate), which was preferred over the plant attractant alone (Dickens, 2006).

Interestingly, potato may be used as a trap crop to protect other crops, such as tomatoes, against Colorado potato beetle: in Canada, tomato plots had significantly fewer adult beetles and significantly higher tomato yields (61%–87% higher) when a potato trap crop was present (Hunt and Whitfield, 1996). Similar effects were found by Gilboa and Podoler (1994) in Israel.

Wireworms *Agriotes sordidus* (Illiger) orientate toward a blend of volatiles emitted by chopped roots of barley. This finding underlines the importance of the identification of these compounds and their role assessment alone or combined, as for their effect on wireworms. Such compounds could be used in IPM strategies (Barsics et al., 2011). Indeed, the maize/wheat mixture bait is very effective in trapping wireworm larvae for monitoring purposes in potato fields (Parker, 1994; Brunner et al., 2005).

Fereres (2000) found that the use of barrier crops of sorghum *Sorghum* spp. and vetch *Vicia* spp. can be an effective crop management strategy to protect against PVY infection. One-meter-wide barrier of oats was effective in reducing PVY spread (Radcliffe et al., 2007). Additionally, if a barrier is sawn earlier than the target crop, some immigrating aphids can be filtered out due to the height difference of plants (Wratten et al., 2007). Barrier crops should have a fallow outside border with no space between the barrier crop and the potato field, since winged aphids usually alight at the border of baer ground and green crop (Radcliffe et al., 2007). Nevertheless, the species of border crop to be used as a virus sink should be selected carefully because it could act as a natural host for either the virus or the vector (Fereres, 2000).

15.4.2 Cover-crop residues

Habitat vegetation management also includes the treatment of cover-crop residues. Cover crops are grasses, legumes or small grains grown between regular crop production periods. Cover crop is not intended to be harvested for feed or sale, and its main purpose is to benefit the soil and/or other crops. Cover crops can interfere with the capacity of pests to colonize hosts by imposing physical barriers, disrupting olfactory and visual cues, and creating diversions to non-crop hosts. For example, the hairy vetch residue reduced the rate of colonization by the Colorado potato beetle (Teasdale et al., 2004). Szendrei et al. (2009) found that the movement of marked Colorado potato beetles into tilled plots was significantly higher than into vetch or rye cover treatments. Interestingly, the marked beetles released inside the potato field tended to move along the release row rather than across rows, and this pattern was stronger for the tilled treatment than for the two mulch cover treatments.

15.4.3 Antifeedants

Once on the plant, a herbivore can be discouraged to feed by the application of feeding deterrents of natural or synthetic origin (see Chapter 13). Antifeedants can also be part in the push-pull strategy (the "push" part). Basically, antifeedants are behavior-modifying substances that deter feeding through a direct action on peripheral sensilla (i.e., taste organs) in insects (Isman, 2002). However, Frazier and Chyb (1995) suggested that insect feeding can be inhibited at three levels: pre-ingestive (immediate effect associated with host finding and host selection processes involving gustatory receptors), ingestive (related to food transport and production, release, and digestion by salivary enzymes), and postingestive (long-term effects involving various aspects of digestion and absorption of food). Consequently, the reduced feeding may cause the rejection of a plant, may affect the development and longevity of the insect, or may lead to its death (Wawrzeńczyk et al., 2005; Wieczorek et al., 2005; Gabryś et al., 2006).

