Floor Management Strategies

FOR VIRGINIA VINEYARDS

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Floor Management Strategies for Virginia Vineyards

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TABLE OF CONTENTS

Vineyard floor management encompasses all activities related to cultivation and other soil modification, weed management, and intentional cover crop management, both between and within vine rows. This bulletin describes the various floor management strategies commonly used in Mid-Atlantic vineyards and weighs the pros and cons of those systems. Particular attention is paid to the role of perennial cover crops used both in row middles (interrows) and in vine rows (under-trellis or intrarows) for mitigating soil erosion, but also for exerting intentional competition with vines for water and nutrients in situations where it's desirable to reduce vine capacity. This bulletin also includes information on crop species selection, establishment practices, and perennial management, as well as potential hazards associated with perennial cover crops. In addition, the physical, chemical, and biological weed control options are described.

Goals of Vineyard Floor Management

Floor management goals differ from vineyard to vineyard, but generally include some variation of each of the following objectives:

- Provide a stable, dust- and mud-free surface for foot traffic as well as the operation of vineyard machinery as soon as possible after rain events.
- Minimize the potential for soil erosion.
- Maintain or improve soil structure, water infiltration, and organic matter, if desired.
- Provide a desirable level of vine competition for water and nutrients to reduce the need for canopy management inputs and potentially improve wine quality.
- Minimize the threat of arthropod, nematode, and other types of pests.
- Enhance the year-round, aesthetic appearance of the vineyard.
- Enhance, in often poorly defined ways, the biodiversity of both the aerial and subterranean environment of the vineyard.

To better understand vineyard floor management goals, it is worth reviewing the historical context of floor management in eastern U.S. grape production. As with certain other aspects of vineyard management, these recommendations for wine grape vineyard floor management were adapted from juice grape production practices that were established and refined in the 20th century. For comparatively lower-valued juice grapes, the primary goal was to grow large grapevines that produced high yields of grapes that met the processor's minimum quality standards, typically assessed as soluble solids concentration at harvest. The perennial goal was to sustain that vine capacity to promote consistently high crop production. There was little or no interest in attaining complex flavor or aroma characteristics and the economics were driven by the quantity of grapes that could be grown per acre. Competition for soil moisture and nutrients was minimized through elimination or substantial reduction of floor vegetation in both the interrow and intrarow spaces.

The goals for wine grape production are similar in that the producer must be able to sustain large crops; however, wine grape value is intrinsically dependent upon the quality of the grapes, where quality is governed in part by grape aroma and flavor, as well as freedom from spoilage organisms. These features are intimately affected by the grapevine canopy microclimate, particularly fruit exposure to sunlight and the higher evaporative potential afforded by a relatively open canopy. Due to their inherent vigor, grafted wine grapes grown in the humid Mid-Atlantic region often produce more vegetation than can be effectively accommodated by typical training systems. The consequences of this excessive vegetative growth include dense, shaded canopies that foster fungal disease and negatively impact fruit and wine quality potential, and that invariably require increased canopy management labor to correct (Smart and Robinson 1991). Wine grape producers use a variety of tools to manage vine vigor and vegetative growth, including elaborate training and trellising systems to accommodate the growth. Canopy management practices such as shoot and leaf thinning and shoot hedging (Reynolds and Wolf 2008) are routinely used to avoid or reduce the excessive canopy density. Wine grape producers may also choose sites that are less likely to contribute to excess vine vigor, such as steeper slopes and thinner soils. And, as explored here, vineyard cover crops can also be used to mitigate excess vine vigor and are particularly important on steeper slopes to minimize soil erosion.

Vineyard Floor Management Strategies and Considerations

Vineyard floor management practices and results can be profoundly affected by climate and soil conditions (Guerra and Steenwerth 2012; Ingels et al. 1998; Tesic, Keller, and Hutton 2007). For example, the effects of cover crops are likely to be more significant in regions with winter-dominated rainfall (i.e., Mediterranean climate) than in the humid, subtropical climate of Virginia where rainfall distribution is relatively uniform throughout the year. Floor management can include cultivation, herbicide application, various mulches, intentionally planted cover crops and/or resident vegetation, and mowing and other means of managing cover crops. The term "resident vegetation" refers to the naturally reseeding or recolonizing vegetation that some might consider weeds, but which can be beneficial in Virginia vineyards by stabilizing soil and reducing vine vigor. All of these elements can be used independently of each other, but are often adopted in various combinations that can be changed with vineyard maturation and/or environmental conditions.

The most common floor management system in Virginia vineyards, and in vineyards elsewhere in the Mid-Atlantic region, makes use of perennial cover crops maintained in the interrow and an alternatively managed intrarow (figure 1).

Figure 1. This vineyard uses herbicide strips in the intrarow and perennial grass in row middles, or interrows. (Photo courtesy of T. K. Wolf, Virginia Tech.)

Table 1. General characteristics of cover crops used in eastern U.S. vineyards.

Cover crop	Life cycle	Comments on use	Recommended seeding rate (lbs/acre)
Grasses (monocots)			
Crabgrass (*Digitaria spp.*)	Annual	Self-seeding, although can be seeded	5 – 10
Oat (*Avena sativa*)	Annual		75 – 100
Italian (annual) ryegrass (*Lolium multiflorum*)	Annual		20 – 35
Tall fescue (*Festuca arundinacea*)	Perennial	Many cultivars available as turf grasses	50
Perennial ryegrass (*Lolium perenne*)	Perennial	Interrow and intrarow	60
Creeping red fescue (*F. rubra*)	Perennial	Generally, only in intrarows; less tolerant of machinery traffic	25
Orchardgrass (*Dactylis glomerata*)	Perennial		20 – 25
Broadleaved plants (Eudicots)			
Crimson clover (*Trifolium incarnatum)*	Annual	For all clovers, ensure adequate soil pH (6.0 or greater, and moderate phosphorus levels)	30 – 50
White clover (*Trifolium repens*)	Perennial	Short-lived perennial, but self-seeding	15
Red clover *(Trifolium pratense)*	Perennial		15
Subterranean clover (*Trifolium subterraneum*)	Annual	USDA cold hardiness zone 7 or warmer	20 – 30
Common vetch *(Vicia sativa)*	Annual		60 – 75
Buckwheat (*Fagopyrum esculentum)*	Annual		50 – 70
Brassica spp.	Annual or biennial	Many species, including mustard, daikon radish, and oilseed radish	Variable; 10-15 lbs/acre for radishes

Intrarow options are variable and can include maintenance of a vegetation-free zone for all or part of the year; use of annually sown and subsequently destroyed cover crops; or maintenance of perennial cover crops. Collectively, the added management costs, and in some cases ownership costs (e.g., seeder purchase), must be balanced against the less tangible benefits of decreased soil erosion, increased water penetration, more rapid accessibility of the vineyard following rains, and decreased herbicide costs. Management varies as a function of whether the cover crops are annuals or perennials; whether they are confined to row middles or planted to both interrows and intrarows (complete vineyard floor covers); and whether cultivation and graft-union protection by way of soil mounding is used in the vineyard.

Four basic floor management strategies are described here. It's important to consider, however, that a vineyard with variable soil quality and vine capacities might be managed with a combination of two or more of these floor management systems; for example, more aggressive use of cover crops in high-vigor areas and less competition in low-vigor areas.

Strategy 1: Perennial cover crops used in interrows with weed-free intrarow zone. This is the "conventional" floor management system used in most Mid-Atlantic vineyards, particularly on erodible sites and where vine size and vine vigor are adequate or excessive. Summer dormant, cool-season grasses such as blends of orchardgrass and tall fescue, or tall fescue monocultures, are typically planted before vineyard establishment (table 1).

When using this system, treat vine rows with a post-emergence herbicide prior to vineyard establishment and then maintain them weed-free for much of the year with cultivation and/or use of herbicides. Mow row middles as necessary or desired to achieve viticultural and aesthetic goals. Meet post-planting nutritional requirements of the vines through soil sampling, plant tissue analysis, and fertilizer placement in the intrarow area where grapevine roots are concentrated (see FAQ section, below). This system also lends itself to annual hilling and dehilling of grapevine graft unions for protection from winter injury (figure 2).

The intrarow zone can be of variable width: 18 to 36 inches is common, with wider bands generally resulting in greater vine growth (Basinger et al. 2018) which can be desirable in young vineyards and those on poorer soils. A common strategy is to reduce the width of the weed-free intrarow zone as the vineyard reaches full capacity in its fourth or fifth year.

Figure 2. Soil-mounded grapevine graft unions for winter protection. (Photo courtesy of Hemant Gohil, Rutgers University.)

Strategy 2: Annual cover crops used only in row middles. This floor management system is still used in many juice grape vineyards to minimize competition with grapevines for nutrients and soil moisture, yet have a stable soil surface over the dormant season. To use this system, drill grasses, such as annual ryegrass (Lolium multiflorum) or cereal rye (Secale cereal), in row middles in late summer or early fall, in time to allow adequate establishment and sward development before cold autumn temperatures curtail growth. Cultivate or desiccate the row middles with a post-emergence herbicide the following spring, generally between grapevine bud burst and bloom. This approach can still be used in the formative years of the vineyard where vineyard establishment might precede perennial cover crop establishment in the row middles, particularly on generally level ground. The use of annual cover crops, however, leaves soil vulnerable to erosion on sites typical of the Piedmont and Mountain regions of Virginia, and is therefore generally discouraged.

Strategy 3: Perennial cover crops used in interrows, combined with annual cover crops in the intrarows. This is similar to the first strategy, but incorporates an intentional planting of an annual cover crop or the maintenance of naturally occurring resident vegetation under the trellis. This system is most appropriate in high-vigor vineyards to suppress vine vegetative growth and to stabilize soil on erodible sites, but where the use of a perennial intrarow cover crop is impractical due to hilling and dehilling of graft unions for winter injury protection or the cultivation of the intrarow for weed management. The annual cover crop of choice (table 1) would be sown soon after spring dehilling of graft unions and would be managed by mowing, if needed, to regulate soil moisture depletion and potential interference with the grapevine canopy.

Variations of this strategy can also be used. One is to combine the interrow perennial cover crop with a weed-suppressive mulch under the trellis (figure 3). The mulch can be organic or inorganic, but involves an added cost of material, equipment operation/depreciation, and labor to apply.

Figure 3. Raw (non-composted) wood chips used as intrarow mulch. (Photo courtesy of Britta Baskerville, University of California Cooperative Extension.)

Another variation that has performed well in some Virginia vineyards involves the combination of perennial interrow sod with a deliberate use of resident vegetation that seasonally develops in the intrarow. Two very different grasses that have been used in the intrarows are crabgrass (figure 4) and bermudagrass (figure 5).

Figure 4. Large crabgrass (D. sanguinalis). (Photo courtesy of Jeffrey Derr, Virginia Tech.)

Figure 5. Bermudagrass (Cynodon dactylon). (Photo courtesy of Jeffrey Derr, Virginia Tech.)

