Cover Cropping in Vineyards

An introduction to vineyard cover crop management

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History

In California cover crops have been used in vineyards since the early 1900s. They were frequently planted in order to reduce erosion, add nitrogen, and improve soil tilth and water penetration. Winter annual grains or legumes or both were planted in the fall and then mowed and disked in the early spring. Cover cropping was largely abandoned during the late 1940s and early 1950s. During this time, conventional agriculture came to rely more on synthetic fertilizers and less on cover cropping to enhance soil fertility. In the late 1980s and early 1990s, however, cover cropping in vineyards experienced a widespread resurgence as a result of the growing interest in sustainable agriculture. New cover crop species and cultivars, tractor implements, and irrigation methods have allowed many growers to adopt new cover cropping techniques to meet today's needs.

Potential Benefits

The use of cover crops can yield substantial benefits or be the source of unforeseen problems or drawbacks. The choice of which species to sow, as well as the decision whether or not to plant a cover crop, is based in large part on the benefits desired. The nature and extent of the problems associated with cover crops are often a result of unsuitable species or inappropriate management practices. However, the best choice of species and practices can be highly site-dependent and often evolves through trial and error. Because species or practices may have benefits and drawbacks, the best choice is often a compromise. It is important to remember that if a cover crop sown one-year is unsatisfactory, it does not mean that cover crops cannot ever give satisfactory results. Many growers take several years to arrive at suitable cover crop regimes, and some of the disadvantages can be overcome or reduced by simply changing cover crop species or using different cultural practices.

One of the most important reasons for using cover crops has been to reduce soil erosion. Stands of vegetation such as grasses are the most cost-effective means of controlling rill and sheet erosion, two of the most common types of erosion. Grasses reduce erosion by improving water penetration and by slowing the movement of water down slopes.

Cover cropping with legumes can add nitrogen to the soil. Specialized bacteria fix nitrogen from the atmosphere into nodules created by the bacteria on the roots. Most of the nitrogen is transported to the foliage; a portion of the nitrogen is later made available to vine roots after mowing or incorporation. Cover crops can also prevent the leaching of some soil nitrate to groundwater during wet winters by taking up and storing excess soil nitrogen.

The addition of organic matter is a frequently cited benefit of using cover crops. Soil tilth and water penetration are improved by cover crops for several reasons: glue-like substances produced by roots and associated soil organisms bind soil particles together, improving soil structure; foliage intercepts raindrops, preventing them from striking and dispersing soil particles; and roots add organic matter and create pores in the soil as they die. In many soils, however, it can be very difficult to increase soil organic matter content substantially—the benefit of organic matter additions is more closely related to improved soil tilth and increased soil microbial activity. Wheel traction may also be improved with certain cover crops, especially grasses.

Pest management may also be improved by cover cropping. Some weeds may be suppressed but not eliminated by the use of appropriate species and cultural practices. Some cover crop species have been shown to suppress populations of nematodes. Although cover crops may also attract beneficial arthropods such as spiders, which may reduce insect and mite pests, research on the effects of cover cropping on these pests has shown mixed results.

A well-managed cover crop can also be quite aesthetically pleasing. This aspect can be very important for many coastal and foothill wineries. Attractive species include crimson clover, rose clover, vetch, buckwheat, wildflowers, and many grasses. Unfortunately, cover crops that are allowed to reseed turn brown in late spring and can look weedy. Still, the public is becoming increasingly aware of the environmental benefits of cover cropping, and additional educational activities on the part of wineries can explain the changing look of cover-cropped vineyards.

Potential Drawbacks

One of the biggest drawbacks to using cover crops is the demand for water. Growers in California are under increasing pressure to reduce water use, and cover crops often compete with the vines for soil moisture, potentially reducing production and quality. While some species can be managed to use no more water than clean cultivated soil, some extra water is usually required to maintain optimal vine growth and fruit development.

Cover crops can also compete with the vines for nutrients. For example, winter annual grasses require large quantities of nitrogen and, if allowed to mature, can delay nitrogen availability to the vines and reduce vine vigor. However, this characteristic can be used to advantage in

vineyards with excessive vigor. Also, adding legumes to the mix or applying nitrogen fertilizer to the cover crop can offset its demand for nitrogen.

Pest problems may also result from cover cropping. For example, flower thrips may move to vines as cover crops mature in the spring or after they are mowed. Some cover crop species may themselves become weeds if they reseed and grow in an undesirable manner. A notable example is 'Lana" woolypod vetch, which can become a problem weed if it reseeds in the vine row and grows up the grapevines. This problem can be prevented by mowing closely or disking before the vetch reseeds. Another pest problem that may result from cover cropping is the buildup of vertebrate pests, especially pocket gophers and meadow voles. Because these vertebrates can be especially damaging to young vines, growers should consider whether cover cropping in young vineyards is worth the potential risk. Gophers are particularly attracted to perennial clovers and berseem clover, and they may build up wherever vegetation of any kind is present. Meadow voles eat bark from the lower trunks of grapevines; their damage increases where plants or residues are present next to trunks. Finally, nematode populations may increase in cover-cropped vineyards, although some species may actually suppress nematodes.

Another concern of most growers is the threat of frost in early spring. Cover crops reduce the amount of solar radiation reaching the soil during daylight hours and can reduce air temperatures on cold, clear nights. This phenomenon occurs because bare ground is better than living foliage at storing and radiating solar heat. The duration of lower temperatures may also be longer in cover-cropped vineyards. However, vineyards with closely mowed cover crops and moist soil may be only slightly colder than soil that is bare, firm, and moist. It may therefore be important to avoid species such as bell beans and peas that cannot be mowed closely during periods of frost hazard, or to disk them in before budbreak. Also, planting cover crops in alternate rows leaves a substantial amount of soil exposed, reducing the hazard of frost. Sprinkler irrigation, often used for frost protection, can partially mitigate the cooling effects of cover crops.

Economics

One of the most important drawbacks for many growers is the increased cost usually associated with cover cropping. There is no question that sowing cover crops costs money and requires extra attention, at least initially. Cover crops such as perennial and reseeding winter annuals are sown only once or every few years. For these cover crops, seed and planting costs incurred in one year can be spread out over many years.

Cover crops can be included in cropping systems for many different reasons, and the potential benefits impact short-term and long-term farm profitability. Unfortunately, virtually all these benefits are difficult if not impossible to measure in dollar terms.

Choosing a Cover Crop and Management System

Criteria that should be considered when choosing cover crop species and a management system for a particular site include:

- ✓ Soil erosion considerations
- ✓ Relative vigor of the vineyard
- ✓ Soil moisture availability
- ✓ Frost hazard
- ✓ Pest management objectives
- ✓ Aesthetics
- ✓ Ease of maintenance
- ✓ Cost of seed and planting

Soil Erosion Considerations

Soil texture, slope, and rainfall all affect the amount of erosion that a vineyard is likely to experience. Sandy soils are the most prone to erosion because they do not aggregate well as they lack clay minerals or other colloids that adhere soil particles to each other.

