14 Orchard Floor Management Systems

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14.1 Introduction

The orchard floor is the soil and understorey vegetation of an orchard ecosystem. Orchard floor management decisions can affect the prevalence of weeds, insects, small mammals, disease, soil fertility, water availability, and potential for erosion and pollution. Appropriate management of the orchard floor is important for economic success of the grower and sustainability of the orchard environment. This chapter considers individual system management components, their integration and their influences when managing a peach orchard floor.

14.2 Components

Orchard floor preparation before planting

An orchard floor management programme should begin before tree planting with an understanding of potential biological pests and of abiotic soil conditions. Site preparation can avoid or reduce problems associated with the orchard floor of young peach orchards. Particular attention should be addressed to weed flora, water availability, soil pH and structure, the presence of hard pans and long-term nutrient needs, which have been discussed elsewhere in this book.

Pre-plant management of weeds and soils

Weed competition can significantly reduce the growth rate of young peach trees and delay time to first cropping year. Prior to planting, weeds that can adversely affect peach trees should be identified and targeted for control. Perennial weeds are problematic because many reproduce vegetatively and spread in undisturbed soils beneath peach trees. The management of perennial weeds like johnsongrass (*Sorghum halepense* (L.) Perse.), poison ivy (*Toxicodenron radicans* (L.) Kutze) and Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.) can require two or more herbicide or cultivation treatments (Tworkoski and Young, 1990). In addition, weeds such as yellow nutsedge (*Cyperus esculentus* L.) are not controlled by herbicides labelled for bearing peach trees. Repeated cultivations or herbicide applications prior to planting can avoid injury to newly planted peach trees.

Annual weeds also compete with young peach trees and harbour insect and disease pests that injure peach trees and fruit (Duffus, 1971; Weller *et al*., 1985; Skroch and Shribbs, 1986). Establishing a grass sod in the year or two prior to planting can help reduce perennial weed and weed seed banks. The weed seed bank in the soil can be reduced if weeds are not allowed to flower. Mowing in conjunction with competition from the grass cover selects against many broadleaved weeds while favouring grass. Grass sod also improves the organic matter, soil structure and other soil properties, compared with bare or tilled soil.

The species of grass used as a pre-planting cover should be adapted to the planting environment and subsequent sod management issues must be considered. Planting fruit trees in soil prepared with 'K-31' tall fescue (*Festuca arundinacea* Schreber) sod, killed before tree planting, reduced subsurface leaching of nitrate-N and also reduced the amount of herbicide used in young orchards (Biggs *et al*., 1997). However, if left as a ground cover, 'K-31' fescue can become competitive with peach trees (Welker and Glenn, 1988). Other ground covers such as common bermudagrass (*Cynodon dactylon* L.) may inhibit the growth of newly planted peach trees by competition and allelopathic effects (Weller *et al*., 1985). Less competitive but well-adapted grasses can also be sown where future tree rows are to be planted (Butler, 1986; Willmott *et al*., 2000).

Several months before planting peach trees, the sod should be killed with a non-selective contact herbicide. In this killed sod, grass residue acts as a mulch to increase soil water availability, suppress weeds and enable water penetration into the soil (Glenn and Welker, 1989b; Welker and Glenn, 1988). The dead sod can break down after it has been killed but it may be removed where trees are planted to reduce habitat for rodents near tree trunks. A planting hole that has been dug with an auger may suffice. Cultivation may still be necessary in narrow strips within the killed sod into which trees are planted. However, soil cultivation should be minimized to reduce bringing weed seed to the soil surface where it may germinate. Additional weed and soil-borne disease control can be obtained by soil solarization in the vegetation-free strips. Clear, polyethylene plastic can be installed on the even surface of moist soil to elevate soil temperatures for 6 to 8 weeks during the warmest times of the growing season prior to planting. Soil sterilization has greatest promise in warm areas such as the south-east USA and California where the required sterilization time can decrease as soil temperatures increase above 37°C. Improved plastic sheeting may enable soil sterilization to be used in cooler regions (Katan and DeVay, 1991).

Raised beds

Poor drainage can be mitigated with raised planting beds. In Ohio, yield of peach trees improved by 56% over 5 years when the trees were grown in raised beds rather than flat areas (Funt *et al*., 1997). The improved yield may have been associated with reduced waterlogging problems that may stimulate shallow rooting and greater root regeneration may have enabled the trees to exploit water from deeper soil when the shallow soil dried. Raised beds did not increase yield of young peach trees grown in sandy soil in New Jersey (Belding *et al*., 2003). Trees grown in raised beds in sandy soils may require supplemental irrigation but, in heavy soils, raised beds appear to benefit trees by increasing gas exchange to the root system. The impact of raised beds on mature tree growth and susceptibility to wind throw requires further study.

Weed effects

Yield loss due to weeds in established orchards

Weeds can reduce yield in 3-year-old peach trees by 94% (Welker, 1984). Older peach trees were less susceptible to weed competition, but the competitive impact of weeds is likely to vary with weed species and the availability of potentially limiting resources (Layne *et al.*, 1981; Glenn and Welker, 1989b; Tworkoski and Glenn, 2001). For example, peach yield is likely to decrease with weed competition under dry conditions. Yield reductions due to weed competition have been demonstrated in other temperate tree crops. In Alabama, cumulative yield of pecans over nine seasons increased by 358% in trees grown with weed control compared with trees grown without weed control (Foshee *et al.*, 1997). However, the costs of complete weed control were not recovered from gains in yield until the eighth season after establishment. In New York, yield and growth of young apple trees increased as duration of weed control increased during the growing season (Merwin and Ray, 1997). Significant benefits were achieved by initiating weed control early in the growing season (e.g. May instead of June). When the orchard floor was maintained weed-free from bloom until 12 weeks after bloom, MacRae *et al.* (2007) found that fruit size, number and total yield of peach were greater than when the weed-free interval was shorter.