Crabgrass (Digitaria spp.) is a summer annual grass that germinates and begins growth early (e.g., April), is generally prostrate in growth habit, and is easily managed with post-emergent or grass-selective herbicides, or by preemergent herbicides. Crabgrass forms seed heads in July, but these heads and the prostrate sward of the grass generally remain below the fruitzone of vertically shoot-position (VSP)-trained vines. Frost kills the plants, and unless the soil is disturbed, as in hilling up of graft unions, the remaining plant residue can effectively suppress soil erosion over winter. Three species of crabgrass are found in Virginia: D. sanguinalis (large crabgrass), D. ischaemum (smooth crabgrass), and D. ciliaris (southern crabgrass). They are similar in growth and development.

Bermudagrass (Cynodon dactylon), sometimes called “devil’s grass” or “wiregrass,” is an invasive, warm-season perennial grass that performs well under the warm conditions of central, eastern, and southern Virginia, is relatively low-growing, and can be mowed to further restrict its height. However, it is extremely difficult to eradicate, and so it’s not advisable to introduce it into areas where it is not already established. Where it has been introduced, however, bermudagrass is very competitive and expands vegetatively by both stolons and rhizomes, quickly shading out less competitive weeds, but also stabilizing erosion-prone soil. As a warm-season grass, bermudagrass is dormant during the winter, but resumes growth with warm weather. Either nonselective herbicides, such as glyphosate, or grass-selective herbicides, such as sethoxydim, can be used to suppress or temporarily eliminate bermudagrass growth under the trellis, in effect providing a variable degree of grapevine competition.

Strategy 4: Perennial cover crops used both in the interrows and in the intrarow. After two or more years of vine establishment, under-trellis (intrarow) areas of the vineyard can be sown with a perennial cover crop if the goals of the vineyardist are to reduce herbicide inputs and/or suppress vine vigor (figure 6).

Figure 6. Elite-II fescue (F. arundinacea) under Cabernet Sauvignon, Yadkin Valley, N.C. (Photo courtesy of Gill Giese, New Mexico State University.)

Delaying the intrarow cover crop establishment encourages growth and trellis fill of the grapevines. This system works reasonably well with VSP or other low-training systems that afford some sunlight exposure of the under-trellis area. High-training systems, such as Geneva Double Curtain, may not lend themselves to intrarow cover crops due to excessive, under-trellis shade. The established intrarow cover crop can be mowed if desired, but specialized, articulating mowing heads are needed to span the under-trellis zone, and most still leave vegetation intact around posts and vine trunks (see section on mowing under Cover Crop Maintenance, below). In our experience, creeping red fescue (Festuca rubra) works well as an intrarow cover crop, but it develops a very thick thatch after several years if not mowed. The accumulated thatch can attract voles and lead to a suppression of new growth from the sod. While we have not observed vole damage to grapevines where intrarow cover crops are used, the chemical weed control of a small, 6- to 12-inch circle around the vine trunks (figure 7) discourages this potential injury, and reduces the potential establishment of woody perennial weeds such as poison ivy or Virginia creeper.

Figure 7. Herbicide "halo" around vine trunks as means of discouraging woody weeds such as Virginia creeper and potentially as an aid to under-trellis mowing. (Photo courtesy of T. K. Wolf, Virginia Tech.)

In addition to harboring voles, the increase in plant debris in the intrarow can favor an increase in climbing cutworms, which can damage developing buds and small shoots by their feeding (figure 8).

Figure 8. Climbing cutworm feeding on bud and newly emerged grape shoot. (Photo courtesy of Joe Ogrodnick, Cornell University.)

It's important to be vigilant from bud swell through 2 inches of shoot growth to manage the potential damage caused by climbing cutworms.

These four general strategies are typically used in Virginia and elsewhere in the eastern U.S., but other floor management scenarios are possible, as well. Whatever system is used, the vineyardist should consider the costs of any input to the vineyard relative to the potential environmental and economic gains. Cultivation can be an effective method of weed management in the intrarow, but must usually be repeated two or more times per growing season. Cultivation costs include machinery and labor, potential soil erosion, and potential vine damage from less-than-perfect operator control. Perennial cover crops have management costs of their own and raise the potential for increased pest pressure, as by climbing cutworms. The questionable availability of affordable, effective, and reliable under-trellis mowers is still somewhat of a weak link with this aspect of floor management. Herbicides remain a popular and cost-effective strategy for intrarow floor management. For growers seeking a reduction in chemical inputs, organic alternatives clearly exist. Weed-free herbicide strips should be thoughtfully managed to gain some competitive effects of the intrarow floor vegetation, where needed, while suppressing the growth of large weeds or those that cannot easily be mowed by tractor-mounted mowers.

Cover Crop Considerations

Vineyard cover crops include both sown crops and weeds that grow naturally in row middles and in the vine row. This vegetation is an integral component of vineyard floor management and serves several purposes, primarily soil erosion control. Beyond the fundamental goals of soil conservation, addition of organic matter, and provision of a firm surface for machinery and foot traffic, cover crops are also used to regulate the growth of overly vigorous grapevines; that is, promote a more optimal vine "balance." Vine balance is generally defined as an appropriate balance of vegetative growth (i.e., vigor, leaf area, cane pruning weights) and crop yields that result in sustained, economic yields of high-quality fruit. While cover crops can effectively reduce the vigor and amount of vegetative growth, their presence may also depress vine capacity and crop yields too much. Crop yield reductions may be desirable from a wine quality perspective, but will vary with the extent of vineyard floor coverage and are typically noted after three or more years of cover crops being used (see FAQs, below). Other potential disadvantages of cover crops include the cost of establishment and maintenance, excessive water and nutrient competition with vines, increased presence and potential damage from animal pests such as voles, and increased spring frost potential. Furthermore, mixed stands of cover crops may attract pollinators that can be unintentionally harmed when the vineyard must be treated with an insecticide to manage Japanese beetles, grape berry moth, or various species of leaf hoppers. Benefits of cover crops often outweigh their liabilities, but overall vineyard management must accommodate the needs of both the cover crops and the grapevines.

Cover crops are broadly classified as annuals, biennials, or perennials. Annuals complete their life cycle from germination through flowering and death in a year or less. Biennials exhibit a two-year life cycle, while perennials may persist for three or more years.

Cover crops are also classified by taxonomy. Annual and perennial grasses (Poaceae family) are commonly used in eastern U.S. vineyards. Broadleaved cover crops include certain legumes, various brassicas, and a wide range of weeds, or resident vegetation (table 1). Although some radishes, carrots, onions, and herbs are technically biennials, most commonly used cover crops in the eastern U.S. are either annuals or perennials.

Annuals vs. Perennials

Annuals: Annual cover crops must be annually sown or naturally reseeded in the vineyard. The most commonly used annual cover crops are winter annual grasses or cereals, such as winter wheat (Triticum aestivum), rye (Secale cereal), Italian (annual) ryegrass (Lolium multiflorum), and barley (Hordeum vulgare). Certain annual legumes, such as crimson clover, which reseeds well, have been studied in eastern U.S. vineyards with variable results. These crops are broadcast or, more commonly, drilled in row middles in late summer or fall, are winter hardy, and mitigate soil erosion during the dormant period. They can either be allowed to reseed in the subsequent year, or be mowed or chemically controlled to reduce competition and avoid reseeding until intentionally reseeded in the subsequent fall.

While annual cover crops can be established in interrows only, vineyard floor management in Virginia is increasingly using perennial cover crops in interrows combined with one of three intrarow options: herbicide or cultivated strip, annual cover crops or resident vegetation, or perennial cover crops.

With low-vigor and low-capacity vines, the intrarow area should be maintained free of vegetation in all but the late fall and winter when native weeds such as winter annuals can be allowed to grow. Compost, other organic matter, and synthetic fertilizers can be applied to the intrarow area to further stimulate vine capacity and increase crop yield potential, without simply benefiting weeds or intentionally sown cover crops.

With erodible sites, or where vines tend to grow too big and too vigorously, annual cover crops are frequently used in the intrarow area. Their use must be compatible with other seasonal vineyard activities. For example, annual cover crops can be used when hilling and dehilling of vine trunks is used to avoid winter injury. Briefly, in areas subject to winter cold injury, vineyardists may hill soil in a berm over the graft unions of grafted vines in order to provide insulation of the graft union and a portion of the scion variety's trunk. The soil conducts heat from the subtending soil and protects the graft union and buds of the scion from which new trunks could be established in the event of subsequent winter injury to the vine. The soil is hilled up each fall and subsequently pulled down each spring to minimize scion rooting. This annual disturbance of the intrarow soil area limits the use of perennial intrarow cover crops, which would interfere with the operation and be damaged or destroyed by the hilling and dehilling. Where desired, however, as in erosion control and vine size suppression, annual cover crops can be used in concert with soil hilling and dehilling operations. Work in the Finger Lakes of New York has demonstrated that buckwheat or Italian (annual) ryegrass were well suited to annual cycles of hilling and dehilling, as these species could be sown soon after dehilling occurred in spring and still achieve sufficient growth to stabilize soil (Jordan, Bjorkman, and Vanden Heuvel 2016). These annual cover crops had essentially no impact on vine size or crop yield in the three-year study, perhaps due to the shortened seasonal period of competition with vines, or the relatively shallow rooting nature of these annual cover crops.

Annual cover crops also include certain annual weeds or resident vegetation that can be "cultivated" and purposefully used to obtain some of the same benefits as sown plants. Annual crabgrass species (Digitaria spp.) and black medic (Medicago lupulina) are common weeds that can be used for this purpose, as described above under floor management Strategy 3.

Perennials: The most common perennial cover crops used in eastern U.S. vineyards are cool-season grasses, such as various fescues. Cool-season grass species exhibit a bimodal pattern of seasonal growth, with vigorous growth in the spring followed by bloom and seed development, a quiescent period in the hot, occasionally dry summer, and a resumption of vegetative growth in the cooler days of autumn. Cool-season grasses are adapted to survival of winter low temperatures typical of Virginia. By contrast, warm-season grasses, such as most zoysiagrass (Zoysia spp.) cultivars, may be damaged or killed by winter low temperatures and show peak vegetative growth during the hottest period of the summer.

Much of the Mid-Atlantic region is considered a "transitional" area for turfgrass selection; both cool- and warm-season grasses may perform well in this area, but the choice of which to use would depend on specific needs. Grapevines have indeterminate shoot growth but exhibit their most vigorous growth between bud burst and the onset of fruit ripening, or veraison. Soil moisture reserves and seasonal rains can promote excessive growth of grapevines during this period. Cool-season grasses therefore exhibit a growth pattern that parallels the vigorous spring growth of grapevines, a period when the imposition of competition for moisture and nutrients is most desirable from a vine canopy management perspective.

Research in the Yadkin Valley of North Carolina compared five different grass species including fescues, perennial ryegrass, and orchardgrass in a mature Cabernet Sauvignon grafted to SO4 rootstock vineyard (Giese et al. 2014). The grasses were sown in both the interrow and the intrarow areas of the research plots. While all had merit, Elite II tall fescue (Festuca arundinacea) provided the greatest durability, persistence, and exclusion of undesirable weed species in that trial. Elite II tall fescue also exerted the greatest degree of competition with vines, which was desired under the conditions of that particular research.