For areas prone to erosion, winter annual cover crops that reseed themselves without tillage are highly desirable. Mustards, cereals, annual ryegrass, 'Blando' brome, and 'Zorro' fescue are all good choices for erosion control.

Relative Vigor of the Vineyard

Soil type, depth, water-holding capacity, and fertility affect grapevine growth. If the soil is of low fertility, vine growth can be increased by growing legumes and incorporating them at the proper time in order to provide nitrogen. If water penetration is poor, cover crops with fibrous root systems, such as cereals, can be grown to improve the physical structure of the soil. If vines are overly vigorous because they are grown on fertile, deep soils containing excessive moisture, perennial grass cover crops can be used to compete with the grapevines to reduce excessive vegetative growth. If vines are producing optimal growth, select cover crops that grow primarily during the wet season (such as 'Zorro' fescue and subterranean and rose clovers) so that the cover crop will have minimal impact on grapevines during their growing season.

Soil Moisture Availability

If water for overhead irrigation is abundant and available year-round, virtually any cover crop can be grown. If overhead irrigation is not possible or water is limited, it will be necessary to select cover crops that can exist on rainfall alone. Winter annuals that require relatively small amounts of moisture to germinate and grow include cereals, field pea, vetch, and bur medic. If rainfall is seasonally heavy and the vineyards are rarely irrigated due to deep moist soils or high water tables, perennial legumes and grasses such as white clover, sheep fescue, or creeping red fescue, can be good choices. If seasonal rainfall is high and the vines are excessively vigorous, dense sod-forming grasses such as turf-type tall fescue and perennial ryegrass may be used to compete with the vines roots, although vines should be closely monitored to prevent excessive vigor reduction.

Frost Hazard

Frost protection is a critical concern for growers whose vineyards are planted on low-lying areas that are prone to spring and fall frosts. Research has shown that vineyards with bare, firm, moist soils are warmer on cold nights than those with a tall-unmowed cover crop and are less susceptible to frost damage. If sprinkler frost protection is available, little risk is taken by having cover crops in the vineyard. The cover crop should be mowed, however, so that the top of the cover crop canopy and emerging grape shoots have as much distance between them as possible.

Pest Management Objectives

Cover crops can provide several features for beneficial insects, including extrafloral nectaries, habitat for prey, and protection from predators. Grower experiences suggest that even allowing naturalized weed species to grow and mowing them all season long can lessen pest pressures from leafhoppers and spider mites.

Some cover crop species compete intensely with weeds and can dramatically suppress their growth. When properly managed, many of the grasses are extremely competitive, especially annual and perennial ryegrasses.

The impact of cover crops on nematodes is not well understood. Tests conducted on containerized cover crop plants indicate that many cover crop species are also good hosts for nematodes known to parasitize grapevines. Although anecdotal information suggests that nematode damage to vines may be reduced, more research is needed to address this issue. 'Cahaba White' vetch has been shown to suppress nematodes in grapevines, and various mustards have been shown to suppress nematodes in other crops. Unfortunately, knowledge of how to use cover crops as a pest management tool for nematode suppression is limited.

Vertebrate pests may also be influenced by cover crops and their management. Pests such as meadow voles, gophers, rabbits, and moles are attracted to areas planted with cover crops, which can offer these pests shelter from predators. Voles and gophers can do considerable damage to a vineyard if left unmanaged. Low-growing cover crops, mowing, and vegetation-free strips beneath vines can minimize the habitat available for these pests and reduce the damage to vines.

Aesthetics

Because coastal and foothill vineyards often adjoin attractive winemaking facilities, vineyard appearance can be critical to the image that a given winery projects to its customers, wine critics, and other industry people. Since grape growers typically take great pride in how their vineyards look, aesthetics can be an important consideration when choosing a cover crop and a cover crop management system. Many cover crop species look very attractive in bloom, including mustards, phacelia, crimson clover, rose clover, and buckwheat. Tall swards of winter grains, vetch peas or bell beans can also be attractive, especially with vegetation-free strips beneath the vines. These cover crops help create the impression the grower is practicing careful stewardship of the farm landscape.

California native wildflowers are occasionally used in mixes for cover crops and can be very attractive when successfully established. They are normally confined to small areas of high visibility due to the expense of seed and the difficulty of establishment. Good choices include tidy tips, California poppy, various lupines, tansy phacelia, farewell-to-spring, and other annual forbs that grow readily from seed.

Even naturalized weeds can look attractive if occasionally mowed. However, in dry summer areas, no-till vineyards are often not aesthetically pleasing when cover crops are dried up and dormant. When choosing a cover crop and management system, vineyard managers should consider what the vineyard is going to look like throughout the year in order to ensure that the aesthetic standards that are expected are obtainable with the system under consideration.

Ease of Maintenance

For a vineyard cover crop system to be effective, it is extremely important that the management required to grow the cover crop be compatible with the management of the grapevines. For example, growing winter annual cover crops is relatively easy when grapevines are dormant and pruning is the only grape operation to consider. Growing summer annual cover crops can be difficult if irrigation is required, as overhead irrigation tends to

cause bunch rot in many wine grape cultivars, and also increases humidity, which could favor the development of powdery mildew.

Cost of Seed and Planting

The retail cost of cover crop seed varies greatly and is determined by the ease of seed production and the amount of seed produced per acre by seed growers. Cost studies indicate that for an annually-sown cover crop, it costs about $92 per acre to prepare a seedbed, plant, irrigate, chop brush once, mow once before disking, and disk three times through the growing season. By comparison, the cost for maintaining no-till resident vegetation is about $40 per acre for chopping once and mowing three times. The first-year cost of planting and maintaining reseeding annual and perennial cover crops is about $58 per acre; this includes one chopping in the spring. Because many perennial cover crops require more than one mowing, about $9.40 per acre is added for each additional mowing.

Establishing Cover Crops

Cover crop species vary greatly in "seedling vigor," the rate at which they germinate and grow. The lower the seedling vigor, the more difficult it is to establish a cover crop. Adequate seedbed preparation, time of planting, and the use of preplant fertilizers and soil amendments should be carefully considered.

