Grape Grower's Handbook
A Guide to Viticulture for Wine Production

Ted Goldammer
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Grapevines are long-lived deciduous plants that have long been cultivated for the production of wine. The annual growth cycle of the grapevine involves many processes and events in the vineyard each year. From a winemaking perspective, each step in the process plays a vital role in the development of grapes with ideal characteristics for making wine. Annual growth of grapevines is frequently described using the following stages: (1) budburst, (2) flower cluster initiation, (3) flowering, (4) fruit set, (5) berry development, (6) harvest, and (7) dormancy. The passing of each event announces the beginning of a new stage in the vineyard management cycle. The timing and duration of events are subject to variations due to the grape variety, local climate, and seasonal weather, but the sequence of events remains constant. It is recognized that many of these events overlap others for a period of time, requiring the vine to allocate its resources among competing activities. From a husbandry viewpoint, knowledge of a plant’s growth stages is advantageous as cultural and chemical practices can be applied at optimum times in a plant’s annual growth cycle. Additionally, information regarding growth stages can be useful in estimating crop yields.

1.1 Grapevine Structure and Function

The grapevine is a woody perennial plant (See Figure 1.1), which is differentiated into the above ground shoot system (e.g., trunk, leaves, flowers, and fruit) and the underground root system.

Roots

The roots of a grapevine are multi-branched structures that grow to various depths into the soil and anchor the vine securely. Roots absorb water and nutrients from the soil, store carbohydrates and produce the hormones that regulate vine growth. The roots are typically multi-branching, producing lateral roots that further branch into smaller lateral roots. The majority of the grapevine root system is usually reported within 3 feet (0.9 m) of the soil. Different varieties of grapes have naturally different root growth patterns. *Vitis riparia* roots grow more vertically, while *Vitis rupestris* roots have more lateral growth.

Trunk

Trunk is the main steam, it’s permanent and supports the above-ground vegetative (leaves and stems) and reproductive (flowers and fruits) structure of the vine. The height of the head (i.e., top of the trunk) is determined by pruning during the initial stages of training a young grapevine. Some training systems utilize cordons, semi-permanent branches of the trunk. Cordons are usually trained horizontally along a trellis wire, with spurs spaced at regular intervals along their length. Cordons can extend from the trunk in either one or two directions—called unilateral or bilateral. Other systems utilize canes, one-year-old wood arising from arms and usually located near the head of the vine. Multiple trunks are often used in grape growing regions that are at risk for winter injury. The term “crown” refers to the basal region of the trunk slightly below and above the soil level.

Buds

A bud is a growing point that develops in the leaf axil, the area just above the point of connection between the petiole and shoot. The first bud to form in the leaf axil is referred to as an axillary bud or lateral bud. It is important to understand that a bud develops in every leaf axil on grapevines, including the inconspicuous basal bracts (scale-like leaves). In viticulture terminology, we describe the two buds associated with a leaf — the lateral bud and the dormant bud (or latent bud). The lateral bud is the
**Cabernet Franc**

Cabernet Franc is similar to Cabernet Sauvignon yet softer and subtler and retains the distinctive Cabernet aroma. Depending on vineyard practices, the flavor profile of Cabernet Franc may be both fruitier and sometimes more herbal or vegetative than Cabernet Sauvignon, although lighter in both color and tannins. Cabernet Franc can make lighter bodied, less tannic wines than many other red grapes and they are generally ready to drink soon after bottling. Overcropping and underexposure each tend to accentuate the vegetative flavor elements. Typically, Cabernet Franc is somewhat spicy in aroma and often reminiscent of plums, especially violets. Cabernet Franc is more often used as a secondary or tertiary element in varietally-blended red wines, such as Bordeaux or Meritage, instead of as a stand-alone varietal bottling. As a varietal wine, it usually benefits from small amounts of Cabernet Sauvignon and Merlot and can be as intense and full bodied as either of those wines.

Commonly cordon trained and spur pruned, Cabernet Franc may also be cane pruned. Cabernet Franc has a moderately vigorous growth habit with clusters that are loose and small to medium in size. The shoots grow strongly upright; therefore, upright shoot-positioned training and trellis systems are preferred. When compared to Cabernet Sauvignon, Cabernet Franc vines bear thinner-skinned, earlier-ripening grapes with lower overall acidity. Cabernet Franc does not develop a deep, skin color. Late and uneven véraison is common, thus cluster thinning at this time is usually warranted to enhance ripening uniformity. Yields are similar to Cabernet Sauvignon, although Cabernet Franc normally ripens somewhat earlier, making it better suited to the cooler climate. The grape is highly yield sensitive and if over-cropped produces wines with vegetal notes.