Elsewhere, growers have used coarse-bladed, pasture or tall fescues such as Kentucky-31 in the interrow, combined with the lower-growing, more shade-tolerant creeping red fescue (F. rubra) in a 24- to 36-inch intrarow band. Grower experience with creeping red fescue, however, suggests that it is not durable enough to withstand frequent, seasonal machinery traffic when used in the vineyard interrows.

Besides various grasses (Poaceae family), legumes have also been explored in eastern U.S. vineyards (table 1). Legumes include several annual and perennial clover species (*Trifolium* spp.), common vetch (*Vicia sativa*), and cowpeas (*Vigna* spp.), among others. Under proper conditions, including adequate soil pH and supply of phosphorus, legume roots are associated with rhizobacteria that "fix" atmospheric nitrogen gas into plant-assimilable nitrogen. The fixed nitrogen is primarily used by the host legume, but some of the nitrogen can become available to the companion grapevines when the legumes are killed, mown, or, more modestly, through rhizodeposition of nitrogen into the soil solution. Some legumes, such as crimson clover (T. incarnatum), are aesthetically pleasing and may add landscape value to wineries associated with the vineyard (figure 9).

Figure 9. Crimson clover (T. incarnatum) in a vineyard in Surry, N.C. (Photo courtesy of Gill Giese, New Mexico State University.)

On the other hand, white clover (T. repens) may attract pollinators such as honeybees, which can be unintentionally harmed by certain pesticides used in the vineyard. White clover and, to a lesser extent, red clover, are commonly found in Piedmont and Shenandoah Valley vineyards of Virginia without intentional planting, and their relative abundance varies from year to year.

Perennial cover crops are ideally established one to two years before grapevines and trellises are installed. This allows the cover crop to be well established before equipment and frequent foot traffic occurs in the early phases of the vineyard. Sow perennial, cool-season grasses between mid-August and mid-September in western and central parts of Virginia or between early September and early October in southeastern parts of the state. They will benefit from the cooler days of fall, then rapidly respond to the warming, lengthening days of the subsequent spring. Spring planting is less desirable with these grasses due to the limited root growth that occurs before the onset of hot, dry summer weather, along with the potential for summer annual weeds overtaking the site, compromising cover crop establishment. Turfgrass varieties are generally suitable for vineyard traffic and variety recommendations (for turf usage) are updated annually (see Goatley, Askew, and Hardiman 2019).

Perennial cover crops provide a firm platform for machinery and foot traffic, which can be extremely important during wet periods of the growing season, particularly when there is a need to access the vineyard for pest management sprays. But this living mulch can also become a liability during extended droughts if vines are not deeply rooted or if the cover crop is active during hot, dry periods of the season. Cover crops can be mowed to provide a short-term reduction in the loss of soil moisture through the cover crop sward (Centinari et al. 2013). Cool-season grass cover crops tend to respond to droughts and cease growth more rapidly than do the companion grapevines, therefore reducing the need for repeated mowing.

Cover Crop Establishment

Whether annual or perennial plants are sown, establishment requires proper seedbed preparation, a determination of the seed sowing rate (table 1), a means of sowing the seed, and a means to lightly cover the seed.

Seedbed preparation: Ideally, soil should be relatively free of plant debris and rocks, smoothed of ridges or troughs, and lightly disked or harrowed to provide an even surface of loose soil. This is comparatively easy with tractor-mounted soil tillage implements in the interrows, but much more challenging in the confined spaces of existing intrarows. Hand-tilling and hand-sowing of under-trellis seed is an option in very small vineyards, but is not practical for larger operations. Offset, or narrow, articulating tillers are available, but require considerable operator skill to avoid damaging vine trunks and roots. Furthermore, the more commonly available, 3-point-hitch-mounted units typically have soil-working widths (3 or more feet) that are wider than desired for intrarow seeding. An option would be to select a tractor-mounted rotavator that can be adjusted by removing one or more tiller tines to narrow the unit to one-half of the under-trellis width. If free of most vegetation, a side-mounted harrow or disk may be sufficient to provide an acceptable seedbed. The surface needn't be perfectly clean or smooth.

Seeding and coverage: Grass seed can be drilled or broadcast and lightly incorporated with a disc or spring-tooth harrow. Seeding rates vary from 30 to 60 pounds per acre; the higher rates typically result in a denser, more uniform stand. Drilling results in more uniform establishment, and has the added advantage of placing seed only in the row middles (interrows) if desired.

Unless irrigation is available, it is generally advisable to maintain an 18- to 24-inch weed-free strip in the intrarow for the first two or three years of vine growth. This allows the thorough vine establishment before cover crop competition occurs.

Broadcast spreaders distribute seed (or fertilizer) in a 180 degree arc behind the tractor-mounted spreader, which limits their utility for sowing seed only in the interrows.

Side-delivery spreaders are available, but generally need to be further modified to place seed in a discrete band under the trellis.

Researchers in New York state (Wise and Walter-Peterson 2018) modified a Vicon spreader to optimize sowing seed under the trellis. While seed delivery was improved, the authors suggested that growers increase their seeding rates by about 30% to account for the imperfect distribution of seed from these “directed” spreaders. Seeded areas should be followed by a very light cultivation or “rolling” of the soil surface to just barely cover seed and to firm the soil around seeds. A fine layer of straw or other organic mulch can be applied to conserve soil moisture and stabilize soil during seed germination and seedling development; however, mulch distribution and spreading are not easily mechanized within the confines of established vine rows.

The above discussion explains some of the obstacles and part of the resistance to attempting to use under-trellis cover crops. It is much easier to apply herbicide in a band under the trellis than it is to establish a uniform stand of cover crop. Unless the grower is prepared to improvise and to consider options for cultivation and seed-sowing, it might not be a viable floor management option.

Floor Management Options and Cover Crop Maintenance

Vineyard floor management options are varied, and depend on the specific space — intrarow vs. interrow — personal preferences, site susceptibility to soil erosion, availability of equipment, and possibly other site-specific factors, such as the degree of resource competition with grapevines desired by the vineyardist. Broadly, the options comprise physical (e.g., cultivation or mowing) and chemical (i.e., herbicide) management, as follows.

Cultivation

Shallow cultivation (less than about 3 inches deep) or soil tillage was used for weed control in vineyards before the advent of herbicides or the use of monocultures of desirable cover crops. As with cover crops, cultivation can be applied to both interrow and intrarow areas, or only to the intrarow. The advantages of cultivation include its ability to be used in organic production, the immediate cessation of weed competition, breaking of soil crusts, and possible liberation of nitrogen in the short term, depending on the nature of vegetation being destroyed. The downsides of cultivation include potential damage to vine roots, erosion of the disturbed soil, loss of soil organic matter and soil structure with repeated cultivation, and associated input costs.

Cultivation is most effective if done repeatedly, before weeds become well established. While this increases costs, it reduces the need for deeper or more aggressive tillage to destroy sod or deeply rooted weeds. Row middle cultivators can be simple disks or harrows, power-driven, 3-point hitch-mounted rotary tillers (rotavators) that mix the top few inches of soil, or, more recently, spaders that mix soil at depth with minimal destruction of soil tilth. Equipment performance comparisons are beyond the scope of this bulletin, but growers should consider consulting with experienced farmers before buying a particular piece of equipment. Several types of cultivators are available for use in intrarows, most of which are side- or front-mounted to tractors with the actual tillage implement borne on a spring- or hydraulically-actuated arm to allow articulation in and out of the row. The tillage tool can be a rotary head of tines, a small rotary tiller, or a knife-like cutting bar that is operated just under the soil surface.

Mowing

As stated earlier, vineyard row middles with resident vegetation or a sown cover crop is likely the most common vineyard floor management system in mature (older than three years) Mid-Atlantic vineyards. Well-managed grass cover crops, especially the various fescue cultivars and perennial ryegrass, can suppress broadleaf weeds, mitigate excessive vine vigor as measured by reduced pruning weights over time, cause minimal yield reduction, and positively impact fruit composition (Giese et al. 2014; Hatch, Hickey, and Wolf 2011; Hickey et al. 2016). However, more significant yield reductions due to cover crops have been documented in arid regions.

Regardless of groundcover species and whether or not they are in the row middle or under-trellis, periodic mowing will be required. Repeated mowing can effectively control weeds, but timing, mowing cut height, and frequency should be considered. Growers should familiarize themselves with weed populations in their vineyards to determine the most useful mowing height. Because the regeneration point for grasses is relatively low on the plant stem, they can be favored by a lower mowing height. However, mowing frequently at a consistent height in fescue turfgrass can encourage horizontal growth of undesired perennials, allowing them to dominate the more desired fescue species (Pirchio et al. 2018). For example, low-growing and common broadleaf weeds such as dandelion (Taraxacum officinale) and white clover (Trifolium repens) can continue to grow and persist horizontally after mowing. Conversely, a consistent mowing height of 3-4 inches of several tall fescue cultivars can limit crabgrass incidence and growth (Cropper, Munshaw, and Barrett 2017; Dernoeden, Carroll, and Krouse 1993). Kentucky bluegrass (Poa pratensis) and fine fescues were favored over dandelion, crabgrass and white clover when mowed at about 2 to 2.5 inches versus 0.75 to 1.6 inches (Busey 2003). Mowing at flowering can control several annual and biennial weed species with a single pass. Other species are quite resilient and can continue to grow in prostrate fashion below the mower cut line and will eventually flower at that height. The mower can be lowered in subsequent passes to "catch" these at flowering. High mowing can reduce seed set in many species while allowing others to grow.

Another consideration coincident with mowing height and species is the amount of water used by a given cover crop. An Italian study showed unmowed fescue (Festuca arundinacea var. Barfelix) groundcover transpired 35%-49% more water compared with mowed fescue (Centinari et al. 2013). Despite reducing the evapotranspiration of grass with mowing, mowing a competitive cover crop such as orchardgrass has only a very limited and temporary effect on reducing the competitive effect of the sod.

Mowing can produce mulch that can be discharged into the vine row to recycle mineral nutrients and aid weed suppression in the intrarow zone, a strategy commonly referred to as "mow and throw." Conversely, growers with excessively vigorous vines might collect and remove mown clippings from the vineyard to deprive grapevines of any additional nitrogen. However, returning clippings to the vineyard floor, in most cases, will favor the growth of grass sod over weed growth. This residue or thatch shades the soil, reducing weed seed germination, and recycles nitrogen that stimulates healthy grass growth (Busey 2003). Overall, mowing is a relatively fast operation and requires minimal or no herbicide application, although with several passes per season, mowing has inherent costs.

There are three common types of tractor-mounted mowers: the sickle bar, rotary (heavy-duty "brush hog" and lighter "finish mower"), and the flail mower.

A sickle bar mower has a cutting bar that severs the vegetation between a fixed guard and a reciprocating blade.

Rotary mowers have blades that rotate parallel to the ground and can chop and cut weeds. Although heavy-duty brush hogs are typically mounted in the rear of the tractor, lighter finish-type mowers with multiple smaller blades can be mounted on the front, back, or belly of the tractor, providing options for tandem operation of other implements such as hedgers or leaf removal units.