Time of Planting

Germination occurs best when soil temperatures are between 70^0 and 80^0F. The prime time for cover crop seeding in most areas is mid-September to mid-October when soils are warm and rainfall is imminent. Unfortunately, this coincides with grape harvest in many California vineyards, so seeding cover crops may be difficult to schedule. Cover crops can be planted before harvest when the vineyard floor is still dry, then irrigated as soon as the grapes are picked. Seeding after October 15 becomes risky due to cooling soil temperatures, slow germination, and early frost. Generally, grasses germinate well through mid-November, but small-seeded legumes often fail to grow with enough vigor to become established. In cooler areas, cold weather, wet soils, and frost can cause extensive damping-off of seedlings, even if they have successfully germinated. Consequently, the earlier in the fall the cover crop is seeded the greater the likelihood of establishing a good stand.

Seedbed Preparation

Regardless of the cover crop species selected, soil preparation is relatively standard. Preparing a well-granulated, soft, friable, and moist seedbed generally works well for virtually any cover crop species. Many growers begin by shallow ripping at a depth of 10 to 12 inches the area between the rows using shanks and narrow sweeps spaced one foot apart mounted on toolbars behind the tractor. Spring-tooth harrows are also used for this purpose. The best results are obtained when the soil profile is quite dry, because ripping tends to shatter and loosen the soil, creating large voids between soil aggregates. The soil is then moistened, either by overhead irrigation or rainfall. The vineyard is then disked twice, leveled with floats or harrows, and seeded. In areas with loose or sandy soils, one or two diskings plus harrowing or rototilling are common procedures.

Seeding

Cover crop seed can be planted either with a drill or a broadcast seeder. Drills place the seed with much more precision than broadcast seeders. Quality drills can be calibrated to apply seed at precise rates and depths. For expensive or small seed, drills are often the best approach.

Irrigation after seeding helps ensure successful germination and establishment. If the vineyard has sprinkler irrigation, water can be applied to germinate the cover crop seed, or seed can be planted just before a postharvest irrigation. Cover crops germinate well with about 1.5 inches of precipitation or 12 to 15 hours of irrigation with most frost protection sprinkler systems. Once germinated, many cover crop species can survive drought surprisingly well; they appear wilted in the summer heat but begin growing quickly when fall rains arrive.

Fertilizing

The nutritional needs of cover crops are very different from grapevines. Cover crops should be fertilized and soil amendments should be added on the basis of soil test results.

Mowing and Sward Management

Timely mowing can improve and enhance cover crop establishment and performance. Mowing removes taller weeds that can shade the cover crop; this is critical for the growth of some species. Mowing also encourages tillering (the growth of shoots from the crown of the plant), spreading, and flowering. Many cover crop species are also pasture forages, which typically respond to grazing by increasing the number of shoots from the crown to quickly regrow and crowd out competition. The first mowing should be no lower than 4 to 6 inches tall in order not to injure desired plants. This mowing can also help to shred vine prunings. Perennial grasses should be mowed early in the growing season to prevent the seed

set of tall weeds, chop the prunings into the cover crop, and reduce the hazard of frost. Fertilizing after mowing stimulates the grasses and helps maintain a dense, healthy sward that resists invasion by weeds. Perennial grasses should be allowed to flower in late spring. Before flowering, the grasses typically go through a cycle of rapid growth followed by a period in which carbohydrates are accumulated in the root system. These reserves allow them to withstand summer drought better and recover during fall rains or irrigation. California native grasses are especially sensitive to decline if they are not allowed to grow, flower, and remain green for several weeks after flowering in late spring. Native bunchgrasses should be mowed no lower than 6 to 8 inches. Mowing too low can kill these plants.

In areas prone to frost, cover crops should be mowed close to the ground to minimize frost hazards and reduce the migration of ice-nucleating bacteria from the cover crops onto grape foliage. The closer the cover crop canopy is to the grapevines and the more surface area that the cover crop has, the more likely it is that ice-nucleating bacteria will be present in large numbers and will migrate to the emerging grapevine shoots, increasing the risk of damage if freezing temperatures occur.

Cover Crop Systems and Management

Monocultures versus Mixes

Monocultures of sown cover crops are often used in vineyards. Monocultures may be preferred where the species has a history of proven performance, enabling the grower to limit the seed purchase and culture to a single well-adapted species. The use of monocultures is a common practice with several species, such as cereals, 'Blando' brome, and bur medic. Self-reseeding stands of bur medic have persisted for over 40 years.

Single-species plantings should usually be rotated to reduce the potential for buildup of insects, pathogens, or weeds associated with that species. For example, soilborne diseases may reduce vetch stands if sown repeatedly. Cereal diseases often increase when the same crop or cultivar is used year after year. In some years, Egyptian alfalfa weevil can be a serious pest of bur medic. Local environmental variations, such as sandy or clay soils with differing soil nutrient availability or drainage characteristics, may also limit growth of a single species. Providing different species in a mix may enable one species to thrive in areas where another might be weak, increasing the chances for a healthy stand throughout the vineyard. Vigorous polyculture stands may also reduce weeds that would otherwise fill the voids in the stand and may aid in pest management. However, the effects of polycultures versus monocultures on arthropod pests have not been tested in California vineyards.

Legume-grass mixtures complement each other in their soil-improving functions. Although both plant types take up soil nitrogen, grasses are usually much more efficient at doing so. As a result, legumes derive more nitrogen from nitrogen fixation than from soil uptake when they are grown with grasses. Typically, though not always, such mixes result in less total nitrogen fixed than would be the case in pure legume stands, simply because less legume biomass is produced. Cereals such as oat and barley also provide structural support for the trailing vetches and peas. The fragile stems of 'Blando' brome and 'Zorro' fescue do not support vetch and are seldom used in mixes with vetches. However, these two species are compatible with bur medic and annual clovers and with low densities of vetch. Dozens of grass-legume blends and seeding rates have been used, including annual-perennial combinations.

California native perennial grasses grown in vineyard middles are typically used in mixtures, with plant species or accessions of like statures grouped together. Because some species are short-lived, it is important to allow them to reseed in the vineyard. Although individual native grass species have been evaluated, mixes have received limited attention from researchers, and there is currently no published data on their use in vineyards. These species are increasingly being sown in vineyards mainly from the northern San Joaquin Valley northward. Seedling growth of many species is relatively slow, so native grasses are susceptible to weed competition during establishment. The lower-growing mixes may contain pine bluegrass, Idaho fescue, 'Molate' fescue, or a prostrate form of California barley. These grasses mature relatively early and are summer-dormant in hot, dry climates, although 'Molate' fescue will persist with irrigation. This is thought to reduce competition for water with the vines. Taller species include meadow barley, blue wildrye, California brome, California medic, and purple needlegrass. Due to greater seedling vigor, meadow barley, blue wildrye, and California brome are more easily established on sandy, droughty soils than are the low-growing species mentioned earlier. We have seen no examples of legumes included in mixtures of California native grasses, but annual clovers and bur medic may be appropriate. Use of California native grasses as vineyard cover crops is on the rise, making it increasingly important to conduct formal experiments on the issues mentioned above.