Winter annual weeds, such as chickweed (*Stellaria* spp.), may not compete significantly with established peach trees but they may threaten the economic viability of the crop by attracting or providing an overwintering habitat to insects (*Lygus* spp. and stink bugs) (Atanassov *et al.*, 2002; Parker, 2003). These piercing-sucking insects can move from the weed and cause cat-facing damage to the exterior of fruit (Killian and Meyer, 1984). In California, mustard (*Brassica* spp.), wild radish (*Raphanus raphanistrum* L.) and vetch (*Vicia* spp.) hosted *Lygus hesperus*, *Lygus elisus* and *Calocoris norvegicus* which moved to trees and caused fruit damage (Pickel *et al.*, 2002). Clean cultivation and effective control of broadleaved weeds can suppress these pests (Atanassov *et al.*, 2002). Programmes that include cultivation for pest management must weigh possible adverse effects of cultivation on the fine, shallow roots of peach trees. Flowering weeds also can disrupt the pollination of peach trees during bloom by attracting bees and other wild insects.

Dandelions (*Taraxacum officinale* Wigg.) and chickweed may serve as alternative hosts for viruses such as *Tomato ringspot virus* which can be transmitted to peach trees by nematodes and adversely affect peach trees (Powell and Forer, 1982; Skroch and Shribbs, 1986). Other weed species can support high populations of insects (e.g. aphids and leaf hoppers) and nematodes that transmit viruses (Duffus, 1971). Nematodes such as root-knot nematode and dagger nematode can cause direct damage to peaches as well as vectoring disease. Based on Duffus' (1971) observations, the general reduction of weeds will help reduce virus-induced diseases because nematodes and nematode-transmitted viruses have a diverse range of weed hosts.

Benefits of weed-like vegetation

Negative impacts of weeds are well documented but some invading plants that are characterized as weeds may have value. A potentially confounding effect of understorey vegetation is that although broadleaved weeds and grass can both deplete soil water, water deficits may be ameliorated by the greater moisture penetration into soil covered with grass (Atkinson and White, 1981; Glenn and Welker, 1989b). Often understorey vegetation is classified as 'weeds' and 'grasses'. This classification can be relevant because grasses can compete with peach trees but they generally do not cause problems as disease and insect hosts. In addition, grouping broadleaved weeds together simplifies management decisions but this form of general categorization should be scrutinized. There is evidence that some broadleaved vegetation may be beneficial by providing habitat to predatory insects that feed on herbivorous insects (see references within Haynes, 1980 and Atkinson and White, 1981; Wooldridge and Botha, 1991). Brown (2001) was able to increase biological control of insect pests on peach with buckwheat (*Fagopyrum esculentum*), dill (*Anethum graveolens*), tansy (*Phacelia tanacetifolia*) and a wildflower mix without increasing the damage by plant bugs or stink bugs (Brown, 2002). Some, perhaps many, broadleaved plants that are classified as weeds may have little impact on peach production or may even be viable ground covers. Improved knowledge of the impact of specific weed populations can contribute to efforts to manage weeds in the understorey community.

Weed management

In established orchards, identification and control of problem weeds should be based on impact potential. Some weeds pose significant threats of competition (e.g. johnsongrass) whereas others do not (e.g. Whitlow grass (*Draba verna* L.) and nimblewill grass (*Muhlenbergia schreberi* J.F. Gmel.)) (Parker and Meyer, 1996). Weeds posing a significant threat are often best managed while they are seedlings since large weeds can be highly competitive, become significant seed sources and be difficult to kill. The location of weeds in an orchard will also influence management strategies. In many established peach orchards the orchard floor is partitioned into areas below the trees (the tree row) and between the tree rows (drive alleys). It is possible that a plant which is desirable in the drive alley (e.g. fescue) may be a weed in the adjacent tree row. A widely used weed control technology in the USA is with synthetic chemical herbicides, but other techniques are available and are of increasing interest. Combinations of cultivation, flaming, mulching and 'natural product herbicides' may be acceptable for use in 'organic' management.

Herbicides

Two general categories of herbicide include pre-emergence and post-emergence herbicides. The pre-emergence herbicides are applied to the soil prior to weed seed germination and are absorbed by the emerging weed seedling. Pre-emergence herbicides kill weed seedlings by different modes of action. Post-emergence herbicides kill weeds on contact and these also have different modes of action. Post-emergence herbicides are useful for 'spot' applications to localized infestations of large or troublesome weeds such as perennial weed escapes. Pre-emergence and post-emergence herbicides can be applied together or separately in rotation to manage weeds. Numerous herbicides may be used to manage weeds in peach orchards but their use must comply with label instructions (Table 14.1). It is vital to distinguish between herbicides used in non-bearing and bearing peach trees because some herbicides will damage young trees with green bark.

Decisions to apply herbicides should be based on scouting results and site history with the goal of maintaining weed populations to acceptable threshold levels. Thresholds can be based on the potential economic loss due to decreased yield or fruit quality or threat to labour operations associated with increased density of weed populations. As noted earlier, some winter annual weeds (e.g. chickweed) and ground covers (e.g. clover) harbour cat-facing insects such as stink bugs that pose an unacceptable risk of fruit quality. In southern locations of the USA these broadleaved plants can be managed with 2,4-D applications 8 weeks prior to bloom without damaging grass in drive alleys. It is generally known that yields decrease due to weed competition and that young peach trees are more susceptible than mature peach trees (Weller *et al.*, 1985). However, little is known about economic threshold levels of weeds related to insect injury and yield loss for peach trees and there is a need for additional research in this area.

Consecutive applications of the same herbicide or of different herbicides with the same mode of action may lead to the development of weed populations that are resistant to the class of herbicides being used (Welker, 1984). Combinations of herbicides with different modes of action have been found to be more effective in weed control than using a single herbicide (Welker, 1984). However, even repeat applications of the

Table 14.1. Herbicides[a] currently recommended for peach culture in the USA.