Flail mowers are built with knives attached to a hooded drum that is powered by the tractor's PTO. The drum spins and the ends of the knives achieve a high speed that allows them to tear through grass and small brush. These mowers are ideal for chopping pruning brush and debris, and the chopped material will quickly decompose, adding organic matter to the vineyard floor.

Flail and rotary mowers can be fitted with side-delivery chutes that deposit clippings, helping to move mineral nutrients to the vine row and aid suppression of weeds with this green "manure." Flail mowers do not throw/eject materials as rotary blade brush hog mowers can. The flail mower knives are attached to the drum with a hinge; consequently, they can "give" if they encounter a rock, stump or other impediment and are less likely to break, damage the unit, or eject debris beyond the hooded shroud. If the knife does break or is damaged, it is relatively inexpensive to repair compared to a possible broken/bent rotary blade or drive shaft. The flail knives do not require the frequent sharpening common to rotary blade mowers. Flail mowers are generally much heavier than rotary blade or finish type mowers and because of their weight are typically rear-mounted on tractors. Consequently, they require a heavier tractor with more horsepower relative to a rotary or sickle bar mower.

Some growers are adopting a flail mower with dual mow-around heads to simultaneously mow row middle and the vine row under the trellis. Various models can be found through equipment dealers, but growers are encouraged to seek the experience of others who have used a particular piece of equipment before making this substantial investment. Effective under-trellis mowing works best and causes minimal vine/post damage when rows are straight and vine trunks are vertically trained and well-aligned in the row. Lighter weight alternative mowers mounted on all-terrain vehicles (ATVs) or stand-alone mowers used for commercial turf maintenance will cause less soil compaction compared to mowers attached to heavier, traditional vineyard tractors.

Small vineyards might manage intrarow vegetation with hand-held hedgers or string trimmers. One should not, however, underestimate the amount of labor to trim weeds or grass in this manner. In addition to the labor, string trimmers (e.g., Weed Eaters or Weed Whackers) have the potential to seriously and irreparably injure grapevines by girdling the trunks by inattentive operators (figure 10). For these reasons, growers should only consider hand-held trimmers a "spot treatment" strategy.

Figure 10. Trunk girdled by careless use of string trimmer ("Weed Wacker"). (Photo courtesy of T. K. Wolf, Virginia Tech.)

Herbicides

Herbicides are chemicals designed to kill weeds by either inhibiting or interrupting plant growth and development. Herbicides are the most common and often the most economical method of vineyard weed control. Principal advantages of herbicides are their effectiveness, their ease of application, and the selectivity with which they can be applied. Disadvantages of herbicides include the risk of toxicity to operators and vines, development of herbicide resistance among weeds, loss of soil organic matter, and potential to pollute surface water and groundwater.

Vineyard herbicides are typically applied in 2- to 5-foot wide, under-vine strips with row middles dedicated to a sown cover crop or native vegetation. This type of application results in only 20% to 50% of each vineyard acre actually being treated with herbicide. This is an important concept to understand: Herbicide labels are typically based on the treated area of the vineyard floor, which is usually a narrow band under the trellis, and not the total area of the vineyard, which would include the row middles. The choice of herbicide depends on whether it is labelled for use on grapevines, type/species of weeds to be controlled, safety, soil type and texture, and cost. Individual vineyard location, vine age, soil, and climate should be considered. For example, clay-based soils require a higher per-acre rate of a preemergence herbicide than needed with a sandy soil. Growing season length and heavy, frequent rainfall can also alter treatment rate and frequency. If both winter and summer weed control is desired, sequential herbicide applications will be required.

Herbicides are broadly categorized as "preemergence" with differing lengths of residual activity or "post-emergence" that control existing weed top growth. Preemergence herbicides work by acting on seeds and seedlings at the point of germination. They should be applied to bare soil and require rainfall or irrigation within a few days for activation. The weed seedlings absorb the herbicide via their roots, cotyledons, or shoots. Herbicide in liquid form is available for uptake, but keep in mind that thorough herbicide-soil contact is essential for best results. Without rain or irrigation to activate and incorporate them, preemergence herbicides will degrade, resulting in poor weed control. When applied according to recommendations and label prescriptions, preemergence herbicides can provide several months of residual weed control. Examples of preemergence herbicides for vineyards include flumioxazin, indaziflam, and oryzalin.

Post-emergence (or "burn-down") herbicides kill existing weeds. These herbicides are most effective on weeds less than 6 inches in height. Post-emergence herbicides can be absorbed and translocated throughout the target weeds (systemic), killing the entire plant, or kill only the green plant tissue they contact (nonsystemic). Systemic herbicides are either selective (active on specific weeds) or nonselective (kill a wide range of broadleaf and grass weeds). Perennial weeds that regrow from roots, tubers, or rhizomes are best controlled with systemic herbicides, and complete coverage of target weeds is not essential. Effects of systemic herbicides take as long as 14 days to be observed. Target weeds should be actively growing and not stressed due to mowing, low temperatures, or drought when herbicides are applied, as active growth aids translocation of the herbicide into and throughout the plant. Annual weeds are most susceptible to post-emergence contact "burn-down" herbicides, and the effectiveness of such herbicides depends on good spray coverage of the target weed. Effects of contact herbicides can be seen in as little as one day. Examples of post-emergence contact herbicides are carfentrazone, glufosinate, and paraquat. Examples of post-emergence systemic herbicides are glyphosate and sethoxydim. Read and follow all labels to determine which materials are safe for application to bearing and/or nonbearing vineyards.

Several organically approved post-emergence type herbicides are currently available. These products often require higher application rates, an additional surfactant, and repeated applications, which adds to their cost.

Consult Extension specialists and pest management recommendations for specific updates to herbicide registrations and recommendations. In Virginia, herbicide recommendations are annually updated in the grape pest management guide (Virginia Cooperative Extension publication 456-017, "Pest Management Guide: Horticultural and Forest Crops").

Due to the widespread development of herbicide-resistant weeds, herbicides with differing modes of action (MOA) should be rotated and tank-mixed, and the application timing should be adjusted and/or their use limited to minimize resistance. With continual use of the same herbicide, some weeds may develop resistance over time and result in stands of weed species not controlled by that product. Rotating and tank-mixing herbicides with different modes of action and using nonchemical controls will decrease or slow the development of herbicide-resistant weeds. Using the correct type and rate of herbicide with properly calibrated, maintained and operated equipment is critical to reducing the development of resistance, minimizing environmental impacts, and achieving success in weed control.

Herbicides can be a very effective component of an integrated vineyard floor management program. They can be judiciously used to regulate the competitive effects of cover crops, and may also be useful to control woody, perennial weeds in the vineyard such as Virginia creeper and poison ivy. A wide (greater than 24 inches), weed-free area under the trellis is, however, rarely if ever needed in an otherwise well-managed vineyard.

Mulches

"Mulch" is any material applied to the soil surface. Mulches are usually organic, such as straw, wood chips (figure 3), or various composts, but inorganic mulches can include shellfish shells, gravel or stones, geotextiles and other inorganic materials. Principal reasons for using mulches include weed suppression, water conservation and erosion management, reflectance of sunlight and heat, and slow incorporation of organic matter into the subtending soil. Some vineyardists use mulches simply for aesthetics. Mulching can be done in row middles, under the trellis, or in both areas, depending on the aims of the grower. As with the other strategies described in this publication, costs and potential benefits of mulches should be given careful consideration before embarking on this floor management option.

Heavy row middle mulching is an effective tool for weed suppression and water conservation. Round bales of straw or hay have been used to stimulate vine vigor and vine capacity in vineyards with low soil fertility or water-holding capacity. For weed suppression, the mulch must be thick enough to exclude sunlight and/or provide a physical barrier to weed development. Options include every-row or alternate-row application, and a single application might provide two or more years of weed suppression. Drawbacks include the need for a tractor-mounted spool to play out the bale, the cost of the hay or straw, including transport costs, the potential introduction of aggressive weeds such as johnsongrass (Sorghum halepense) or herbicide-resistant redroot pigweed (Amaranthus retroflexus) into an otherwise "clean" vineyard, and the potential fire hazard under dry conditions. Row middle mulching is also generally incompatible with the maintenance of a perennial cover crop in this zone.

Under-trellis mulches are probably more commonly used in wine grape vineyards. These include variations of a "mow and throw" strategy wherein row middle vegetation is mowed with the resultant mulch discharged to the vine row as an organic mulch. This system is particularly useful in more arid regions where winter annuals such as barley or annual oats are used as overwintering row middle vegetation. The sward is mown in the spring before seed maturation and deposited in the vine rows to suppress weeds and to provide an organic form of nitrogen and other nutrients. Wood chips, shredded paper, chicken litter, and various composted materials can also be applied only to the intrarow region to suppress weeds, add nutrients, and conserve soil moisture, depending on the peculiar needs of the vineyard. Again, one must consider the pros and cons: All inputs associated with material, transport, and labor costs should be considered on a cost-benefit basis. If, for example, the primary need is nitrogen fertilizer, adding 20 pounds of actual nitrogen to the vineyard as urea fertilizer is far easier than adding a comparable amount of nitrogen in the form of composted chicken litter. But compost might be more desirable if one is trying to reduce synthetic inputs to the vineyard, as in an organically managed operation.

Web-based landscaping mulch calculators can be used to gain a sense of the volume of mulch required using inputs of linear feet of row, width (18-24 inches), and depth (3-5 inches) of coverage. Even with differences in the density of landscaping grade mulch, wood chips, and other mulches, one quickly realizes that an extraordinary volume of mulch would be needed for adequate weed suppression for 5 to 10 acres of vineyard.

A concern with mulches is the potential for increased rodent populations, such as voles, which can feed on grape roots and trunks. Mulches can conceal rodents, sheltering them from predators.

Black geotextile fabric, reflective white geotextile fabric, composted bark mulch, as well as a "grower standard treatment" of under-trellis cultivation were evaluated over a two-year period in a Finger Lakes (N.Y.) Pinot noir vineyard (Hostetler et al. 2007). The mulch (4-inch deep layer), the two geotextile treatments, and the under-trellis cultivation zone each extended approximately 20 inches to either side of the vine row. Remaining areas of all row middles were shallow-cultivated in late spring, and then mowed monthly for the rest of the season. Objectives were to evaluate effects on weed suppression and to research other potential benefits to fruit composition, crop yield components, and vine pruning weight. In the first year, weed suppression was excellent with both geotextiles as well as the bark mulch compared with the cultivation treatment, but by the second year, those benefits had subsided due to weed growth around the base of vines, encroachment from the edges of the treatments, and some damage to the synthetic covers due to row middle traffic and floor management practices. Slight increases in soil organic matter concentrations were found in the second year under bark mulch; however, few if any benefits were found for any of the treatments compared with the cultivation used in the grower standard treatment, including effects on vegetative growth, winter hardiness of vines, petiole nutrient composition, or fruit composition at harvest. That said, year two did see an increase in clusters per vine and cluster weights with the white geotextile covers, resulting in greater crop per vine (4.9 pounds/vine) compared with the control (3.2 pounds/vine). While the white geotextile treatment resulted in an estimated $2,710 greater annual crop value per acre, its relatively greater unit cost, combined with an estimated three-year lifespan, led the researchers to conclude that the increased yields did not economically compensate for added costs relative to the standard grower cultivation practice.