No-Till versus Tilled Vineyards

Whether to cultivate is perhaps the first and most im-

portant choice to make in choosing a cover crop strategy for a vineyard. Preventing soil erosion and saving energy are two obvious benefits to no-till vineyard floor management. Another benefit is firm footing in wet weather, which can make a tremendous difference, especially if unseasonable rains occur during harvest. Growers also report fewer insect and mite pest problems in no-till vineyards. Drawbacks include a "weedy" appearance and possible competition between the cover crops and vines. Dryland vineyards on shallow soils are not good candidates for no-till cover crop systems due to excessive competition.

On deep, fertile soils where excess vigor is a problem, competitive cover crops can reduce vine growth, compete with weeds, and provide beneficial arthropod habitat. Some perennial species can survive well from season to season without summer irrigation, allowing drip systems to irrigate the vines and not the cover crops. However, overhead irrigation or favorable rainfall is often critical in establishing these cover crops. Some California native bunchgrass species are particularly well suited for drip irrigation.

Annuals versus Perennials for No-Till Vineyards

Cover crops used in no-till vineyards are planted once and regrow year after year. They can be self-reseeding annuals that produce a new crop of seed every year or perennials that do not grow during the dry summer months but resume growing with the fall rains.

A major disadvantage of perennials is that they can compete excessively with the vines. Some are attractive to gophers, voles, and other rodents that can damage vines. When properly chosen and adapted, however, perennials can be among the best choices due to their ease of maintenance, especially in higher rainfall areas or in vineyards with deep soils. For example, a dense stand of hard and sheep fescues grow to only 3 inches tall, needs to be mowed only once annually, and can compete with both summer and winter weeds.

Although winter annual species that reseed themselves regularly are generally not as competitive with vines as are perennials, fall weather may not favor their germination.

Types of Cover Crop Systems and Soil Fertility Implications

Annual Cover Crops

Green manures. Green manure cover crops are typically planted in vineyards from September to early December. They consist of winter annual grasses, legumes, or forbs. If the green manure is used to add nitrogen, legumes are used alone or in combination with nonlegumes, usually cereals.

The cover crop germinates within several weeks with adequate soil moisture and proper soil temperatures. Most species do not develop substantial biomass until daylength and temperatures increase in late February or early March. The cover crop is usually incorporated into the soil while still green and succulent, usually from late March to early May. At this time, the carbon to nitrogen (C/N) ratio is low so there is rapid decomposition and a net release of nitrogen. The cover crop is often disked or mowed in late March if there is a danger of frost. If reseeding is desired, incorporation may be delayed until the cover crop sets mature seed.

Perennial Cover Crops

Permanent perennial cover crops that grow during the summer usually compete strongly with vines for soil nutrients and water. Research indicates that perennial ryegrass and other sod-type cover crops may significantly reduce vine nutrient status. Sod-type cover crops are unsuitable in nitrogen-limited vineyards. Although these cover crops may be useful in reducing excessive vine vigor, their impact may take several years.

Grapevine Nutrition

Grapevines have fewer mineral deficiency problems and fertilizer demands than many other horticultural crops and is adaptable to a wide range of soil types and soil fertility. In general, only four nutrients, nitrogen (N), potassium (K), zinc (Zn), and boron (B) are widely supplemented in vineyards. Local areas may require additional phosphorus (P), iron (Fe), magnesium (Mg), and manganese (Mn).

Nitrogen

The nutrient that is most frequently required in vineyards is nitrogen, which can be supplied through commercial fertilizers, compost, manure, or cover crops. Cover crops can be grown to supply nitrogen to the vines and improve the soil structure and the movement of nitrogen through the soil root zone. Conversely, they can be used to take up surplus nitrogen and water from soils, which may reduce excessive vine vigor and also reduce nitrate leaching into groundwater. Decomposition and nitrogen mineralization of cover crop residues may provide a more gradual release and uptake of nitrogen to vines than the use of commercial fertilizers alone. In order to understand the role of cover crops in nitrogen nutrition, it is important to understand nitrogen dynamics in the soil, in the vineyard, in cover crop species, and in the vines.

The greatest need for nitrogen is in the spring during

rapid shoot growth. Between bud break and bloom, vines rely heavily on nitrogen stored through the dormant season in the trunk and roots. From bloom to veraison (the beginning of fruit ripening) vines depend mostly on root uptake of nitrogen. This is when nitrogen demands are greatest, whether supplied through cover crop decomposition or fertilizer. Nitrogen supplied during fruit ripening tends to accumulate in the fruit and is removed with the grape crop.

Although grapes are grown on a wide range of soils and under a wide range of conditions, generally 30 to 50 pounds per acre of supplemental nitrogen is adequate for most vineyards. This amount of nitrogen can easily be supplied by many different legume cover crop systems.

Excessively vigorous vines have increased canopy growth, resulting in shading of crop and fruiting buds; the effect is a decrease in fruit quality and bud fruitfulness. Dense canopies provide favorable microclimates for diseases such as bunch rot and powdery mildew and can impede spray coverage of fruit and foliage with fungicides.

Groundwater contamination by nitrate is widespread in California. It is critical to manage nitrogen sources so that excess nitrate is not present in soils, especially during periods of high rainfall or water saturation. Cover crops may be useful in reducing nitrate leaching in soils. Cover crop residues that are incorporated in the late spring decompose and are mineralized within a few weeks, providing soil nitrogen at a time of rapid vine uptake. Cover crops that grow rapidly in the winter, such as cereal rye, may use soil nitrogen that might normally be leached past the inactive grapevine roots.

Nitrogen fixation by legumes. The main source of environmental nitrogen is the atmosphere, which is approximately 78 percent nitrogen gas. However, this gaseous form of nitrogen is unusable by most plants. Nitrogen fixation is the process of changing gaseous nitrogen into nitrate or ammonium forms usable by plants. Legumes are capable of fixing nitrogen through a symbiotic association with bacteria from the genus *Rhizobium*. Because rhizobia occur in low levels naturally in most soils, the bacteria must be present on legume seed at planting. The bacteria gain entry into developing roots through root hairs. The plant responds with rapid cell division, creating nodules on the root.

Nitrogen production and availability. Research indicates that legume cover crops can fix from 50 to 200 pounds per planted acre of nitrogen. The amount of fixation depends on the cover crop species, soil pH, soil temperature, soil moisture, soil nitrogen status, and inoculation.

Cover Crop Fertilization

Fertilization of Legumes

Generally, supplemental phosphorus fertilizer is the only nutrient required for legumes in vineyard cover crop systems. Phosphorous can be applied by broadcasting single-superphosphate on the soil surface during seedbed preparation or banding at planting with a seed drill. Soil tests for phosphate phosphorous are a good indicator for fertilizer need. Other fertilization is not necessary. Nitrogen fertilizer should be avoided since it reduces nitrogen fixation. Sulfur is also necessary for good legume growth, but it is usually not limiting in vineyard soils.