Herbicide and active ingredient	Application
Pre-emergence	
Dichlobenil (Casoron) 2,6-dichlorobenzonitrile	Established trees for control of broadleaved weeds, quackgrass and fescue
Diuron (Karmex) 3-(3,4-dichlorophenyl)-1,1-dimethylurea	Trees established at least 3 years in the orchard for control of annual broadleaved and grass weeds
Isoxaben (Gallery) *N*-[3-(1-ethyl-1-methylpropyl)-5-isoxazolyl]-2,6-dimethoxybenzamide	Control of broadleaved weeds in non-bearing trees
Napropamide (Devrinol) *N,N*-diethyl-2-(1-naphthalenyloxy)propionamide	Established bearing and non-bearing trees for control of annual grasses and small-seeded broadleaved weeds
Norflurazon (Solicam) 4-chloro-5-(methylamino)-2-(α,α,α-trifluoro-*m*-tolyl)-3(2H)-pyridazinone	Control of annual grasses and small-seeded broadleaved weeds
Oryzalin (Surflan) 3,5-dinitro-N^4,N^4-dipropylsulfanilamide	Bearing and non-bearing trees for control of annual grasses and small-seeded broadleaved weeds
Oxyflurofen (Goal) 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene	Control of broadleaved weeds in established trees
Pendimethalin (Prowl) *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine	Non-bearing established trees for control of annual grasses and small-seeded broadleaved weeds
Pronamide (Kerb) 3,5-dichloro-*N*-(1,1-dimethyl-2-propynyl) benzamide	Control of grass and small-seeded broadleaved weeds in established trees
Simazine (Princep and generics) 2-chloro-4,6-bis(ethylamino)-*S*-triazine	Trees established at least 1 year in the orchard for control of annual broadleaved weeds
Terbacil (Sinbar) 3-tert-butyl-5-chloro-6-methyluracil	Established trees for control of grass and broadleaved weeds
Post-emergence	
2,4-D amine (generics) (2,4-dicholorophenoxy)acetic acid	Control of annual and perennial broadleaved weeds in established trees
Fluazifop (Fusilade) (*R*)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy] phenoxy]propanoate	Control of annual and perennial grasses in newly planted and established trees
Glyphosate (Roundup/Touchdown) *N*-(phosphonomethyl)glycine	Control of broadleaved and grass weeds
MSMA (MSMA Arsonate) monosodium acid methanearsonate	Selective control of annual and perennial weeds in non-bearing trees
Paraquat (Gramoxone) 1,1′-dimethyl-4,4′-bipyridinium dichloride	Control of broadleaved and small grass weeds
Scythe pelargonic acid	Non-selective burn-down of weeds
Sethoxydim (Poast) 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one	Control of annual and perennial grasses in established trees

[a]Not endorsed by the US Department of Agriculture. Labels and state extension recommendations should be followed.

same combination of herbicides can result in population shifts and new weed problems (Tworkoski *et al.*, 2000b). Long-term applications of the same herbicide may also contribute to herbicide residue carryover which can adversely affect the growth of newly planted peach trees (Tworkoski *et al.*, 2000a; Tworkoski and Miller, 2001). Repeated control of weeds with pre-emergence herbicides and mechanical tillage may reduce soil structure, fertility and orchard productivity compared with 'living' and straw–hay mulches (Merwin *et al.*, 1994) and killed-sod systems (Glenn and Welker, 1989b). Productivity loss may be associated with reduced organic matter and water infiltration, and with elevated soil temperatures in non-mulched sites. At the time of flowering, heat absorbed during the day by vegetation-free orchard floors will radiate from the soil at night, warm the air and possibly reduce cold injury to peach blossoms. Thus, soil that is continuously bare may contribute to reduced long-term orchard productivity but time intervals without vegetation cover can protect current-year cropping.

Herbicides which may be acceptable for organic growers have been developed. In general they are contact-active and may require repeated applications when established plants are being controlled. These herbicides include pelargonic acid (Scythe; Mycogen Corp., San Diego, California), vinegar (BurnOut; St Gabriels Laboratory, Orange, Virginia) and essential oil of clove (Matran; EcoSmart Technologies, Inc., Franklin, Tennessee). Essential oils of cinnamon, clove, summer savory and red thyme have herbicidal activity and may be useful as 'natural product herbicides' (Tworkoski, 2002). However, these herbicides can be expensive and may have limited efficacy against some weeds. These herbicides appear to be most effective when applied to small weeds, generally early in the growing season.

Mechanical and flaming techniques

Mechanical weed control devices such as discs or cultivators can control ground vegetation in areas where the orchard floor is not maintained with ground covers, such as in tree rows. Where drive alleys are maintained in permanent ground cover, cultivation can be performed beneath trees but care is necessary to avoid damaging low branches or tree trunks. Where drive alleys are maintained in winter ground covers, shallow disking in early spring can eliminate or reduce competition and provide residual mulch. Shallow disturbance of the soil is necessary to minimize bringing new weed seed to the soil surface and to avoid damaging shallow peach roots. Mechanical cultivators have been developed that can till to the tree and reduce or avoid damaging the trunk (Weed Badger, Marion, North Dakota; The Green Hoe Co., Portland, New York).

Flame weeding eliminates weeds by searing, not burning, the vegetation (Ames and Kuepper, 2004). Torches fuelled by kerosene or propane are pulled behind a tractor at a speed that will wilt vegetation. Drawbacks to flaming include fire and fuel hazards, potential tree injury, water and fuel requirements, and lack of uniform weed kill. Flaming is an alternative weed management technology that may be useful in organic systems. Hand and tractor-mounted flame weeding equipment is commercially available (Flame Engineering, Inc., LaCrosse, Kansas; Thermal Weed Control Systems, Inc., Neillsville, Wisconsin).

Mulching

Organic mulches, such as straw, sawdust and composted animal waste, can be applied beneath fruit trees to suppress weeds (Fig. 14.1/ Plate 87). Composted poultry litter applied to a depth of 10 cm beneath peach trees suppressed soil-germinating weeds but additional control was necessary for weeds germinating in the mulch (Preusch and Tworkoski, 2003). Composted mulch that is applied in too deep a layer may have the undesirable effect of releasing significant P to the soil (Preusch *et al.*, 2002). A layer of newspaper or cardboard could be applied beneath the mulch to increase weed suppression (Ames and Kuepper, 2004) but moisture penetration may be impeded and, as this lower layer degrades, weeds can grow through the mulch (T.J. Tworkoski, personal observation). If the mulch is raked aside, the lower newspaper layer replaced and the mulch raked back, then weeds can be suppressed for a longer time. These are labour-intensive practices which may not be economically

Fig. 14.1. Ten-year-old 'Sunhigh' peach trees, originally planted in 2.4 m vegetation-free areas with composted poultry litter placed beneath some trees at a rate of 11.6 kg litter/m^2 to a depth of 10 cm (1.1 kg N/tree). Photograph was taken the second season after application when some weeds had begun to grow through the mulch.

viable for large-scale commercial operations. Other beneficial effects of mulch include slow release of some nutrients, increased soil organic matter and improved soil structure (Haynes, 1980). Soil moisture retention is improved when mulch is applied to tree rows (Skroch and Shribbs, 1986). Compost mulch has also been shown to inhibit growth of the brown rot fungus, *Monilinia fructicola* (G. Wint) Honey, in the laboratory (Brown and Tworkoski, 2004). High microbial biodiversity in compost may increase competition for resources and reduce production of inoculum. Pine straw or hay applied beneath trees to a depth of 12 cm can provide some mulching benefits; however, they may pose a fire hazard.