Cabernet Franc vines survive cold winters better than Cabernet Sauvignon, but are more susceptible to spring frosts because of earlier bud break. Cabernet Franc can adapt to a wide variety of vineyard soil types but seems to thrive in sandy, chalk soils, producing heavier, more full-bodied wines. It has good resistance to fruit rots and splitting but is susceptible to leafroll virus and Botrytis bunch rot. On average, it is more susceptible to Pierce's disease than Cabernet Sauvignon, yet less susceptible to Eutypa dieback.

**Cabernet Sauvignon**

Cabernet Sauvignon is one of the most widely grown wine grapes in the world and is one of the main varietals (See Figure 2.4), along with Merlot, and Cabernet Franc. It is frequently used in Bordeaux-style blends, producing a high-quality wine. Cabernet Sauvignon makes the most dependable candidate for aging, more often improving into a truly great wine than any other single varietal. Its classic flavors are currant, plum, black cherry, and spice. It can also be marked by herb, olive, mint, tobacco, cedar, and anise, and ripe, jammy notes. In cooler areas, it can be marked by pronounced “vegetal,” bell pepper, oregano, and tar flavors. Cabernet has an affinity for oak imparting a woody, toasty cedar or vanilla flavor to the wine while slowly oxidizing it and softening the tannins.

Vines are commonly trained to a bilateral cordon system and quadrilateral training is often practiced where high vigor is expected. Cabernet Sauvignon often produces blind buds, typically in the mid-cane region, which is particularly a problem in the training phase when long canes are laid to become cordons. Vertically divided trellis systems such as Scott Henry or Smart-Dyson are sometimes used to balance expected vigor with additional retained nodes in the fruiting zone. Bud break is early with Cabernet Sauvignon, just after Chardonnay, and it matures later than Cabernet Franc. This variety has a vigorous,
(See Figure 4.5). USDA soil surveys are a good tool for understanding the spatial variability of soils at a vineyard site and to identify sampling areas. Alternatively, Geonic electromagnetic conductivity meters (EM38) and Verdis electrical conductivity systems are available as diagnostic tools to develop site-specific soil maps to help understand spatial variability. See Mapping Soil Electrical Conductivity in following section for a description of EM38 and Veris diagnostic methods.

**Mapping Soil Electrical Conductivity**

In addition to soil survey data, commercial services are available to develop “real time” field maps illustrating spatial patterns of soil variability within a parcel of land. The equipment used to develop soil electrical conductivity (EC) maps consists of Geonics EM38 electromagnetic sensors (See Figure 4.6), Veris electrical conductivity sensors, global positioning systems (GPS), and global information system software (GIS). GPS and GIS are discussed in more detail in Chapter 34, *Precision Viticulture*.

**Electrical Conductivity**

The electrical conductivity of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity. Consequently, EC correlates strongly to soil particle size and texture. Electrical conductivity (EC) is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of milliSiemens per meter (mS/m). Soil EC measurements may also be reported in units of deciSiemens per meter (dS/m), which is equal to the reading in mS/m divided by 100. The advantage of a standard unit of measure is that it makes the data quantitative. Visual identification of soils can often determine color differences, but cannot attribute quantitative values to those colors. Soil EC maps showing values of “X” dS/meter enables the grower to identify and similarly manage other areas of the vineyard with the same values.

**Evaluating Soil Properties**

Over the years, soil scientists have used EC to measure soil salinity. However, soil EC measurements also have the potential for estimating variations in soil physical properties where soil salinity is not a problem, including mapping soil types; characterizing soil water content and flow patterns; assessing variations in soil texture, compaction, organic matter content, and pH; and determining the depth to subsurface horizons, stratigraphic layers or bedrock, among other uses. In nonsaline soils, where root zone salinity as indicated by ECe is less than 2.0 dS/m, there is reasonable correlation; between the soil particle sizes that determine soil texture and Eca (in-situ soil salinity). This makes it possible to develop electrical conductivity maps that reflect spatial variability of physical soil properties for a parcel of land using properly calibrated EM38 and Veris equipment. When soil salinity is known to exist and without proper calibration, it is difficult to discern whether spatial patterns of soil variability is attributable to soil physical properties or to soil salinity and other related soil chemistry problems. It is advisable to use EM38 or Veris when the soil moisture profile throughout the field is at field capacity to avoid additional variability due to nonuniform soil moisture conditions. Figure 4.7 shows a soil map generated from EM38 data. Blue shows the lowest electrical conductivity of that vineyard at that time, it then grades through green and yellow and orange and red as conductivity increases.
Healthy planting stocks establish quickly, are better able to withstand stresses such as drought and pests and diseases, and are long lived. Unhealthy vines often fail in the first season, or, if they do eventually become established, they form short-lived vineyards that produce low yields of fruit of poor quality resulting in higher management costs.