Fertilization of Grasses

Nitrogen fertilizer is usually required for grass cover crops. A common practice is to apply 25 to 50 pounds per acre of nitrogen at planting. Many growers will also apply 25 pounds at the time of incorporation to hasten breakdown and mineralization. If cover crops are used to reduce vine vigor and nitrogen status, or if soil or water nitrogen content is excessive, nitrogen fertilizer use should be reduced or eliminated.

Soil Erosion

The erosion of soil by water should be an important consideration by anyone growing grapes on sloping land. Soil erosion is detrimental to the vines due to the loss of nutrients and rooting depth, and gully erosion can be costly to repair. Also, the washed-away sediment pollutes streams, rivers, and estuaries and increases the flooding potential downstream. Local governments in several areas of California have implemented strict erosion control programs for grape growers, especially as wooded hillsides have increasingly been converted to vineyards.

How Cover Crops Reduce Soil Erosion

Vegetative cover plays a vital role in controlling erosion as it:

- ✓ Shields the soil surface from the impact of falling raindrops.
- ✓ Holds soil particles in place.
- ✓ Prevents crust formation.
- ✓ Improves the soil's capacity to absorb water.
- ✓ Slows the velocity of runoff.
- ✓ Removes subsurface water between storms through transpiration.

Growers should strongly consider maintaining and enhancing existing vegetative cover on areas of high ero-

sion potential, such as erodible soils, steep slopes, bench terrace slopes, drainageways, stream banks, buffer strips, and existing or potential slips. The use of cover crops, particularly grasses, is a cost-effective means of controlling sheet and rill erosion where water flows will not exceed 5 feet per second. Flows greater than this rate require engineered structures such as diversions, subsurface drainage systems, lined waterways, and bench terraces. Vegetation combined with structural measures provide optimal soil protection where the erosion potential is highest.

Cover Crop Selection for Erosion Control

Among the best cover crops for erosion control are perennial sods, which have dense foliage and root systems. Reseeding winter annual grasses, such as 'Blando' brome, also greatly enhance erosion control, but do so less than perennial sod because annual grasses begin each fall with small root systems. Reseeding winter annual legumes are often not as effective as grasses because the root systems of grasses are usually more dense. Although winter annuals that are not self-reseeding can reduce erosion once established, the disking required to plant them can cause serious erosion if heavy fall rains occur. It is also important to consider other factors when selecting a cover crop for erosion control, such as seed cost, seedling vigor, reseeding ability, water needs, and the cover crop's effects on vines, fruit yield, and quality. For maximum erosion control, the best cover would be a vigorous permanent sod that forms a dense root system, such as perennial ryegrass, tall fescue, or strawberry clover. Winter annual grasses effectively reduce erosion after they become established, and they reseed and die as vine growth begins in early spring. But, the soil may be prone to erosion during heavy fall rains before young seedlings develop sufficient root structure.

Winter Annual Cover Crops

Grasses. Reseeding winter annual grasses, particularly 'Zorro' fescue and 'Blando' brome, are frequently used on hillside vineyards. They are generally well suited for erosion control because of their dense growth habit and fibrous root system. They are seeded in the fall and germinate and establish rapidly after fall rains, protecting the soil from erosion and anchoring soil particles in place. When properly managed, these species provide a self-sustaining cover crop that requires no tillage beyond the first year, although some years if weeds reinvade.

Other winter annual grasses, such as cereal rye, barley, and oat, provide a protective cover crop for one year but generally do not produce sufficient viable seed for reestablishment in subsequent years. These species are sometimes used in new vineyards where a cover crop is desired for erosion control in the fall and winter, but where further soil disturbance is required for planting, trellising, irrigation, or other activities that will occur the following spring. Disking to smooth the surface will be warranted, after which a perennial or reseeding winter annual cover crop is planted.

Legumes. Legumes are often included in cover crop mixes to add nitrogen, provide color, or increase diversity. Established legume plants shield the soil from raindrop impact in late winter and spring. However, young legumes generally provide less protection against soil movement than young grasses because legumes have less fibrous roots. As with grasses, some legumes reseed themselves, such as rose clover and subterranean clover. Subclover forms a dense network of low growing stems by late winter that helps reduce soil erosion. These legumes may be added to a seed mixture with reseeding grasses. Other legumes such as bell beans and field pea grow only for one season and should be planted when specific benefits are desired, such as adding more nitrogen to the soil.

Perennial Cover Crops

Most perennial grasses do not develop as rapidly as annuals but, when established, have deeper roots and provide excellent erosion control. Perennial clovers, although taprooted, also reduce erosion because of their invasive growth and their tendency to produce roots at each node. Due to the longer period needed during establishment, perennial cover crops may need to be mixed with a small amount of annual grass seed to provide adequate cover during the first year. Growers should exercise caution when using perennials because they may devigorate vines excessively.

Growers should strongly consider maintaining and enhancing existing vegetative cover on areas of high erosion potential, such as erodible soils, steep slopes, bench terrace slopes, drainage-ways, stream banks, buffer strips, and existing or potential slips. Figure 1 demonstrates methods for controlling drainage and erosion in a vineyard.