Organic material that can be used for mulch may not be widely available and transportation costs of the large quantities necessary for mulch may prohibit its use. These problems can be ameliorated if mulch can be obtained from 'on-site' activities such as growing sorghum sudangrass (*Sorghum* × *drummondii* (Steudel) Millsp. & Chase) for mulch (Ames and Kuepper, 2004). Cover crops between trees or in fields near the orchard can be a source of organic mulch. Sickle bar mowers can cut ground covers which can then be raked or blown beneath trees. To prevent the ground cover from becoming a weed problem in the tree rows, the ground cover in the drive alley should be mown before it produces seed. In addition, mulch should be kept at least 20–30 cm from the trunk to avoid rodent and collar rot injury to peach tree trunks (Ames and Kuepper, 2004).

Inorganic mulches such as black plastic and geotextile sheets can effectively suppress weeds. Their use requires a greater initial investment than most organic mulches. Another drawback is that the waste fabric must be removed and disposed of, but this problem may be less significant if longer-lived mulch is used. In the south-eastern USA, growers using black plastic and raised beds can achieve weed control for up to 2 years, provided weed seed has been killed with methyl bromide. Drip irrigation beneath the plastic is necessary in this system.

Biological control of weeds in peach orchards has been attempted by planting a short-lived cover plant which grows quickly and dies, resulting in weed suppression by competition and residue which acts as a mulch. An example of such smother crops is *Brassica campestris*, which was planted in May and suppressed early-season weeds while it was actively growing (Halbrendt, 1993). However, by July weed growth was similar to untreated plots. For success, smother crops require weed suppression for longer periods without competition that reduces yield of peach trees.

Orchard floor management effects on insects and small mammals

Cover crops and weeds can provide food and habitat for rodents, insects, nematodes, microbes and viruses (Norris, 1986). Management of the orchard floor can influence the balance between organisms that are beneficial and those that are harmful to peach production. Research has provided insight into orchard floor manipulation effects on insect populations and behaviour in apple and pear orchards but less is known in peach orchards. The potential impact of such pests or the benefits of other insects should be considered in the selection of an orchard floor management system.

Insect populations are directly and indirectly affected by the composition and abundance of flora on the orchard floor (Alston, 1994). In peach, control of many annual broadleaved weeds and legumes is necessary because they provide habitat for tarnished plant bugs and stink bugs (LaRue and Johnson, 1989; Atanassov *et al.*, 2002; Ames and Kuepper, 2004). In apple orchards, broadleaved weeds such as common mallow (*Malva neglecta* Wallr.), field bindweed (*Convolvulus arvensis* L.), knotweed (*Polygonum* spp.), morning glory (*Ipomoea* spp.), prickly lettuce (*Lactuca serriola* L.), puncture vine (*Tribulus terrestris* L.) and white sweetclover (*Melilotus alba* Medikus) enhanced phytophagous mites that are detrimental to tree productivity (Alston, 1994). Phytophagous mites were managed to economically acceptable levels by reducing these host broadleaved weed species to less than 12% of ground cover while maintaining ground cover of at least 50% of other ground cover species (orchardgrass (*Dactylis glomerata* L), red fescue (*Festuca rubra* L.) and lucerne (*Medicago sativa* L.)) which harbour predatory mites.

Research has demonstrated that ground covers such as mustards (*Brassica* spp.), buckwheat (*Fagopyrum* spp.), dwarf sorghum (*Sorghum* spp.) and various members of the *Apiaceae* (*Umbelliferae*) and *Asteraceae* (*Compositae*) families can attract more beneficial insects than pests. In addition to floristic effects, management of the orchard floor can influence insect behaviour and population demographics (Brown *et al.*, 1997; Brown and Glenn, 1999). Mowing frequency can affect the population size of phytophagous and predacious insects, with increases of both groups resulting from decreased mowing in pear orchards in the north-western USA (Horton *et al.*, 2003). There is a possibility of managing movement of natural enemies of insects into fruit tree canopies with cultural manipulation of the orchard floor, such as mowing. In California it is recommended that lucerne growing near a fruit crop not be mowed if there are *Calocoris* bugs feeding on the legume, since mowing may induce movement of *Calocoris* bugs into the tree canopy where they may damage fruit (Ames and Kuepper, 2004). Increased research is needed to understand and improve the use of understorey vegetation as a tool for insect pest management in peach orchards.

In addition to cover crops and weeds, mulches and herbicides that are part of the orchard floor management system can influence insect populations. Modification of the orchard floor with composted mulch enhanced ground-foraging generalist predators and predator activity may be enhanced when the orchard floor is disturbed or treated with herbicide (Brown and Tworkoski, 2004; Mathews *et al.*, 2004). Mulch increased prey resources to support predator populations and herbicides enhanced habitat for predators with improved physical cover and microclimate effects. However, herbicide use can also decrease predatory insect populations. Integrated pest management (IPM) programmes that target control of the two-spotted spider mite (*Tetranychus urticae* Koch) with the predacious mite (*Neoseiulus* (*Typhlodromus*) *fallacies* (Garman)) should avoid use of 2,4-D amine, gramoxone and terbacil because these herbicides were more toxic to the predator and were likely to differentially decrease predator populations (Rock and Yeargan, 1973).