It is a good investment to take time to tour prospective nurseries. Ask questions about procedures and practices in the grafting and care of newly-grafted vines. Pay particular attention to sanitation practices used and the general cleanliness of the facility, especially the grafting room.

Vines should be ordered well before the intended planting date. Dormant benchgrafts should be ordered two years prior to planting to allow plenty of time for the nursery to graft and establish the vines, and green benchgrafts are generally ordered one year prior to vineyard establishment. Late ordering runs the risk of the nursery unable to supply the requested variety in the required quantity, thus delaying vineyard development for at least 12 months. Nurseries typically require a written contract from a prospective wine grape grower and usually a deposit.

### 6.2 Buying Grapevines

There are many factors that should affect this decision. First and most important is to only work with nurseries that are well established and that have a reputation for producing high-quality, disease- and pest-free vines. Some nursery practices that will lead to better quality vines include the proper matching of the scion diameter to the rootstock diameter. A good match will allow complete callus development and subsequently a strong graft-union. Other practices used include a hot-water dip and a preventive insecticidal treatment to prevent introduction of pests, especially the vine mealybug, into your vineyard.

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### Nursery Stock Grades

Nurseries often sell grapevines according to grades of quality such as #1, #2, etc. These growing standards are applied according to the size and branching patterns of the root system. However, there are no uniform industry grading standards in place for evaluating nursery rootstock.
cm) above the ground are oriented downward when they become long enough to be shoot positioned. The two tiers of clusters are separated by a 10 inch (25 cm) horizontal window that runs the length of the vertical curtain. The upper shoots are topped just like VSP. Listed below are some of the advantages and disadvantages of a Scott Henry trellis system.

**Advantages**

- Scott Henry is well adapted to sites where the vigor is moderate to high because it allows growers to lay down more buds without excessive shoot density.
- Suitable for narrow rows with tight vine spacing and/or row spacing.
- The two fruiting zones allow crop loads to be varied until a balance between fruit and vine growth is achieved.
- Promotes better sun exposure and allows for good air movement through the canopy, which minimizes losses to bunch rot and other diseases.
- Vines may be mechanically harvested.

**Disadvantages**

- The downward-pointing shoots must be positioned at the correct time. If not the lower shoots will turn upwards and grow into the upper fruiting zone.
- Fruit maturation in the lower fruiting zone often lags behind the upper fruiting zone, which can be minimized by carrying a somewhat lower crop level on the lower canopy than the upper.
- The lower canopy may interfere with weed control and other soil-management practices.

**Smart-Dyson System**

The Smart-Dyson system (See Figure 8.10) is similar to the Scott Henry system where curtains are vertically divided but instead shoots originate from the same cordon or fruiting zone. Unlike the Scott Henry system, the Smart-Dyson is cordon pruned. The cordon is placed slightly higher on the trellis [about 44 inches (1.1 m) above the ground] to accommodate the need for lower canopy shoot development. Between-row spacing should not be less than 7 feet in order to prevent shading of lower portion of canopy. Listed below are some of the advantages and disadvantages of a Smart-Dyson trellis system.

**Advantages**

- Smart-Dyson is adaptable to mechanical harvesting, pruning, and leaf removal.
- It is less likely to develop differences in fruit maturity and bud quality than with Scott Henry system.
- It is easy and relatively inexpensive to retrofit to a VSP system if the vines are more vigorous than anticipated.

**Disadvantages**

- Canopy separation is somewhat more laborious than with Scott Henry system because there aren’t two distinct fruiting zones and canopies to facilitate shoot positioning.

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**Selected References**

7. Dami, Imed, Bruce Bordelon, David C. Ferree, Maurus Brown, Michael A. Ellis, Roger N. Williams,
De Chaunac and Seyval with fruitful basal clusters, which tend to over-crop.

The amount of crop to remove during thinning depends on the yield potential, vine size, the variety, and growing region. Vigorous vines (large vine size) have large canopies and are generally capable of ripening more fruit than small, lower-vigor vines. Vines in cool climate regions are often crop-thinned to a higher degree than warmer regions to be able to increase the canopy size relative to the yields. It is important to remember that reducing the crop level too much can lead to increased vegetative growth and canopy density, which negatively impacts fruit quality and vine productivity in the future. Weak or low-vigor vines generally produce less fruit and may not require heavy crop thinning to bring them into balance.