This study illustrates several rationales for floor management that might be considered under the conditions of Virginia grape growing. On the one hand, all of the treatments used in the Finger Lakes study were organically acceptable, in keeping with the wishes of the host vineyard. The white reflective covers could have merit in a cloudy environment by reflecting sunlight back into the vine canopy. The increased irradiance can increase fruitfulness of developing buds. In fact, there was some evidence of that early in the first season, which might have led to the greater crop yields in the second year. The short duration of this project did not allow a more critical examination of this potential benefit, but there is evidence from other studies that demonstrate that fruitfulness can be improved by increasing the irradiance levels around developing buds. This might be an important goal in some situations. The use of textile covers or bulk mulch prevented the normal, fall hilling of graft unions, a standard practice for winter protection of cold-tender vinifera grapevines in the Finger Lakes region. Thus, floor management practices need to harmonize with other vineyard practices that are standard practices in a given region.

Thermal weeders

In addition to cultivation and mulching, an additional but less common form of physical weed management uses either steam or liquid propane-fired burners to suppress weeds. Flamers, as the name suggests, use an open flame directed from nozzles mounted on arms or even hand-held wands that allow under-trellis or berm application of the flame to weeds. Steamers have an added step of super-heating water with the same principle of directing the steam to the under-trellis area by directional nozzles. In both cases, the rapid increase in temperature of the weed tissue results in tissue disruption and death.

Weed flaming alone was compared to weed flaming combined with weed “take-out” cultivation in a Finger Lakes Concord vineyard (Pool et al. 1995). Flaming alone only achieved satisfactory weed control when applied in late July; the two earlier season (May and June) flame applications resulted in similar weed cover as an herbicide treatment, which was used as a control.

As with other floor management strategies, there are pros and cons to using flamers or steamers. The chief benefit of either flaming or steaming of weeds is that it’s an organically acceptable means of weed control. Both require combustion of fuel to raise the temperature of weed tissue to a lethal temperature of 140 to 160 degrees F. Literature for orchard and vineyard flamers suggest 3 to 6 gallons of LP gas per acre per application, depending on row width (about $8 to $16), with a need for two to four applications per year. Among basic factors such as ground speed of equipment, the efficacy of flaming also depends on the extent of weed cover, size or age of weeds, and atmospheric conditions. Weeds are more easily killed by heat application if only 1 to 3 inches tall. Heat acts like a nonsystemic contact herbicide with larger weeds and while it can destroy exposed tissue, larger weeds recover and resume growth in time. Flaming will not control the underground portions of perennial weeds as they regrow from rhizomes, tubers, or bulbs. A heavy dew can reduce efficacy due to the added heat required to vaporize the liquid water; however, the dew may ultimately increase the efficacy of a slower moving flamer by conducting more of the heat into the subtending weed tissue. Although weed steamers are mechanically more sophisticated pieces of equipment, they can be more effective than dry heat due to the deeper penetration of heat into the meristematic crown of weeds.

While heating and steaming do not leave an herbicide footprint, they do require fuel consumption which does release carbon dioxide. In addition, flaming may have the unintended consequence of igniting fires where combustible organic matter has accumulated under the trellis. Plastic irrigation lines, vine shelters (grow tubes), wooden trellis posts, and low-hanging grapevine vegetation are all susceptible to damage if precautions are not taken to avoid prolonged exposure to the open flame.

Several companies, including at least one Virginia-based business, market weed flaming equipment and can be found online.

Grazing

Using sheep for vineyard floor management has been used in some situations, particularly where both sheep and grape production are done in close proximity to each other. There are obviously additional requirements of fencing, protection from predators, and training of vines to discourage the sheep from feeding on the grapes and grapevines. The latter can be approached by introducing sheep to the vineyard only during the dormant season. Sheep can also be fitted with muzzle guards, which rotate out of the way while the sheep is watering or feeding head-down on grass or weeds, but falls over the sheep's mouth if its head is raised to the level of grapevines.

A benefit of using sheep is the "recycling" of weed biomass back into the vineyard system, although some weed seeds can remain viable after passing the digestive tract of sheep. However, sheep (and some goat breeds) are very susceptible to copper toxicity caused by ingesting this element. Given that copper is occasionally used for disease management in vineyard, its use as a fungicide has to be coordinated with the rotation of sheep in and out of the vineyard prior to the first seasonal use of copper fungicides.

The use of grazing as a vineyard floor management tool is only mentioned here to illustrate the creative approaches some have gone to with vineyard floor management plans. Sheep might be a viable option in situations where the vineyardist establishes a cooperative arrangement with a nearby shepherd. In this situation, the shepherd would provide, possibly for a nominal rental fee, his or her flock to the vineyardist for a specified period of time, similar to a beekeeper who rents beehives to an orchardist only during the flowering period of the trees. This puts the business of sheep management and veterinary expenses on the shepherd, and allows the grape grower to pursue grape production.

Floor Management Tips for Steep Terrain and Poorly Drained Spots

Two situations are occasionally encountered that warrant consideration for modifications to floor management strategies: steep terrain conditions and wet, poorly drained areas of the vineyard.

In vineyards that are located on steeper sites, particularly those with slopes greater than 20%, machinery traffic and row orientation increasingly impact the maintenance and durability of vineyard floor cover crops. Vineyard rows in these cases are more often run up and down, rather than across perpendicular prevailing slopes, for added machinery operational safety. This row orientation also reduces the tendency for the downslope wheel track to become rutted. Once initiated, wheel ruts tend to enlarge due to water erosion and the mechanical wear of repeated machinery traffic. Once formed, the only solution to ruts is to fill them with an inert material such as coarse stone that supports the machinery and allows water drainage (figure 11).

Figure 11. Ruts in this swale that bisects a vineyard block have been filled with stone. (Photo courtesy of T. K. Wolf, Virginia Tech.)

Tracked machinery that is sometimes used on steep vineyard sites can also damage sod, particularly at row-ends where sharp turns are made. To reduce the potential for this damage, use very robust grasses such as Kentucky-31 tall fescue.

Poorly drained areas should be avoided, sculpted to promote surface drainage, or tiled prior to vineyard establishment to avoid water ponding. Despite such forethought, an unusually wet season will occasionally reveal wet areas or sections of rows in otherwise well-designed vineyards. Machinery traffic through these zones will lead to poor cover crop performance and potential rutting in the wheel tracks. There is no easy means of draining these spots where rows run perpendicular to the slope. "French drains" or tiling can be installed across the rows/trellises to drain soil moisture downhill, with all the costs and hand-labor required to trench under trellises and across row middles. An alternative is to temporarily take out a panel of trellis and possibly a vine from each row and use a self-propelled ditching machine to install a drainage line perpendicular to the rows to a point outside the vineyard. Although it's an added development cost, hiring a civil engineer to proactively anticipate surface and soil moisture movement and ponding on a site with undulating topography can be money well-spent in terms of later vineyard management.

Cover Crops and Soil Compaction

Soil compaction, or the collapse of soil pore space, is most commonly caused by tractors, harvesters, and other heavy implements, and can reduce water infiltration, increase water runoff, and escalate soil erosion. Soil compaction can reduce microbial activity and root growth, and decrease yields in many crops. The potential for soil compaction varies as a function of soil texture, structure, and water content; floor management practices; and of course, the weight and frequency of vineyard machinery traffic. Perennial cover crops can reduce the potential for soil compaction through their root development and generation of soil organic matter over time.

The perception of soil compaction occasionally leads growers to "deep rip" row middles, which has questionable benefits but undisputed energy and labor costs. With few exceptions, reductions in vine growth or grape crop yield or quality have not been quantitatively associated with soil compaction. Thus, in a general case, deep-ripping or other means of modifying soil structure are generally not recommended. See the sidebar about soil compaction for further details.

Measuring and Mitigating Soil Compaction

Soil compaction can directly limit root distribution and the roots' ability to extract water and nutrients. Compaction reduces the air-filled porosity in soil and increases soil strength. A soil strength or resistance of 2.0 to 2.5 MegaPascals (MPa), as measured in soils at or just below field capacity water content, is suggested as a general upper limit for optimal root growth and function; however, those values were largely determined on the basis of agronomic crops such as corn and cotton. An optimal value proposed for grapevine root function, and corresponding wine quality, is as low as 1.0 MPa (Lanyon, Cass, and Hansen 2004).

Soil compaction can be measured and mapped within the vineyard using an instrument called a penetrometer. Penetrometers are available for as little as $260 to over $1,500, but they require calibration, and their accuracy is highly dependent on operator consistency. The penetrometer is pushed into the soil by hand and is equipped with a load cell or strain gauge to measure pressure or force exerted by the operator against the soil's resistance (figure 12).

Figure 12. Penetrometer being used to measure soil compaction in a young vineyard. Inset is digital readout of resistance in pounds per square inch (PSI). In this example, 165 PSI equates to 1.14 MPa. (Photos courtesy of Gill Giese, New Mexico State University.)

However, the resistance reading depends on speed of insertion and is prone to error as the operator encounters different amounts of resistance and reacts accordingly. Consequently, penetrometer data can be difficult to accurately interpret. Another consideration is the difference in the resistance encountered by the metal rod of a penetrometer and that of a plant root. Unlike a plant root, a metal rod cannot deviate from its path of advance when resistance is encountered. Despite these shortcomings, penetrometer measurements likely correlate to root growth and distribution, soil bulk density, and overall available root volume. But, when interpreting soil penetrometer readings, one must consider soil texture, density, and moisture content from site to site. Ideally, soils should be tested for resistance when they are close to field capacity with respect to water content.

Cover crops can reduce soil compaction and degradation and positively affect water infiltration and water-holding capacity (Aljibury and Christensen 1972) but the impact of a given cover crop is contingent on the climatic, site, and soil conditions of a particular vineyard. In a Czech study, where various blends of grasses and flowering plants were evaluated as vineyard cover crops, soil compaction was generally reduced by mixtures that contained either fescue (various species) or Italian ryegrass (Lolium multiflorum), compared with those that did not (Burg Mašán, and Zemánek 2017). However, not all cover crops reduce soil compaction to a degree accepted as superior to conventional tillage. A systematic study of a hillside vineyard in northwest Italy (20% slope, vine rows perpendicular to the slope), with grass or cultivated row middles in which only crawler tractors had been used, revealed that the tracks on the uphill side of the row middle were less compacted relative to the downhill tractor tracks, regardless of vineyard floor

continued on page 16

continued from page 15

treatment. This was due to the tractor's weight being more displaced to the downhill side of the row that had increased soil bulk density and penetration resistance (Ferrero, Usowicz, and Lipiec 2005). Surprisingly, greater penetration resistance was measured under grassed versus cultivated treatments at comparable depths and locations. This was attributed to the lower soil water content under the grassed floor treatment, due to water depletion and greater internal soil strength induced by the grass roots.

Overall, perennial cover crops in row middles generally reduce the potential for soil compaction from routine vineyard traffic; however, cover crops should first be considered for their substantial benefits beyond possible mitigation of soil compaction.