Ground cover and mulch near tree trunks can lead to rodent damage in fruit orchards. In New York, meadow vole (*Microtus pennsylvanicus* Ord) density increased and young apple trees were injured in orchards with crown vetch (*Coronilla varia* L.), hay–straw mulch and red fescue (*F. rubra* L.) sod below trees (Merwin *et al.*, 1999). Tree damage was controlled by reducing vegetation, trapping, and using tree guards and vole predators. In British Columbia, Canada, intensive weed control within an orchard reduced montane vole (*Microtus montanus*) abundance but a compensatory increase in other small mammal populations (deer mouse (*Peromyscus maniculatus*) and northwestern chipmunk (*Eutamias amoenus*)) was observed (Sullivan *et al.*, 1998). Montane vole damage to apple trees was reduced with scent mixtures from ermine (*Mustela erminea*) (Sullivan *et al.*, 1990). Such chemical repellants may have application to rodent control in peach orchards.

Management of ground covers, row middles and drive alleys

The entire orchard floor, or a part of it, can be mulched, cultivated, treated with herbicide or maintained with ground covers. The tree rows can be maintained vegetation-free while the drive alleys between tree rows are managed with ground covers. Ideal ground covers should help control erosion, stand up to traffic, require low maintenance, suppress weeds, improve soil quality and not compete with the peach trees. However, ground covers and mulch can reduce flood and furrow irrigation efficiency and may not be used during the growing season, particularly under dry conditions in areas that include parts of California. Ground covers must adapt to climatic and edaphic conditions. In addition, management of drive alleys must be coordinated with tree rows. For example, ground covers in drive alleys may be cut to provide organic mulches beneath tree rows and they may also provide habitat for beneficial insects such as predatory mites and spiders.

Generally, grass is more beneficial to soil flora and fauna than clean cultivation (Haynes, 1980). Grass ground covers with potential for use in drive alleys have been evaluated in terms of rate of grass establishment, height and spreading characteristics, root and water use traits, and tolerance to drought, heat, shade, cold and traffic (Butler, 1986).

Many growers in the eastern USA plant vigorous grasses on the orchard floor such as Kentucky bluegrass (*Poa pratensis* L.), fescue (*Festuca elatior* L.) and orchardgrass (*D. glomerata* L.) with herbicide strips in the tree row (Skroch and Shribbs, 1986). These cool-season grasses may not be the best choice as an orchard floor cover because they may require frequent mowing and can spread aggressively from drive alleys into tree rows (Willmott *et al.*, 2000). In New Jersey, perennial ryegrass (*Lolium perenne* L.) and creeping red fescue (*F. rubra* L.) may succumb to infectious diseases or environmental stress and should not be used. A number of grass cultivars of tall, hard and chewings fescues (*F. arundinacea* Schreber, *Festuca longifolia* Thuill. and *F. rubra*, respectively) that require lower maintenance have been recommended (Willmott *et al.*, 2000). In North Carolina, Parker and Meyer (1996) determined that peach tree growth was greater when grown with nimblewill grass (*M. schreberi* J.F. (Gmel.)) than in plots with weeds, centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.) or bahiagrass (*Paspalum notatum* Flugge). Peach roots grew deeper and in greater number and lateral distribution in nimblewill grass or bare ground than in other grass treatments. In the Pacific north-west, most orchards use perennial grass with shallow roots as ground cover between tree rows and vegetation-free strips beneath trees (Granatstein, 2002).

In the southern USA winter legumes such as vetch (*Vicia* spp.) and subterranean clover (*Trifolium subterraneum* L.) have been used as cover crops to improve soil physical and nutrient properties that can benefit fruit trees (Hoyt and Hargrove, 1986). Subterranean clover had excellent reseeding ability, and may contribute N and organic matter to the orchard floor. However, the timing of nutrient release from legumes must support peach production without adversely affecting fruit quality or vegetative tree growth that can result from excessive N late in the season. In addition, some warm-season legumes may compete with trees for water and harbour phytophagous insects. None the less, after weighing costs and benefits, legumes may play a role in sustainable practices for peach orchard floor management. Subterranean clover has been proposed as a useful ground cover for drive alleys in peach orchards in warm locations where winter temperatures do not drop below –18°C (Ames and Kuepper, 2004). The subterranean clover reseeds in early summer and dies in the heat of late summer to produce a weed-suppressive mulch in Arkansas and California. The clover has also provided a habitat for beneficial insects.

Ground covers with different species composition, including broadleaved weeds, favour diverse arthropod communities that have been useful for IPM in orchards (Wooldridge and Botha, 1991). Such broadleaved plants may serve as alternative food sources for predatory mites that feed on thrips, aphids and other mite species. However, ground cover flora must be managed to reduce injury from phytophagous insects. Cat-facing injury by stink bugs (Pentatomidae) and tarnished plant bugs (*Lygus lineolaris*) was correlated with the presence of legumes such as vetch (*Vicia* spp.), clover (*Trifolium* spp.) and annuals such as chickweed, pepperweed (*Lepidium* spp.) and henbit (*Lamium amplexicaule* L.) (Killian and Meyer, 1984; Meyer, 1984). Some species of plants, if kept succulent, may be used to attract stink bugs away from the peaches as a trap crop (Brown, 2002). Spider mite (*Tetranychus* spp.) populations may also increase in these ground covers and migrate to peach trees when ground covers begin to senesce (Meagher and Meyer, 1990). Ring nematode (*Mesocriconema xenoplax*) may move from legumes as well as from weeds such as dandelion and purslane to peach roots (Zehr *et al.*, 1986, 1990).

Ground cover management is not restricted to vegetation management. Synthetic ground covers have been used to modify the orchard environment to enhance fruit quality. Reflective mulches have been applied in drive alleys to increase light intensity in orchards and to increase red colour of peaches. Reflecting films can modify the composition of anthocyanins, flavonoids, chlorophyll and carotenoids in apples (Ju *et al.*, 1999). Layne *et al.* (2001) found increased red surface colour of peaches when metallized reflective film was placed beneath peach trees 2 to 4 weeks before harvest. Peaches in the tree lower canopy were redder and overall price could increase by $1 per 11-kg box with increased colour. Estimated costs for the metallized mulch was $220/ha.