The application of antifeedants as crop protectants has attracted a lot of attention and, as a result, a vast literature on laboratory and field trials has been accumulated. The studies concentrate on various aspects of antifeedant use: structure/activity relationships, insect chemoreception mechanisms, insect feeding habits/application method relationships, mode of action at cellular, organismal and ecosystem levels, etc. (Koul, 2005). For example, extracts of *Asclepias tuberosa* (L.) and *Hedera helix* (L.), exhibited exceptional levels of feeding deterrency toward wireworms and in the field trial using an X-ray technique it was found that although the wireworms burrowed indiscriminately between soil containing either of these extracts and surrounding, untreated soil, they were found more frequently in the untreated areas (Villani and Gould, 1985). The antifeedant activity toward Colorado potato beetles and their larvae was noted for *Pelargonium* x *hortorum* (Bailey) and *Geranium sanquineum* (L.) extracts. The *P.* x *hortorum* extract added to food showed an unfavorable effect on the development of female reproductive organs and significantly inhibited the number of eggs laid; however, it showed no effect on either the period of winter diapause or spring emergence of beetles. The highest effectiveness under field conditions was recorded for an extract from *Erodium cicutarium* (L.). Potato leaves covered with *P.* x *hortorum* extract showed an unfavorable effect on the development of reproductive organs in females, significantly reducing the number of eggs laid; however they showed no effect either the period of winter diapause or spring beetle emergence (Lamparski and Wawrzyniak, 2004). Pulegone and its derivatives, silphinene and its derivatives, and many others were efficient antifeedants against Colorado potato beetle in the laboratory (Gonzales-Coloma et al., 2002; Szczepanik et al., 2005). High ovicidal and oviposition-deterrent effects of *Lavandula gibsonii* J. Graham extracts were exhibited against *P. operculella* (Sharma et al., 1981).

A survey of literature on the plants used for the control of the potato tuber moth has revealed that the preparations from 35 plant species were effective against the pest either in the storage (non-refrigerated) or in the laboratory. In some studies, chopped and dried leaves were used, while in others leaf/seed extracts, fruit peel, bulb, root, and rhizome were used. Plant preparations were effective in reducing the pest damage or killing the pest at different stages (Das, 1995). Extracts of garlic, wormwood, and tansy deterred the settling of the peach potato aphid (Dancewicz and Gabryś, 2008). A number of natural terpenoids and their synthetic analogs were also feeding-deterrent to *M. persicae* (Gabryś et al., 2005, 2006; Dancewicz et al., 2008).

Unfortunately, the commercial use of antifeedants in field crop production systems is still very limited. Many factors contribute to such situation: antifeedants are not lethal to the target organism; natural antifeedants are difficult to apply on a large scale because of their low content in plants; the laboratory synthesis is often complicated and economically unjustified as insects are extremely sensitive to the spatial structure of chemical compounds; sometimes the activity is stage-specific, etc (Szczepanik et al., 2005; Gabryś et al., 2006; Alyokhin, 2009). Therefore, the search for effective antifeedants should be concentrated on natural sources or the synthesis of natural antifeedant analogs. Such compounds will be very selective (species-specific) and easily biodegradable in the environment (Koul, 2005; Wawrzeńczyk et al., 2005; Wieczorek et al., 2005; Dancewicz and Gabrys, 2008; Grudniewska et al., 2011).

15.5 Concluding remarks

Cultural practices are among the oldest techniques used for pest control and many of the protective procedures used in agriculture today have their roots in traditional crop growing (Altieri, 1999; Zehnder et al., 2007). Many of these traditional ways are compatible with natural processes (Morales, 2002). Nowadays, and in the future, this compatibility should be of the highest priority for consideration in early stages of crop management strategies as indirect, precautionary measures. It is especially important in the situation when organic farming is one of the fastest growing segments of agriculture. Globally, the organic agricultural land is estimated to cover 71.5 million ha in approximately 186 countries, the world organic market is worth *ca*. €96.7 bn., and organic per capita consumption per year is *ca*. €12.8 bn (The World of Organic Agriculture, 2020, IFOAM and FiBL). In the USA alone, a 19% annual growth rate in per capita organic potato consumption to 2013 has been predicted (Greenway et al., 2011).

One must keep in mind though, that there is no universal cultural method to significantly reduce all insect pests and increase the crop yield concurrently. Moreover, the protected crop is a part of the network of environmental interactions. The simultaneous application of various cultural management techniques in correspondence with other supplementary methods (biological, chemical, physical, behavior-modifying) should finally contribute to the increase in biodiversity, which is crucial for the integrity, stability, and sustainability of agroecosystems (Altieri, 1999; Zehnder et al., 2007).

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