Frequently Asked Questions about Vineyard Cover Crops

Establishment and maintenance of inter- and intrarow cover crops increase vineyard management and lead to issues, both real and perceived, with respect to grape yields and quality potential. Here are some of the more common questions encountered in our research and grower experiences.

How do cover crops affect vine growth and crop yield?

Cover crops are generally thought to regulate vine vigor through resource competition. Regardless of whether cover crops are intentionally planted monocultures or mixed stands of weeds, roots of these plants will effectively colonize soil and often out-compete grapevine roots for soil moisture and nutrients (Guerra and Steenwerth 2012). The degree to which cover crops compete with grapevines for soil moisture will be a function of the extent to which the cover crops occupy the soil surface, explore the subtending volume of soil, the age and rooting depth of the grapevines, the species or cultivar of cover crop, soil moisture reserves, and frequency of rains or irrigation. The vegetative growth of grapevines is directly and positively affected by the width of a weed-free soil strip maintained under the trellis (Basinger et al. 2018). Sodded row middles also compete with vines for moisture, as grapevine roots extend into the row middles. As described above, the vineyardist can minimize cover crop competition in those situations where vine size and vigor are inadequate (i.e., less than 0.25 pounds of dormant cane prunings per foot of canopy), and may wish to increase the competition with cover crops where vine size is chronically excessive (greater than 0.35 pound of dormant cane prunings per foot of canopy).

An experiment conducted at Virginia Tech's Agricultural Research and Extension Center in Frederick County, Virginia (Hickey et al. 2016) illustrates the long-term impact of intrarow cover crops compared with a 2-foot wide herbicide strip maintained under the trellis. The under-trellis cover crop of creeping red fescue decreased annual cane pruning weights by an average of 26% compared with vines grown with the herbicide strip (figure 13).

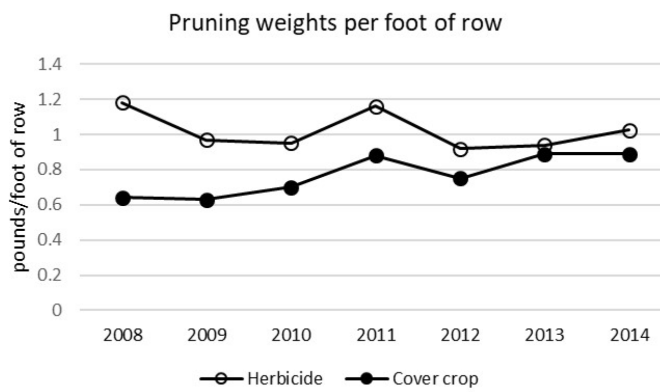

Figure 13. Cabernet Sauvignon cane pruning weights of vines grown either with an intrarow herbicide strip or with creeping red fescue in the intrarow area. Pruning weights were significantly different as a function of floor management each year except 2013. (Figure adapted from Hickey et al. 2016.)

In reducing vine size, fruit exposure was increased by an average of 35% by virtue of less vigorous shoot growth. Note that the greatest impacts of cover crop on vine pruning weights occurred in the first four years of the experiment.

What was the "cost" of the vine size reduction? Except for clusters per vine, which were reduced to a uniform number each season, all measured components of yield were slightly reduced by the intrarow cover crop (table 2).

Table 2. Fruit soluble solids concentration at harvest and components of crop yield of Cabernet Sauvignon grown with under-trellis cover crop or with a 2-foot wide under-trellis herbicide strip, averaged over six seasons (2008-2013). All variables, except for clusters per vine, were significantly different between floor management treatments.

Treatment	Soluble solids (Brix)	Crop yield (lbs/vine)	Clusters per vine	Cluster weight (g)	Berries per cluster	Berry weight (g)
Cover crop	23.14	8.57	27	139	101	1.35
Herbicide	22.83	9.85	27	172	123	1.40

Data from Hickey et al. 2016.

Yield components included berry size, cluster weights, and crop per vine. The reduction in crop yield in the cover crop treatment was likely due in part to a reduction in vine nitrogen status, which could be expected to reduce berries per cluster and potentially berry size with the modest reductions in vine nitrogen measured (Hickey et al. 2016). This highlights that vine nutritional management must be carefully monitored where perennial cover crops are used in the vineyard, especially with intrarow culture (see related question, below). In addition to taking up soil moisture, cover crops will use nutrients, particularly nitrogen and phosphorus, which may lead to deficiencies of these nutrients in companion grapevines (Klodd et al. 2016). Nitrogen deficiency symptoms include a faded green coloration in leaves, reduced fruit set and crop yield, and diminished vine capacity in successive years. Phosphorus deficiency has been observed where cover crops are intensively used and where soil pH has slipped below 5.3 to 5.5. Symptoms appear as interveinal reddening on the basal leaves of red-fruited varieties (Bates and Wolf 2008). Beyond the competitive effects for moisture and nutrients, cover crops might also exert allelopathic effects on vine growth, although this has not been well documented in vineyard situations. Leguminous cover crops (e.g., clovers, cowpeas, common vetch) can be used to add nitrogen to the vineyard system if desired (see following sections).

While measurable and statistically significant, the "reduced" crop yield related to intrarow cover crops still reached 4.15 tons/acre, an appreciable average by most standards. Furthermore, the cover crop-maintained vines produced slightly riper fruit (table 2). These results are comparable to other long-term studies of cover crops in humid climate regions such as the eastern U.S. and New Zealand.

Research has shown that grapevines can adapt to competition from perennial cover crops in some situations by root exploration of deeper soil layers, where soil moisture reserves are less apt to be depleted by the cover crop (Celette, Gaudin, and Gary 2008). The vineyardist must balance the competitive stresses imposed by cover cropping with the benefits of regulated vine vegetative growth. This is a dynamic balance that can be affected by seasonal rainfall or irrigation within a year, and by year-to-year variation in vine performance. Thus, floor management practices of a young vineyard (less than five years) might differ from practices used in older vineyards.

Do cover crops reduce the movement of nutrients or pesticides out of the vineyard?

There is limited data with eastern U.S. vineyards, but cover crops can be expected to reduce the movement of nutrients and some pesticides out of the vineyard. There are likely several reasons for this observation, including a greater infiltration of water (and contaminants) into the soil where cover crops are used, and therefore less surface movement. But cover crops are also generally associated with more abundant and more diverse soil microbial activity (see related question, below), some of which can be involved in degradation of and sequestering of nutrients and organic pesticides. An in-depth reference on means of reducing off-site movement of pesticides from vineyards is provided by Prichard et al. (2013). While geared toward the arid farming conditions of California, many of the described principles and strategies for minimizing off-target movement apply to Virginia producers.

An apple orchard floor management study in the Finger Lakes of New York (Atucha et al. 2011) provides evidence of how vineyard floor management might impact nutrient runoff and leaching. Briefly, the experiment examined four floor management systems:

one (PreHerb) used a preemergent/post-emergent herbicide combination applied once in mid-May; a second (PostHerb) used two applications of a post-emergent herbicide (spring and early summer); a third (Sod) used mowed sod (creeping red fescue); the fourth (Mulch) used a 6-inch layer of composted hardwood bark mulch. Nitrogen and phosphorus fertilizer applications were made in a single year (2005) of the multi-year study. Leachate and surface runoff water samples were collected in both 2005 and 2007 to measure nutrient loss from the orchard as a function of floor management systems. Nitrate runoff was generally greatest for the two herbicide treatments and less from the sod or mulch treatments, and nitrogen runoff varied between the two measurement years as a function of fertilizer application, rainfall, and nitrate mineralization. Interestingly, the PreHerb plots had the least nitrate measured in leachate (internal drainage), while mulch had elevated leachate nitrate levels owing to a greater pool of mineralizable nitrogen. While sod reduced nitrate runoff in one of the two years, it had little or no impact on leachable nitrate. The authors of the study cautioned that prolonged, annual application of compost or other organic mulches carries an increased risk of nitrate leaching from such systems, as the compost leads to increased soil organic matter nitrate mineralization.

Do cover crops improve "soil health"?

Most growers have a general notion of soil health: good physical structure, drainage, and chemical composition, as well as less clearly quantified biological components. Other metrics include carbon content, soil particle aggregation, water infiltration rate, soil respiration, soil methane and nitrous oxide emissions, and total soil microbial biomass. These physical, chemical, and biological components interact and when harmonized contribute to soil health, which can be defined as "the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal and human health" (Doran, Sarrantonio, and Liebig 1996). Soil biology is important because the soil biome is a reservoir of plant-available nutrients, it serves to recycle soil nutrients, it can improve soil structure through formation of soil aggregates and humus, and the mycorrhizal component of the so-called "soil food web" directly benefits grapevines by establishing symbiotic associations with grapevine roots.

Vineyardists can move the soil health "needle," for better or worse, by management practices and malpractices, including tillage; addition of organic matter, lime and other inputs; soil erosive and compaction factors; chemical inputs; and other activities. The U.S. Department of Agriculture's Natural Resources Conservation Service provides a general roadmap for sustained soil health with recommendations of four general practices: minimize disturbances, maximize biodiversity, maximize soil cover, and maximize living roots. More in-depth discussions can be found in texts such as "Cover Cropping in Vineyards: A Grower's Handbook" (Ingels et al. 1998), which provides an excellent overview of soil ecology and how it can be impacted by floor management practices such as tillage (generally deleterious) and use of cover crops (generally beneficial).

As pointed out by Stewart et al. (2018), soil health depends both on inherent features of the soil (texture, location or place, climate) and management practices (cultivation, chemical and organic inputs, etc.). It is not surprising therefore that vineyard management practices might impact soil health in different ways depending on the peculiar environmental conditions and soil conditions present. For example, in a 30-year German study, soil bacteria increased with shallow tillage whereas soil fungi increased with fescue cover cropping. Increased organic carbon, soil organic matter (SOM) and phosphorus levels were associated with the minimal disturbance of permanent groundcover, whereas tillage decreased soil carbon and nitrogen levels. However, tillage promoted a more diverse annual plant community, showing that disturbance does not necessarily reduce plant species richness (Pingel, Reineke, and Leyer 2019).

In a 22-year California study, interrows naturalized with rough-fruited buttercup (nontilled) were compared with interrows tilled annually and sown with wheat, rye, garden pea, and fava bean post-harvest, and a third treatment of interrows tilled but not sown (Belmonte et al. 2018). The sown/nontilled interrows had more organic carbon and nitrogen and greater microbial biomass and respiration compared with the sown/tilled interrows. Tilled soil had limited soil organic matter, reduced aggregate stability, and was more likely to erode compared with the nontilled rows.

In a Spanish study, resident vegetation increased soil organic carbon and nutrients, soil structural stability, water-holding capacity, and amounts and biodiversity of bacteria, yeasts and molds compared with tillage performed three times per year. Interestingly, yeasts and bacteria increased at harvest time regardless of the soil management system. Soil compaction decreased under the native vegetation system (see Soil Compaction sidebar). Seasonal variation impacted soil organic carbon, and the amount of water impacted the amounts of microorganisms cultured and counted (Lopez-Pineiro et al. 2013).