Ground cover interactions with irrigation and fertilization

Irrigation combined with managed competition may increase peach tree productivity while reducing excess vegetative growth. In Australia, vegetative vigour was suppressed and yield was increased by intraspecific root competition from a high-density orchard planting in combination with restricted irrigation (Chalmers *et al.*, 1981). Interspecific weed competition from ground cover can also dwarf young peach trees without reducing yield expressed on a trunk cross-sectional area basis (Glenn and Welker, 1996). Reducing tree size by manipulation of the orchard floor ground cover requires close management of fertilizer and water inputs. In older, 8-year-old peach trees, grass sod competition reduced total yield and yield of large fruit (>65 mm) in West Virginia (Glenn and Welker, 1996). In Ontario, Canada, permanent drive alleys with creeping red fescue combined with trickle irrigation increased total yield and yield of large fruit (Layne and Tan, 1988). Yield decreased when peach trees were grown with grassed drive alleys but without irrigation. Yield and the fruit in large size classes increased with irrigation when ground covers were present but the economic balance of irrigation costs and yield benefits should be analysed.

It is likely that supplemental fertilizer will be needed in productive orchards, regardless of the ground cover used, and fertilizer applications must be prescribed on the basis of appropriate soil and leaf analyses. In addition to fertilizer applications, soil nutrients can be manipulated by partial or complete kill of ground covers or by addition of organic mulches. In Europe, a permanent ground cover of white clover (*Trifolium repens*) was mowed regularly under older trees or winter rye was sown under young trees in late summer, followed by mechanical removal in spring (Bloksma, 2000; Bloksma and Jansonius, 2002). The permanent ground cover and late summer sowing provided a means of transferring soil N from late summer/autumn to the following spring. Organic mulches of bark, grass and composted waste may also provide a slow release of nutrients while conserving water and suppressing weeds throughout the year. However, organic mulches can increase the balance of C to N in the soil and immobilize nutrients from soil-applied fertilizer.

14.3 Management Systems

The primary goal of orchard floor management systems is to control understorey vegetation and manage resources to ensure the economic success and sustainability of the orchard. Selection of the type of ground cover, its spatial and temporal distribution, and the method of control are critical aspects that must be integrated for orchard floor management. The ground may be completely covered with permanent vegetation or be controlled by cultivation, mulch or herbicides so that some portion of the ground cover remains (Hogue and Neilsen, 1987). This section considers the integration of several of the previously described management components in management systems.

Year-round vegetation-free orchard floor

Benefits and disadvantages of different orchard floor management systems have been reviewed (Haynes, 1980; Skroch and Shribbs, 1986; Hogue and Neilsen, 1987). Continuous, clean cultivation of the orchard floor aerates the soil and eliminates competition but loss of organic matter, breakdown of soil structure, increased potential for erosion and destruction of shallow tree roots will occur. In dry areas where irrigation is the primary source of water for peach crops, year-round vegetation-free conditions have been used. Year-round tillage is used in California to control weeds, save water and provide ditches for furrow and flood irrigation (Vossen and Ingals, 2002). Soil compaction resulting from repeated cultivations can occur. Rip cultivation may then be necessary with shanks deep enough to break through the cultivated layer and allow water to penetrate the soil profile. However, deep cultivation can require heavy equipment which may contribute to further soil compaction.

East of the Rocky Mountains, the practice of clean cultivation in bearing peach orchards declined during the middle part of the 20th century (Fogle *et al.*, 1965). However, in South Carolina and Georgia, some large peach producers returned to a herbicide-maintained bare orchard floor system (D.R. Layne, South Carolina, 2004, personal communication). In other eastern locations, in place of complete removal of vegetation, ground covers were grown as permanent or temporary components of the orchard floor. Ground cover vegetation increases soil organic matter, structure and water penetration, but ground covers must be managed to control competition and reduce pests that are associated with them.

Vegetation-free tree rows with vegetated drive alleys

In the USA the orchard floor beneath peach trees is often maintained free of weeds with herbicides and drive alleys may contain temporary or permanent ground covers (Elmore *et al.*, 1997). Management decisions regarding the orchard floor before and shortly after planting will affect the composition and management of the orchard floor in a mature orchard.

Establishment of the orchard floor

In preparation for planting, a ground cover of grass sod should be installed as a fallow crop for at least 2 years to adjust soil pH and to decrease numbers of nematodes, weed seeds and soil pathogens. The goal of a 2-year fallow period should be pursued but growers may reduce time to replant based on economic pressures on the available land. Several months before planting (e.g. September before an April planting), tree rows are laid out and sod is killed with a post-emergence, non-selective and non-residue herbicide (e.g. glyphosate). The killed sod can improve growth of newly planted peach trees due to increased organic matter and water penetration, while acting as a mulch to suppress weeds (Welker and Glenn, 1988, 1990; Glenn and Welker, 1989a) (Fig. 14.2/Plate 88). Planting peach trees in killed sod increased growth by 120% and fruit yield by 160% during the first three years after planting, compared with vegetation-free strips maintained by cultivation or herbicides (Glenn and Welker, 1989a). Often sod is killed only where trees are to be planted so that living grass remains as the foundation for drive alleys. The width of the killed-sod area in tree rows will strongly affect peach tree growth and branch angle (Welker and Glenn, 1989, 1991). Tree size decreases as killed-sod width is reduced below 2 m.

Proximity of living sod to the planted peach tree can regulate competition and subsequently affect tree size and yield (Welker and Glenn, 1989, 1991). Newly planted peach trees were significantly dwarfed by 1 m and not by 3 m vegetation-free strips. Dwarfed trees were as efficient (i.e. yield per unit trunk cross-sectional area) as large trees. 'Cultural dwarfing' of peach trees by sod competition may enable growers to increase tree density and yield per hectare with trees that require less pruning. Yield efficiency of peach trees increased as the size of vegetation-free ground area increased to 9 m^2 and then yield efficiency remained constant, suggesting that closer tree spacing within a row can increase yield per hectare (Welker and Glenn, 1989). Reduced vegetation-free ground area has reduced sprout growth and pruning needed to maintain tree size (Glenn and Welker, 1996). All ground covers are not equally competitive and selection of a ground cover will influence the dwarfing effect on planted peach trees. Planting peach trees into subterranean clover (*T. subterraneum* L.) resulted in reduced growth and leaf N, P and K compared with trees planted in a herbicide-treated strip. However, tree growth recovery was observed in the second year after planting (Stasiak and Rom, 1991).