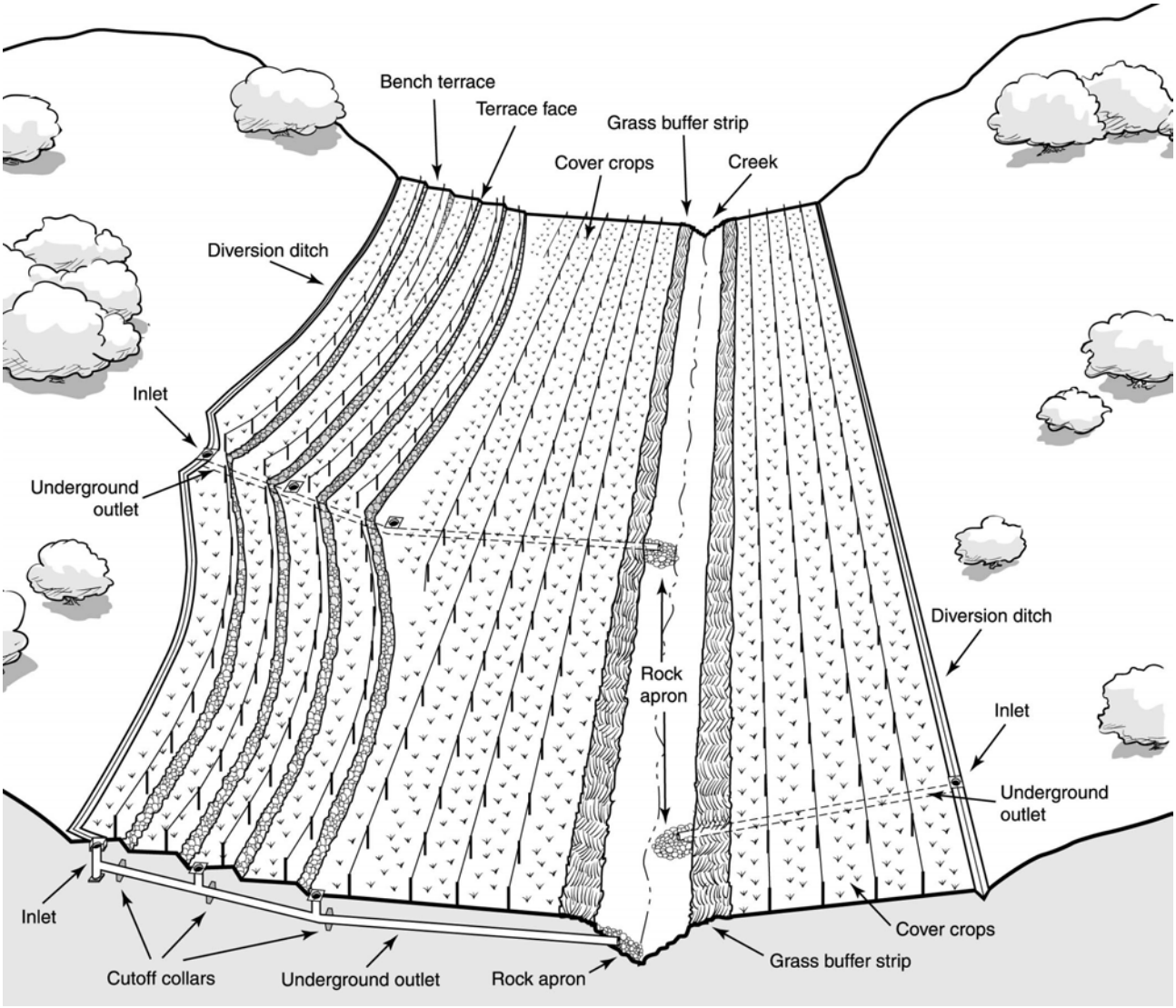

Figure 1. Controlling drainage in a vineyard reduces erosion. Diversion ditches catch water that would otherwise flow through the vineyard. The water from the diversion ditches flows to inlets and through underground outlets (pipes) and is directed to a creek. Additional inlets along the hillside help divert water from the bench terraces. Rock aprons provide armoring where the pipes drain to the creek. Grass buffer strips along both sides of the creek provide a filter for sediment. Cover crops are planted in the drive rows. (From Cover Cropping in Vineyards – A Grower's Handbook Chapter 6 "Soil Erosion". 1998. University of California DANR Publication 3338).

Effects of Cover Crop Management on Water Use

Annual Cover Crop

In general, winter annual cover crops use less water than those that grow during summer months or those that grow year-round. During the winter and early spring, water demand is lower and growth occurs during a time when rainfall is likely. A vetch cover crop grown in Davis, California, from November through early March produced nearly 6,000 pounds per acre of above ground dry matter. Soil water contribution between November and March measured less than 0.5 inch in a below-normal rainfall year. The water required to produce the 6,000 pounds per acre of dry matter was mostly supplied by winter rainfall. Using the relationship of 300 pounds water to produce one pound of dry matter, a 6,000 pound dry matter cover crop would use approximately 8 inches or 217,000 gallons per acre of water. If water were available from rainfall or irrigation and the crop were growing in the highest water-demand months of March and April; water consumption would have been substantially higher.

Perennial Cover Crops

Perennial cover crops, which live year round, offer the advantage of not having to be reseeded each year. However, the stand must be maintained throughout the season, and at least small amounts of water are required to maintain the stand from late spring through fall. Resident vegetation, usually consisting of winter annuals followed by summer annuals, also fits in this category since it can grow and use water for the entire season. Perennial grasses that are less active during the summer offer some hope to less competitive water use.

Irrigation Frequency

Most cover crops are more shallow rooted than grapevines. After an irrigation, they compete directly with the vines for available moisture. As the moisture is depleted in the shallow area of the root zone, the vines acquire moisture at lower depths, which are generally inaccessible to the cover crop. Frequent irrigation can allow the cover crop to compete with the vines, leading to increased water use.

Fertility

Wine grape vineyards are fertilized with relatively low amounts of nitrogen. Typically broadcast applications are from 30 to 50 pounds per acre of nitrogen per year. When injected into microirrigation systems, the rates are reduced to 10 to 20 pounds per acre per year. Broadcast fertilizer applications are usually made in the spring, leaving little nitrogen available at a time when the annual cover crop germinates or the perennial crop begins to grow after fall rains. To increase cover crop biomass production, it is common to fertilize in the fall while temperatures are still warm. Research in wine grape vineyards has shown a 1,000 percent biomass production increase by applying 30 pounds per acre of nitrogen at germination of resident vegetation. Biomass collection occurred on March 31. Additionally, if 2 inches of sprinkled water was applied in early October prior to rainfall, an additional 100 percent increase in biomass was produced totaling 5000 pounds per acre for the fertilizer plus water treatment.

Weed Management

Weed Suppression between Vine Rows

Any planted cover crop can interfere with the growth of resident plants. Cover crops do not target a single weed or family of weeds for reduction, but instead reduce the overall density of plant species in the vineyard. A dense cover crop population reduces weeds more than does a sparse stand or open-type growth habit. Below are three vineyard floor management strategies that use cover crops to suppress winter annual weeds.

Winter cereals. In the fall, plant and fertilize tall-growing cover crops such as cereal grains (oat, cereal rye, barley, wheat, and triticale) that grow faster than the weeds.

Mixtures of cereals and legumes. Plant a mixture of tall winter cereal and a vetch or peas available to fill in the open areas to further reduce the amount of light available to the soil and inhibit growth of winter annuals. Maximum effects are achieved by planting early in the fall or in the late summer into a prepared seedbed followed by an irrigation to increase germination, early growth, and soil cover.

Perennials. Plant a perennial cover crop such as strawberry clover, white clover, birdsfoot trefoil, 'Berber' orchardgrass, or perennial ryegrass and plan to mow frequently, which reduces both winter and summer annual weed populations. Additionally, these cover crop plants are generally very competitive and will reduce vine growth in shallow or weaker soils, especially if the vines are young and the cover is allowed to grow into the vine row.