Simple and inexpensive bioindicator measurements of soil health that correlate to pH, bulk density, water-holding capacity, and soil microflora would be practical and useful for vineyard managers. The presence of earthworms is generally indicative of good soil health (Paoletti et al. 1998). A simple field test to measure the biological health of soil is to examine a block of soil for earthworms. More than 10 earthworms per 15 cubic centimeters (about 6 cubic inches) of soil indicates good drainage/aeration which supports root growth and microbial activity (White 2015). Although not complete or comprehensive, bioindicators can be an accessible, efficient and fairly accurate first-step assessment of soil health and vineyard biodiversity.

How can I fertilize my grapevines if I use intrarow cover crops?

Efficient fertilizer use means applying only the nutrients needed, at the optimal rate and timing, and in the optimal location for grapevine uptake and use. The majority of grapevine roots are concentrated in the under-trellis area although they easily extend into row middles if soil physical conditions are not restrictive. Cover crops can alter the abundance and distribution of grapevine roots (Klodd et al. 2016). Cover crops can effectively sequester mobile nutrients such as nitrogen, which can be helpful in reducing off-target leaching of these nutrients. But at the same time, the uptake by cover crops and weeds deprives the grapevines, at least temporarily, of access to that fertilizer. This can be mitigated by banding most fertilizers under the trellis, where there is usually a greater density of grapevine roots and where a vegetation-free area is often maintained on the vineyard floor for some period of the season (Bates and Wolf 2008). Broadcast application of lime is still performed, if needed, in this situation.

The more extensive use of complete floor cover crops, including those in the intrarow, presents a special situation where adjustments to floor management and fertilizer application may need to be harmonized. In particular, long-term maintenance of intrarow cover crops have shown a negative impact on vine nitrogen status, which can lead to a reduction in vine capacity; both vine size and crop yield can be diminished in time (Moss 2016). There might be other factors that lead to the reduction in vine capacity, but the reduction in vegetative growth due to reduced vine nitrogen status is consistent with commonly observed problems with vineyard weed infestation.

Growers can consider several approaches to avoid or correct the situation where nitrogen becomes limiting to vine capacity. One is to apply nitrogen fertilizer to soil at the rate and timing (bud burst to fruit set) recommended for this nutrient (Bates and Wolf 2008). Where a vegetation-free strip is used under-trellis, the nitrogen fertilizer can be restricted to this zone to minimize the sequestering of the fertilizer by the cover crop. If annual cover crops are used in the intrarow, the nitrogen application timing might be adjusted slightly to minimize uptake by the cover crop, as by application of the nitrogen before the full development of the cover crop. The greatest logistical challenge is where perennial, intrarow cover crops are used. Here the vineyardist might consider first “burning down” an 18- to 24-inch strip of the cover crop with a post-emergent, contact herbicide such as glufosinate to temporarily minimize the uptake of the nitrogen (or other banded nutrients) by the cover crop. Foliar application of nitrogen, as with feed-grade urea, is also an effective means of increasing fruit yeast-assimilable nitrogen (YAN) levels while having less impact on vine size (Moss 2016). Foliar applications can be made regardless of the status of intrarow cover crops, and be made repeatedly through the growing season if the goal were to increase vine size; however, care must be exercised with rates and combinations of other spray materials to avoid potential foliar burning, particularly under high summertime temperatures.

Do vineyard floor management practices leave a sensorial “signature” on wines?

There is ample evidence that the microbiome found on grapes can be uniquely expressed at regional and even site-specific levels, suggesting that “microbial terroir” may perhaps impact wine sensory properties in measurable ways (Bokulich et al. 2014; Gilbert, van der Lelie, and Zarraonaindia 2014). It is also apparent that this biome can be altered by grape variety, environmental conditions, interannual climate (vintage) (Bokulich et al. 2014), and possibly through human processes such as vine training and pesticide application. Evidence linking specific vineyard practices to the harvested grapes (and wine) is, however, very elusive. Kecskeméti, Berkelmann-Löhnertz, and Reineke (2016), for example, found no significant differences in fungal and bacterial diversity of grape biomes from conventionally, organically, or biodynamically-managed Riesling vines in a research vineyard in the Rheingau, Germany. Closer to home, Chou et al. (2018) found that under-trellis floor management led to differences in soil fungal and bacterial community composition. Soils maintained with natural vegetation under the trellis, for example, had a different fungal profile than did soils that were kept vegetation-free with glyphosate or with cultivation. Over a three-year period, the soil fungal structure of natural vegetation increasingly diverged from that of glyphosate treatment and cultivation, suggesting a strengthening of the vegetation impact on fungal diversity over time. Interannual variation had a greater impact on fungal community structure than did treatment. Bacterial communities also differed somewhat from natural vegetation and the other two floor management systems, but less consistently. Perhaps the most interesting finding from this study was the lack of fungal community segregation on grapes as a function of soil management. In other words, although natural vegetation led to discrete changes in soil fungal profiles, there was no corresponding changes in the grape microbiome. The presence of fungal pathogens such as powdery mildew, botrytis, various molds and yeasts, dust, certain insect infestations, smoke particulates, and potentially certain volatiles adsorbed by grapes may certainly impact the sensory properties of wine. Discovering a direct link between vineyard floor management and specific wine sensory impacts, however, is an evolving science and, at this point, should probably not be a principal factor in choosing one floor management system over another.

Do cover crops increase the potential damage from grape root borers or other arthropods?

Resistance to the incorporation of intrarow cover crops has included growers' concerns about increased grape root borer (Vitacea polistiformis) larvae survival and subsequent infestation of grape roots where weeds or cover crops are maintained under the trellis. Grape root borer eggs are laid in the grapevine canopy and the recently emerged larvae fall to the vineyard floor, enter the soil and some find their way to grape roots where feeding occurs typically over a two-year period (Bergh 2012). Mature larvae can cause significant vine damage and loss before pupating near the soil surface and emerging as adult moths. While it is known that recently emerged grape root borer larvae do not survive long in a dry environment, the evidence for weeds or other vegetation under the trellis increasing their survival, and therefore increasing vine injury and death, is equivocal. Grape root borer adult emergence was studied in an own-rooted Catawba vineyard in Missouri as a function of under-trellis floor management (Townsend 1991). Treatments included either a 3-foot or 10-foot wide vegetation-free strip, a 3-foot hay mulch strip, a 3-foot bark mulch strip, or grass maintained under the trellis. Drip irrigation was established on one-half of the plots to ensure that moisture was present during egg-laying and larval hatch. Adult emergence from the plots was monitored over a five-year period. The researchers hypothesized that the vegetation, the irrigation, and the mulch treatments would all foster greater larvae survival and eventual adult emergence. Emergence was counted by weekly recording of the number of pupal skins (exuviae) on the soil surface from July through September. In the end, the research revealed no significant differences among the treatments over the five-year period. For nonirrigated plots, the grass strips actually had the lowest cumulative count of emerged adults (70) over the five years, compared with 87 for 10-foot bare strips and 102 for 3-foot bare strips. Bark mulch tended to show more cumulative, emerged adults over five years (106), but the important point made was that there were no statistical differences among the treatments.

More recently, researchers at Virginia Tech (Rijal, Brewster, and Bergh 2014) extensively surveyed cultural and environmental parameters to predict grape root borer emergence over a five-year period. Again, there was very little if any evidence that weed management, including perennial cover crops, impacted the detection of the borer exuviae in 48 blocks at 19 commercial vineyards, none of which were treated with insecticides targeting the grape root borer. In summary, while the potential for direct or indirect effects of in-row vegetation on grape root borer larvae survival and eventual infestation of vines can't be ruled out, there is little or no evidence that it's a problem.

Growers who choose to use extensive cover crops in the vineyard, however, should be vigilant to other potential pests that use intrarow cover crops as a refuge. Anecdotal observations from our own work suggests that grape mealybugs (Pseudococcus maritimus) can increase in abundance in the sward of under-trellis vegetation. These insects can increase the spread of certain viruses such as leafroll, although we have not seen a correlation between the use of intrarow cover crops and incidence of these diseases. Similarly, European red mites can be harbored in under-trellis vegetation and may move into grapevine canopies when such cover crops go dormant or are treated with herbicides. As previously mentioned, climbing cutworms can be more problematic where intrarow cover crops are maintained, possibly due to daytime protection afforded by the cover crop to these nocturnal feeders. Under-trellis vegetation has also been associated with an increased abundance of ticks in some cases, which can pose a hazard to vineyard workers. As with nutrient management, the more intensive use of cover crops requires greater attention to potential problems that might arise with their use.

Do cover crops increase the potential for spring frost?

Cover crops can increase the potential for spring frost damage in vineyards by reducing the heating of soil during daylight hours. Bare, moist soil typically absorbs more heat, mostly by radiant heating, than does a living groundcover such as grass. Consequently, moist, bare soil has more thermal heat units that can be released at night compared with vineyard floors that are covered in vegetation. This might only be an issue in vineyards that are prone to spring frost, but is one consideration with using cover crops. In cover-cropped vineyards, keep cover crops closely mowed when there's a threat of spring frost to increase the soil's temperature.

Summary

Vineyard floor management strategies should consider the intended goals and weigh the costs, benefits, and risks of each component. In most vineyards, floor management will likely use several elements and might be altered over time; herbicides might be used in the young vineyard but phased out in favor of intrarow cover crops as the vines become fully established. Floor management can also be adjusted within a vineyard block in any given year to account for spatial and temporal variance in vine vigor. Vineyards on thin, relatively infertile soils might require a different approach to those on deeper soils with greater water-holding capacity. Floor management strategies will also be influenced by production goals, vine-training system, rootstock, graft union protection techniques, and personal convictions about certain inputs such as herbicides. It is not surprising, therefore, that vineyard floor management options are so diverse, that there is no single perfect management strategy for all situations, and that there are inherent costs and benefits associated with each strategy. The costs and benefits outlined here allow growers to make informed decisions on which options are appropriate in their own situation.

Suggested Reading

Ingels, C. A., R. L. Bugg, G. T. McGourty, and L. P. Christensen (eds.). 1998. Cover Cropping in Vineyards: A Grower's Handbook. University of California Division of Agriculture and Natural Resources Publication 3338.

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References

Aljibury, F. K., and L. P. Christensen. 1972. "Water Penetration of Vineyard Soils as Modified by Cultural Practices." American Journal of Enology and Viticulture 23: 35-38.

Atucha, A., I. A. Merwin, C. K. Purohit, and M. G. Brown. 2011. "Nitrogen Dynamics and Nutrient Budgets in Four Orchard Groundcover Management Systems." HortScience 46: 1184-1193. https://doi.org/10.21273/HORTSCI.46.8.1184.

Basinger N. T., K. M. Jennings, D. W. Monks, W. E. Mitchem, S. Chaudhari, J. L. Heitman, J. L. Havlin, A. M. Howard, and S. E. Spayd. 2018. "Vegetation-free Strip Width Affects Growth, Berry Composition, and Yield of Cabernet franc in Vigorous Growing Environments." Catalyst 2: 15-23.