Young peach orchards may require up to three seasons until they bear fruit. During this establishment time, crops such as potatoes, strawberries and other vegetables can be interplanted within row middles to provide income and offset initial expenditures. For example, up to four seasons of horticultural crops were

Fig. 14.2. Trees planted in cultivated (left) and killed-sod (right) strips. Killed sod provides weed suppression and improves water penetration.

harvested prior to the first year of commercial peach production (Leuty, 2003). Intercropping requires careful management, is labour-intensive and is not amenable to moderate- or high-density plantings that are commonly used. In addition, pesticide drift from one crop to another that it is not registered for is a potential problem. Finally, the tree crop can be inadvertently damaged while managing or harvesting the crop planted in the row middle.

Orchard floor composition of the established orchard

Grass is often used as permanent ground cover in drive alleys because it is amenable to management and harbours fewer pests than broadleaved ground covers. Although grass competition severely inhibits growth of newly planted peach trees, permanent sod in drive alleys of established trees is often less debilitating (Hill, 1962). The amount of competition can be managed based on the species of grass used, the size of the vegetation-free area within a tree row, suppressive treatment of the grass, irrigation and fertilization.

Some grass cultivars (e.g. 'K-31' tall fescue) are highly competitive with peach trees and less competitive cultivars have been recommended for orchard floor cover. Used as a permanent and complete ground cover, orchard grass reduced peach yield by up to 37% but 'Linn' perennial ryegrass did not reduce yield in 8-year-old peach trees (Tworkoski and Glenn, 2001). Other non-competitive grasses have been recommended as suitable ground covers (see section on 'Management of ground covers, row middles and drive alleys' above; Willmott *et al.*, 2000). Ground covers other than grass have been recommended for apple (Vossen and Ingals, 2002) but more research is needed to determine benefits of forbs (herbaceous plants, excluding grasses) ground cover in peach. For example, common vetch has extrafloral nectaries on the stipules which may provide nectar to beneficial insects.

Legumes and weeds are often controlled with herbicides although other techniques have been used (see 'Weed effects' above). Site conditions influence availability of nutrients and water and pest threats. These environmental conditions can be used to construct models that determine action thresholds for vegetation control. Weed suppression was more critical early in the season rather than late in the season for apple production (Merwin and Ray, 1997). In North Carolina, MacRae *et al.* (2007) noted that when the orchard floor was kept weed-free with paraquat during the first 12 weeks after bloom for peach, fruit number, size and total yield were greater than for weed-free periods of shorter duration.

Vegetation-free tree rows in summer with control of cover crops

Ground cover can positively affect orchard productivity and sustainability. As previously discussed, ground covers may provide a storage pool of nutrients that can be carried from one growing season to the next. In tree rows, early-season herbicide applications allowed N mineralization to begin. Grass cover that incorporated herbicide application for no-till control of ground covers may also be used to increase availability of Ca, Mg, K and P (Haynes and Goh, 1980). Grass cover can reduce leaching of Ca, Mg, K, P, NH_4^+ and NO_3^- and management of grass, by frequent mowing, can contribute significantly to mineral cycling and nutrient availability within an orchard (Haynes, 1980). Ground covers in drive alleys can be mowed, possibly chopped, and transferred to tree rows as mulch for weed suppression. However, large amounts of biomass may be needed to control weeds successfully (Elmore *et al.*, 1993).

One ground cover management strategy is to plant seed mixtures in late summer or autumn with one or two mowings in late winter or spring to control ground cover height. Ground covers are then killed by mowing close to the ground (e.g. legumes) and/or by tilling and incorporating ground covers into the soil the following spring. In Europe, late-season ground covers included fodder radish (*Raphanus sativus* v. *olieferus*), turnip (*Brassica rapa* v. *rapa*), Phacelia (*Phacelia tenacetifolia*) and winter rye (*Secale cereale*) (Bloksma and Jansonius, 2002). In California, legume and legume/grass blends have also been sown in late summer, grown in autumn and winter, and mechanically killed with shallow soil disking or close mowing in the next growing season (Vossen and Ingals, 2002). The planted ground covers can be used as 'green manure' to suppress winter weeds and add N and organic matter to soil. If the mowed ground cover is not incorporated into soil it can be used as a mulch to suppress weeds in tree rows but fewer nutrients are added to soil in the short term. Total ground cover may require early spring cultivation in orchards that are furrow, flood or sprinkler irrigated.

In a review of orchard floor management systems, Hogue and Neilsen (1987) determined that organic mulching in tree rows combined with managed grass in drive alleys would provide the most benefit for cropping and for soil properties. However, costs, rodent control and mulch availability must be considered. Significant increase in consumer demand for reduced inputs of synthetic chemicals and for increased organic production presents new challenges for orchard floor management in peach orchards. Research is needed to discover and develop components for orchard floor management that can serve organic production systems. Components such as mechanical tillage and non-competitive ground covers that have been discussed will be useful, but additional tools are needed. Compatible cultural and genetic components can be integrated in the orchard ecosystem. Emergent traits of an ecosystem, such as productivity, nutrient cycling and nutrient loss to ground and surface water, can be optimized in orchards under organic and conventional management. Broad comparisons between systems, including energy inputs and extrinsic costs (e.g. CO_2 emissions and topsoil loss), will eventually be needed to critically compare management systems. In the near term, improved understanding of nutrient dynamics and the relationships among antagonistic or synergistic organisms, and the manipulation of the orchard ecosystem to achieve grower goals will be likely areas for future progress in orchard floor management.

Vegetation-free tree rows year-round

In this management scheme drive alleys, not tree rows, are vegetated in winter. Tree rows may be kept vegetation-free year-round to reduce competition and eliminate pest habitat. Pre-emergence herbicide applied early in the growing season effectively controls weeds. Post-emergence herbicides, cultivation and flaming may also be used effectively (see 'Weed management' above; Table 14.1). Vegetation in drive alleys can act as filter strips which foster vertical infiltration of surface water that reduces pesticide runoff (Watanabe and Grismer, 2001). Another benefit is that night-time air temperatures can be increased in early spring by radiant energy release from bare soil to reduce chances for frost damage. Disadvantages include surface compaction of soil that can reduce water infiltration and break down soil structure in the absence of ground cover.