Weed Suppression in the Vine Rows

Weeds in the vine row can be suppressed by preventing the light required for seed germination from reaching the soil directly under and between the vines. This can be done by using live plant material or by applying various types of mulches.

Live plant material. Although not recommended as a general rule, cover crops can be planted in the vine row to suppress weeds. When considering this control method, carefully review the cover crops' stature, aggressiveness, and competitive ability before planting in the vine row. There is a fine line between planting a cover crop for weed control and reducing the growth and yield of the grapevines. Although dense plant growth in the vine row may lend itself to weed control, it will also compete with the vines.

Dry organic mulch. Although a dry, dead mulch produced from organic material can prevent germination of weed seed, it does not kill existing weeds very well. It can, however, reduce moisture and temperature fluctuations near the soil surface, which may result in better vine growth.

A dry mulch can be made from a vigorous cover crop grown between the vine rows by chopping it and mowing the clippings into the vine rows. Or, mulch can be purchased from an outside source and evenly spread under the vines. Mulching is especially effective at reducing weeds in the vine row if the weeds are controlled prior to mulch application using residual or preemergence herbicides or recent in-row cultivation. This assures a weed-free surface for the initial mulch application.

Overview of Soil Organisms

Microorganisms

Although invisible to the naked eye, soil microorganisms are an important part of the below ground community in farm soils, and are a potentially valuable asset to the grower. Their value lies in the roles they play in the decomposition of organic matter, improvement of soil structure, cycling of nutrients, and as a living reservoir of nutrients. The microbial community is most beneficial to the grower when it is diverse, abundant, and active. Microbial populations play active and passive roles in soil fertility.

Arthropods

The role of cover crops in vineyard IPM is not well understood, and the use of cover crops to help manage vineyard pests is a controversial practice. Similar to studies in orchards, studies in vineyards have not shown that the addition of ground covers consistently leads to lower pest densities. This is due, in part, to the wide variety of cover crops and cover crop management practices used, to differences in the arthropod community among vineyards, and to annual fluctuations in pest and natural enemy populations.

Vineyard Natural Enemies

In theory, natural enemy populations increase in more diverse ecosystems because cover crops or other floor vegetation provide natural enemies with additional habitat, food, or both. Habitat enhancement is the increased availability of shelter because of a broader range of environmental conditions and oviposition and overwintering sites. The availability of alternate food is important during periods when the most common prey are not present. Alternate food can be other prey species or food for adult predators or parasitoids. There have been few attempts to document how these theories apply to grape pests and their natural enemies. Of those that have been conducted, most have focused on leafhoppers. Cover cropping by itself cannot be relied on for leafhopper control from one year to the next. Furthermore, the mechanisms involved are not clear, but the evidence points to lower leafhopper numbers because of reductions in vine vigor by the cover crop, and may also include occasional enhancement of spider populations.

It is popularly believed that biological controls in vineyards are enhanced because of the increased abundance and diversity of generalist predators on the cover crop. In our replicated studies we did not find a pattern of increased generalist predator abundance on the vines that corresponded to the presence of cover crops. Most often, cover cropping did not affect total numbers of spiders (the most common vineyard predator of leafhoppers) on vines. Cover cropping did, however, alter spider species composition.

Although in theory, cover crops can provide alternate hosts or food sources for parasitoids of moth and mealybugs pests, no formal studies on this have been conducted. Few formal studies have been conducted on cover crops and spider mites, but it is generally accepted that the beneficial effect of cover crops on soil condition, water infiltration, and dust removal can help boost vine tolerance to spider mite outbreak.

The vineyard ecosystem is complex and many factors combine to influence both pest and natural enemy densities. Because natural pest control is an interwoven assemblage of migrating and resident pests and natural enemies, vineyard cultural practices, vineyard age, soil characteristics, and regional characteristics, it is difficult to predict how cover cropping will affect pest or natural enemy numbers. The annual fluctuation in leafhopper and spider populations, which can be dramatic, often rendered insignificant the effect of the cover crop in terms of applied pest management. Overall, our studies show that cover crops and other floor vegetation can play a role in vineyard arthropod pest management, but they cannot be expected to provide complete control of any of the pests discussed. Properly managed cover crops should be con-

sidered as but one part of an overall IPM program.

Nematodes

Nematodes are wormlike unsegmented invertebrate animals found in marine, freshwater, and terrestrial habitats. Depending on the species, nematodes may feed on a variety of organisms, including plants, other nematodes and their eggs, fungi, protozoa, bacteria, tardigrades, enchytraeids, and insect larvae.

Nematode Management

Before considering possible cover crops that might be used to manage nematodes in vineyards, it is important to discuss the fact that although a cover crop may be used to reduce numbers of a particular nematode, the cover may act as a host for other nematodes, pathogens, or pests. Cover crops are not, generally, biological nematicides. Effective nematode management using cover crops should be based on the integrated application of several control tactics. Manipulating the soil environment to reduce pest densities and increase plant tolerance requires recognition of the soil food web and the ecological relationship among host plants, their parasites, and other soil fauna.

Vertebrate Pests

Several vertebrate pest species currently cause economically significant damage in vineyards. These include pocket gophers, meadow voles, ground squirrels, rabbits, and deer. Pocket gophers are probably the most wide spread and significant pests, with economic losses resulting from their feeding on the roots of vines, their gnawing on irrigation lines, their burrows diverting irrigation water and causing erosion, and their mounds impeding other management practices. Meadow voles, ground squirrels, rabbits, and deer may also cause significant damage by feeding on the vines.

Current knowledge indicates that cover cropping in vineyards increases most mammal pest problems by providing additional food and cover resources that favor higher population levels. However, the magnitude on these populations may vary depending on the location of the vineyard, history of the pests in the area and the type of cover crop selected and its management. The potential effect of a cover crop on vertebrate pest populations should be considered prior to planting. In many cases, the benefits of a cover crop may more than outweigh the expense of the additional vertebrate control required or the additional damage that may occur in spite of control efforts. Further, the anticipated increase in vertebrate pest problems may, in part, be offset by the species or management of the cover crop. In some situations, such as in newly planted vineyards, the only option to avoid costly damage by mammal pests may be to delay planting a cover crop for one or two years.

Conclusion

The result of all this research and experience is that a vineyard manager has a tremendous "plant palette" from which to choose when selecting cover crop species. Just as there is no universal wine grape cultivar, rootstock, or trellis system, there is no universal cover crop for all vineyards. The choice of cover crop systems depends largely on the benefits one hopes to attain from the cover crop. Cover crops should be chosen on their suitability for a production system and the style of farming that the manager wishes to use. The cover crop's physical stature, water use, competition with vines, and ease of establishment and maintenance are only a few reasons why they should be chosen carefully. There are numerous benefits to planting cover crops, and growers are encouraged to experiment on a small scale first to determine whether a particular species or management system is appropriate.