Bates, T. R., and T. K. Wolf. 2008. "Nutrient Management." In Wine Grape Production Guide for Eastern North America, edited by T. K Wolf, 141-168. Ithaca, N.Y.: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension. https://hdl.handle.net/1813/67189

Belmonte, S. A., L. Celi, R. J. Stahel, E. Bonifacio, V. Novello, E. Zanini, and K. Steenwerth. 2018. "Effect of Long-term Soil Management on the Mutual Interaction Among Soil Organic Matter, Microbial Activity and Aggregate Stability in a Vineyard." Pedosphere 28: 288-298.

Bergh, J. C. 2012. "Grape Root Borer." In Arthropod Management in Vineyards, edited by N. J. Bostanian, C. Vincent, and R. Isaacs, 383-402. Dordrecht, Netherlands: Springer.

Bokulich, N. A., J. H. Thorngate, P. M. Richardson, and D. A. Mills. 2014. "Microbial Biogeography of Wine Grapes is Conditioned by Cultivar, Vintage, and Climate." Proceedings of the National Academy of Sciences, 111 (1) E139-E148. https://doi.org/10.1073/pnas.1317377110.

Burg, P., V. Mašán, and P. Zemánek. 2017. "Evaluation of Effect of Vegetation Cover on Soil Compaction." Conference paper, 16th International Scientific Conference on Engineering for Rural Development, 1346-1353. Jelgava, Latvia: Latvia University of Agriculture, May 24-26, 2017.

Busey, P. 2003. “Cultural Management of Weeds in Turfgrass: A Review.” Crop Science 43: 1899-1911.

Celette, F., R. Gaudin, and C. Gary. 2008. “Spatial and Temporal Changes to the Water Regime of a Mediterranean Vineyard Due to the Adoption of Cover Cropping.” European Journal of Agronomy 29: 153-162.

Centinari, M., I. Filippetti, T. Bauerle, G. Allegro, G. Valentini, and S. Poni. 2013. “Cover Crop Water Use in Relation to Vineyard Floor Management Practices.” American Journal of Enology and Viticulture 64: 522-526.

Chou, M., J. Vanden Heuvel, T. H. Bell, K. Panke-Buisse, and J. Kao-Kniffen. 2018. “Vineyard Under-vine Floor Management Alters Soil Microbial Composition, While the Fruit Microbiome Shows No Corresponding Shifts.” Scientific Reports 8: 1-9. https://doi.org/10.1038/s41598-018-29346-1.

Cropper, K., G. Munshaw, and M. Barrett. 2017. “Optimum Seasonal Mowing Heights for Smooth Crabgrass Reduction in Tall Fescue Lawns.” HortTechnology 27: 73-77. https://doi.org/10.21273/HORTTECH03588-16.

Dernoeden, P. H., M. J. Carroll, and J. M. Krouse. 1993. “Weed Management and Tall Fescue Quality as Influenced by Mowing, Nitrogen, and Herbicides.” Crop Science 33: 1055– 1061.

Doran, J. W., M. Sarrantonio, and M. A. Liebig. 1996. “Soil Health and Sustainability.” In Advances in Agronomy, edited by D. L. Sparks, 1-54. San Diego, California: Academic Press.

Ferrero, A., B. Usowicz, and J. Lipiec. 2005. “Effects of Tractor Traffic on Spatial Variability of Soil Strength and Water Content in Grass Covered and Cultivated Sloping Vineyard.” Soil and Tillage Research 82: 127-138.

Giese, G., C. Velasco-Cruz, L. Roberts, J. Heitman, and T. K. Wolf. 2014. “Complete Vineyard Floor Cover Crops Favorably Limit Grapevine Vegetative Growth.” Scientia Horticulturae 170: 256–266.

Gilbert, J. A., D. van der Lelie, and I. Zarraonaindia. 2014. “Microbial Terroir for Wine Grapes.” Proceedings of the National Academy of Sciences 111: 5-6. https://doi.org/10.1073/pnas.1320471110.

Goatley, M., A. W. Askew, and T. Hardiman. 2019. “2019-20 Virginia Turfgrass Variety Recommendations,” SPES-154. Blacksburg, Virginia, Virginia Cooperative Extension, School of Plant and Environmental Sciences. https://www.pubs.ext.vt.edu/SPES/SPES-154/SPES-154.htmlhttps://www.pubs.ext.vt.edu/SPES/SP.

Guerra, B., and K. Steenwerth. 2012. “Influence of Floor Management Technique on Grapevine Growth, Disease Pressure, and Juice and Wine Composition: A Review.” American Journal of Enology and Viticulture 63: 149-164.

Hatch T. A., C. C. Hickey, and T. K. Wolf. 2011. “Cover Crop, Rootstock, and Root Restriction Regulate Vegetative Growth of Cabernet Sauvignon in a Humid Environment.” American Journal of Enology and Viticulture 62: 298-311. https://doi.org/10.5344/ajev.2011.10001.

Hickey, C., T. Hatch, J. Stallings, and T. K. Wolf. 2016. “Under-trellis Cover Crop and Rootstock Affect Growth, Yield Components, and Fruit Composition of Cabernet Sauvignon.” American Journal of Enology and Viticulture 67: 281-295.

Hostetler, G. L., I. A. Merwin, M. G. Brown, and O. Padilla-Zakour. 2007. “Influence of Undervine Floor Management on Weed Competition, Vine Nutrition, and Yields of Pinot Noir.” American Journal of Enology and Viticulture 58: 421-430.

Jordan, L. M., T. Bjorkman, and J. E. Vanden Heuvel. 2016. “Annual Under-vine Cover Crops Did Not Impact Vine Growth or Fruit Composition of Mature Cool-climate ‘Riesling’ Grapevines.” HortTechnology 26: 36-45. https://doi.org/10.21273/HORTTECH.26.1.36.

Kecskeméti, E., B. Berkelmann-Löhnertz, and A. Reineke. 2016. “Are Epiphytic Microbial Communities in the Carposphere of Ripening Grape Clusters (Vitis vinifera L.) Different Between Conventional, Organic, and Biodynamic Grapes?” PLoS ONE 11 (8): e0160852. https://doi.org/10.1371/journal.pone.0160852.

Klodd, A., D. Eissenstat, T. K. Wolf, and M. Centinari. 2016. “Coping with Cover Crop Competition in Mature Grapevines.” Plant and Soil 400: 391-402.

Lanyon, D. M., A. Cass, and D. Hansen. 2004. “The Effect of Soil Properties on Vine Performance.”

Commonwealth Scientific and Industrial Research Organization Land and Water Technical Report No. 34/04. http://www.clw.csiro.au/publications/technical2004/tr34-04.pdf.

Lopez-Pineiro, A., A. Munoz, E. Zamora, and M. Ramirez. 2013. “Influence of the Management Regime and Phenological State of the Vines on the Physicochemical Properties and the Seasonal Fluctuations of the Microorganisms in a Vineyard Soil Under Semi-arid Conditions.” Soil Tillage Research 126: 119-126.

Moss, J. R. 2016. “Evaluation of Nitrogen Management Schemes upon Vine Performance in Cover Cropped Vineyards.” MSc thesis, Virginia Tech, Blacksburg, Virginia. https://vtechworks.lib.vt.edu/handle/10919/77500.

Paoletti, M. G., D. Sommaggio, M. R. Favretto, G. Petruzzelli, B. Pezzarossa, and M. Barbafieri. 1998. “Earthworms as Useful Bioindicators of Agroecosystem Sustainability in Orchards and Vineyards with Different Inputs.” Applied Soil Ecology 10: 137-150.

Pingel, M., A. Reineke, and I. Leyer. 2019. “A 30-years Vineyard Trial: Plant Communities, Soil Microbial Communities and Litter Decomposition Respond More to Soil Treatment than to N Fertilization.” Agriculture, Ecosystems and Environment 272: 114-125.

Pirchio, M., M. Fontanelli, C. Frasconi, L. Martelloni, M. Raffaelli, A. Peruzzi, M. Gaetani, S. Magni, L. Carturegli, M. Volterrani, and N. Grossi. 2018. “Autonomous Mower vs. Rotary Mower: Effects on Turf Quality and Weed Control in Tall Fescue Lawn.” Agronomy 8 (2): 15. https://www.mdpi.com/2073-4395/8/2/15/htm.

Pool, R. M., A.N. Lakso, R. M. Dunst, J. A. Robinson., A. G. Fendinger, and T. J. Johnson. 1995. “Weed Management.” In Organic Grape and Wine Production Symposium, 49-56. Special Report No. 69. Geneva, New York: NY State Agricultural Experiment Station.

Prichard, T. L., P. Verdegaal, L. Schwankl, and R. Smith. 2013. Controlling Offsite Movement of Agricultural Chemical Residues: Winegrapes. University of California Agriculture and Natural Resources Publication 8456. https://anrcatalog.ucanr.edu/pdf/8456.pdf.

Reynolds, A. G., and T. K. Wolf. 2008. “Grapevine Canopy Management.” In Wine Grape Production Guide for Eastern North America, Publication NRAES-145, edited by T. K. Wolf, 124-134. Ithaca, N.Y.: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension.

Rijal, J. P., C. C. Brewster, and J. C. Bergh. 2014. “Effects of Biotic and Abiotic Factors on Grape Root Borer (Lepidoptera:Sesiidae) Infestations in Commercial Vineyards in Virginia.” Environmental Entomology 43: 1198–1208.

Smart, R. E., and M. Robinson 1991. Sunlight into Wine: A Handbook for Winegrape Canopy Management. Adelaide, Australia: Winetitles.

Smith R., L. Bettiga, M. Cahn, K. Baumgartner, L. E. Jackson, and T. Bensen. 2008. “Vineyard Floor Management Affects Soil, Plant Nutrition, and Grape Yield and Quality.” California Agriculture 62: 184–190. https://doi.org/10.3733/ca.v062n04p184.

Stewart, R. D., J. Jian, A. J. Gyawali, W. E. Thomason, B. D. Badgley, M. S. Reiter, and M. S. Strickland. 2018. “What We Talk About When We Talk About Soil Health.” Agricultural and Environmental Letters 3: 180033. https://doi.org/10.2134/ael2018.06.0033.

Tesic, D., M. Keller, and R. J. Hutton. 2007. “Influence of Vineyard Floor Management Practices on Grapevine Vegetative Growth, Yield, and Fruit Composition.” American Journal of Enology and Viticulture 58: 1-11.

Townsend, H. G. 1991. Annual Progress Report: The Effect of Drip Irrigation and Ground Cover on the Grape Root Borer. Grape and Wine Development Program of the Missouri Department of Agriculture. Mountain Grove, Mo.: Southwest Missouri State University.

White, R. E. 2015. Understanding Vineyard Soils, 2nd Edition. New York: Oxford University Press.

Wise, A., and H. Walter-Peterson. 2018. “Expanding the Use of Under-vine Cover Crops in New York Vineyards.” Appellation Cornell Research Focus 2018-2. https://grapesandwine.cals.cornell.edu/sites/grapesandwine.cals.cornell.edu/files/shared/Research%20Focus%202018-2%20May.pdf.

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