Permanent vegetation management by mowing

Permanent vegetation beneath peach trees requires management to prevent tall plants from growing into the peach canopy and disrupting orchard worker operations. The concept is to maintain low vegetation by planting ground covers with genetically based low stature or by reducing ground cover height by mowing. As young peach trees are very susceptible to competition, this approach seems more viable with older trees and irrigation may be necessary. Allelopathic interactions between ground cover and peach trees must also be monitored (Weller *et al.*, 1985). In addition, pest problems and tree damage from mowing can result. In New Zealand, research identified dichondra, hard fescue and creeping red fescue as shallow-rooted, low-growing ground covers that were dense and could suppress new weed growth beneath fruit crops (Harrington *et al.*, 2000a,b). Additional weed control, such as mowing or selective herbicides, was needed to control perennial weeds that could grow through these ground covers. Benefits of improved soil quality and reduced herbicide use may justify permanent vegetation beneath peach trees in some applications. Also, permanent sod may recycle NO_3^- near the soil surface and reduce NO_3^- leaching that can pollute ground water (Wiedenfeld *et al.*, 1999). White clover (*Trifolium repens*) mixed with sod may contribute N to soil after mowing and subsequent mineralization of organic matter (Bloksma, 2000). Supplemental fertilizer may be needed in early spring and summer if organic matter pools are small and the dynamics of nutrient movement in this system have yet to be clarified.

Shallow-rooted grasses such as Kentucky bluegrass (*P. pratensis* L.), annual bluegrass (*Poa annua* L.), fescue (*F. elatior* L.) and orchardgrass (*D. glomerata* L.) deplete less moisture from an orchard than deep-rooted sods (Skroch and Shribbs, 1986; Hogue and Neilsen, 1987). A variety of grasses and legumes can be used in California apple orchards that manage the understorey with mowing or cultivation (Vossen and Ingals, 2002). Similar species may have use in peach orchards. Combination of low ground cover or mulches with weed control (e.g. flaming, mowing, natural product herbicides) merits closer scrutiny for organically acceptable practices (Weibel and Haseli, 2003).

14.4 Orchard Floor Influences

Effects of management systems on the environment

Ground cover can affect heat transfer and energy relationships in orchards (Snyder and Connell, 1993). Reducing vegetation allows greater absorption of solar energy by soil and increases radiant heating from the soil in the night-time. The resulting increase can help prevent freeze injury of flowers in spring. The range and fluctuation in soil temperature can affect root growth rates and frost injury to roots. Permanent sod cover of creeping red fescue in row middles reduced fluctuations in daily soil temperatures and provided some frost protection compared with a system of clean cultivation in summer and temporary ground cover in winter (Tan and Layne, 1993). Irrigation lowered soil temperature in summer with evaporative cooling and elevated soil moisture persisted to ameliorate soil temperatures in winter.

Soil water availability to peach trees was increased when cultivated for two or more years compared with trees grown with permanent sod cover (Kenworthy, 1953). However, in the long run (25 years) sod cover improved soil water penetration and holding capacity compared with long-term cultivation. Research demonstrated that this long-term effect was in part due to increased rainfall capture (less runoff) and improved soil properties (increased aggregate stability, macroporosity and microbial respiration) (Welker and Glenn, 1988; Glenn and Welker, 1989b).

Orchard floor management interactions with the peach tree

Orchard floor management will affect peach tree size. Obviously, nutrient availability will affect growth and yield but it can also influence growth in more subtle ways. Root density of young peach trees will decrease in sod (Glenn and Welker, 1991; Parker and Meyer, 1996). When maintained in weed-free alleys, trees exploit more of the grassed areas as they age (Atkinson, 1980). Competition might be manipulated, perhaps to the growers' advantage, to affect branch angle, excessive vegetative growth and possibly tree architecture. Reduced peach root growth resulting from competing ground cover may alter root-produced signals that can affect shoot development and tree architecture. Grass competition altered both dry weight and N partitioning within branches of a 3-year-old peach tree, the proportion of the N and mass partitioned into fruit decreased as the size of the vegetation-free area decreased (Tworkoski *et al.*, 1997). In contrast, the proportion of N and mass partitioned into stem and leaves increased or were unaffected as the size of the vegetation-free area decreased. The implication of these findings is that peach yield may be more sensitive than vegetative shoot growth to increased grass competition.

Young peach trees can be dwarfed and growth of mature peach trees reduced when grown for several years with grass competition (Tworkoski, 2000; Tworkoski and Glenn, 2001) (Fig. 14.3/Plate 89). However, peach tree size (mass, trunk diameter and crown size) influenced shoot regrowth following pruning more than grass competition (Tworkoski, 2000). In this case, ground covers appeared to deprive peach trees of soil nutrients by exploiting the upper soil. Fruit yield was reduced when peach trees are dwarfed by competition from sod in drive alleys but the yield efficiency based

Fig. 14.3. 'Jersey Dawn' and 'Redskin' peach trees, the same age (approximately 3 years after planting) but some planted and grown in 0.6 m (small trees in foreground) and others grown in 2.4 m (large trees) vegetation-free areas with 'K-31' fescue in drive alleys.

on tree size (kg yield/cm^2 trunk area) and water use (kg yield/cm water use plus precipitation) was not changed (Glenn and Welker, 1996). High-density plantings might, therefore, be attained by dwarfing peach trees with grass competition. The cumulative yield of such plantings has not yet been determined.

Orchard floor management of peach has undergone a significant change from complete mechanical control of vegetation to management of temporary and permanent vegetation with mechanical and chemical techniques. The future may incorporate ground covers that can be managed with environmentally appropriate techniques for weed control that enhance soil fertility and stability. These techniques will almost certainly be incorporated with information-based technologies and with computer models to help establish economic action thresholds for weed, water and nutrient management decisions. Management decisions are often based on increases from yield and cosmetic quality, but decisions can include less evident gains from soil and water conservation and from biological regulation of pest populations. Such economic and environmental benefits should be incorporated into future models that assist with orchard floor management decisions.

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Mention of trade names or commercial products in this book chapter is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

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