Bibliography

Adapted from Cover Cropping in Vineyards – A Grower's Handbook 1998. University of California Cooperative Extension DANR Publication 3338). Complete references available upon request.

Table 1. Seeding information for vineyard cover crops.

Scientific name	**Common name**	**Suggested cultivars**	**Relative seedling vigor**	**Maximum height (in)**	**Time of flowering**	**Time of maturity**	**Seeding rate(lb/ seeded acre)**	**Price ($/lb)**
Winter annuals for tilled vineyards								
Legumes								
Pisum sativum	field pea	'Australian Winter,' 'Magnus,' 'Miranda'	mod. to high	18-30	Mar-May	May-Jun	70-100	0.40
Trifolium alexandrinum	berseem clover	'Multicut,' 'Joe Burton'	mod.	18-30	May-Jun	Jun-July	15-20	1.65
Vicia benghalensis	purple vetch	-	high	18-24	Apr-May	May-Jun	40-60	0.75
Vicia faba	bell (fava) bean	-	high	36-84	Mar-May	May-Jun	100-150	0.32
Vicia sativa	common vetch	-	mod.	18-24	Apr-May	May-Jun	40-80	0.65
Vicia sativa x Vicia cordata	'Cahaba White' vetch	-	mod.	18-24	Apr-May	May-Jun	50-80	0.94
Vicia villosa	hairy vetch	-	high	18-24	Apr-May	May-Jun	30-50	0.70
Vicia villosa ssp. dasycarpa	woollypod vetch	'Lana'	high	18-24	Mar-May	Apr-Jun	40-60	0.90
Grasses								
Avena sativa	oat	'California Red,' 'Cayuse,' Montezuma,' 'Ogle,' 'Swan'	high	24-60	Apr-May	May-Jun	100-120	0.23
Hordeum vulgare	barley	'UC 476,' 'UC 603'	high	24-36	Apr-May	May-Jun	80-100	0.18
Lolium multiflorum	annual ryegrass	'Common,' 'Gulf,' 'Wimmera 62'	high	36-48	Apr-May	Jun-Aug	20-35	0.50
Secale cereale cv. 'Merced'	cereal rye	'Merced'	high	36-72	Feb-Apr	Apr-May	60-120	0.32
Triticum aestivum	wheat	'Anza'	high	24-40	Apr-May	May-Jun	100-120	0.18
X Triticosecale	triticale	'Juan'	high	24-60	Apr-May	May-Jun	100-120	0.28
Forbs								
Brassica spp.	brassicas	-	high	24-60	Mar-May	Apr-Jun	5-12	1.00-2.00
Phacelia tanacetifolia	tansy phacelia	'Phaci'	high	12-36	Mar-May	May-Jun	10-15	2.00
Winter annuals for no-till vineyards								
Legumes								
Medicago polymorpha	bur medic (burclover)	'Santiago,' 'Circle Valley,' 'Serena'	mod.	6-15	Feb-Apr	Apr-May	15-20	1.80
Trifolium hirtum	rose clover	'Hykon,' 'Kondinin,' 'Overton,' 'Wilton'	mod.	8-15	Mar-Apr	May-Jun	15-20	2.20
Trifolium incarnatum	crimson clover	'Dixie,' 'Flame'	mod.	12-20	Apr-May	May-Jun	15-25	1.70
Trifolium subterraneum	subterranean clover	'Clare,' 'Koala,' 'Karridale,' 'Mt. Barker,' 'Nungarin,' 'Trikkala'	mod.	6-15	Mar-May	Apr-Jun	20-25	1.80

Grasses								
Bromus hordeaceus ssp. molli-	(‘Blando’	-	high	12-30	Mar-Apr	Apr-May	10-15	2.75

Scientific name	**Common name**	**Suggested cultivars**	**Relative seedling vigor**	**Maximum height (in)**	**Time of flowering**	**Time of maturity**	**Seeding rate(lb/ seeded acre)**	**Price ($/lb)**
Perennials for no-till vineyards								
Legumes								
Lotus corniculatus	birdsfoot trefoil	‘Empire,’ ‘Viking’	very low	12-24	Jun-Sep	Jul-Oct	5-12	3.50
Trifolium fragiferum	strawberry clover	‘Salina’	low	8-12	Jun-Jul	Jul-Aug	10-15	3.75
Trifolium repens	white clover	‘New Zealand,’ ‘Dutch White,’ ‘Ladino,’ ‘Huia’	low	8-12	May-Jul	Jul-Aug	5-12	2.75
Grasses								
Bromus carinatus	California Brome	-	mod.	20-47	Apr-May	May-Jun	15-20	5.50-7.00
Dactylis glomerata	orchardgrass	‘Berber’	low	24-48	Mar-Apr	Apr-May	20-25	2.60
Elymus glaucus	blue wildrye	‘Anderson,’ ‘Berkeley’	mod.	24-48	Apr-May	May-Jun	20-25	8.50-11.00
Festuca arundinacea	tall fescue	‘Fawn,’ turf types (‘Bonsai,’ ‘Rebel’)	high	24-48	Mar-Apr	Apr-May	20-30	1.40
Festuca idahoensis	Idaho fescue	-	very low	12-40	Apr-May	May-Jun	20	17.50-20.00
Festuca ovina	sheep/hard fescue	‘Covar’	low	3-10	Mar-Apr	Apr-May	15-20	3.75
Festuca ovina var. duriuscula	hard fescue	‘Durar,’ ‘Eureka’	-	-	-	-	15-20	3.25
Festuca ovina var. commutata	chewings fescue	-	-	-	-	-	20-25	1.65
Festuca rubra	red fescue		very low	16-40	Mar-Apr	Apr-May	20-25	1.50
Festuca rubra	‘Molate’ fescue	-	-	-	-	-	20	8.00-10.00
Hordeum brachyantherum ssp. brachyantherum	meadow barley	-	mod.	8-28	Mar-Apr	Apr-May	20-25	9.00-14.00
Hordeum brachyantherum ssp. californicum	California barley	-	mod.	12-24	Mar-Apr	Apr-May	20-25	9.50-14.00
Lolium perenne	perennial ryegrass	‘Elka’	high	12-30	May-Sep	Jun-Oct	25-35	1.30
Melica californica	California melic	-	very low	24-36	Apr	May-Jun	15	15.00-22.00
Nassella cernua	nodding needlegrass	-	very low	24-36	Apr-May	May-Jun	15	25.00-35.00
Nassella pulchra	purple needlegrass	-	very low	16-40	Mar-Apr	Apr-May	15	27.00-35.00
Poa secunda ssp. secunda	pine bluegrass	-	very low	20-40	Mar-Apr	Apr-May	15	15.00-25.00