**Timing of Cluster Thinning**

Cluster thinning can be done at any time from pre-bloom through just prior to harvest. Timing is important because shoots and flowers (or fruit) are competing with each other for resources within the vine, and, depending on when thinning is reduced, there may be different results for either the canopy or the fruit. Research suggests that pre-bloom thinning can lead to increased fruit set of the remaining clusters and can potentially increase vegetative growth. In small or weak vines, removing crop earlier in the season may help improve berry development because there is less competition, allowing for more vegetative growth to support the berries through ripening. Thinning at or near fruit set has been shown to increase concentration of such metabolites in the berry as phenolics (mouth feel characters) and anthocyanins (color) by harvest. Having fewer clusters on the vine at fruit set allows the remaining clusters to develop with less competition. Thinning at lag phase allows growers to estimate yields and determine the amount of fruit to remove to achieve yield goals. When clusters are thinned at véraison, the grower aims to remove fruit that is lagging in development as well as make a reliable crop estimate. If clusters are removed at véraison, maturity can be advanced in the remaining clusters, especially if lagging clusters are removed. Pre-harvest cluster thinning is conducted to remove damaged and unmarketable fruit.

In the case of weak vines or vines in areas with more water stress and smaller canopies, early season thinning may help manage the amount of fruit while encouraging healthy canopy growth. In low-vigor or weak vines, thinning fruit late in the season may put a strain on canopy growth due to the competition between shoots and fruit for carbohydrates and nutrients earlier in the season. In the case of the higher-vigor vines, it may be more beneficial to maintain higher fruit levels for a longer period of time to keep the canopy growth in check so as to allow more sunlight into the canopy and reduce canopy management costs.

**Impacts on Fruit Quality**

Crop thinning, when warranted, can help ensure that the fruit obtains adequate ripeness (Brix, pH, and titratable acidity). However, there is a point in some cultivars where there can be either too high or too low a crop level in terms of fruit quality. There are no set crop levels that will guarantee the best fruit quality.

10.4 Indirect Canopy Management Techniques

While direct canopy management practices can be used to modify the canopy, indirect canopy management techniques are also used to alter vine growth and canopy size, thereby affecting vine balance. For example, vines with a weak canopy typically require methods such as irrigation and fertilization to increase vine size relative to fruit yield.
will not have good hydraulic contact with the surrounding soil, which may require re-installation of the tensiometer. If not re-installed, the gauge reading will either remain at 70 to 80 cB or it will drop to a deceptively low value. In more severe cases, the porous cup could break, and air will enter the tensiometer. In locations where temperatures fall below freezing, the tensiometers should be protected or removed from the vineyard. Finally, the porous cup of a tensiometer should not be exposed to the atmosphere for long periods of time because it causes evaporation of water from the cup’s surface, which in turn results salt buildup and clogging of the cup.

12.2 Plant-Based Scheduling Methods

The primary advantage of plant-based irrigation scheduling for a vineyard is that grapevine performance relates directly to vine water status and only indirectly to soil water and weather conditions. The vine essentially integrates its soil and atmospheric environments and reflects the prevailing conditions in growth and reproductive processes. Some of the more commonly used plant-based methods in scheduling vineyard irrigation include visual observations of grapevine water stress and the use of a pressure chamber, which measures leaf water potential.

Monitoring Visual Appearance of Vines

This method is based on appearance of the grapevine, and although not entirely accurate with some experience the grower can detect early stages of water stress. When there is adequate water the rapidly growing shoots of the grapevine appear soft and yellowish-green. However, as water stress develops shoot growth is noticeably reduced, internode length is reduced, and the growing tips become harder and appear darker green in color. Unfortunately, with this method yield reduction has probably already occurred by the time visual symptoms of grapevine water stress are observed in the vineyard.

Pressure Chamber

The pressure chamber often called the pressure bomb has been shown to be a reliable physiological measure of water stress in grapevines (See Figure 12.7). The pressure chamber allows the wine grape grower to measure how much tension the leaf is experiencing and the degree of water stress—the higher the tension the higher the water stress. Direct measurements of vine water status (water potential) have the advantage that no assumptions need to be made about the root distribution or the relationships between soil water content and uptake.

Operation of the Pressure Chamber

Prior to excising the leaf, place a small, thin plastic bag securely over the leaf to minimize transpiration after the cut. The leaf petiole is then cut with a sharp razor blade, leaving sufficient length of petiole to extend through the sealing-stopper of the pressure chamber cover. It is best to cut the petiole as close to shoot as possible. The cut through should be done at a right angle across the length of the petiole. It is more difficult to see sap exudation on a slanted cut. If the petiole is cut again, less pressure is required to squeeze out the sap, which may result in the water potential in being overestimated (Ritchie, 1975). As soon as the leaf is cut, the leaf with the bag still secured around it should be put into the pressure chamber for testing.

Pressure is then slowly applied until the water (sap) within the petiole is pushed out of the cut surface. As soon as the drop appears, the user reads the corresponding pressure from the chamber gauge. This pressure value is the leaf water potential, read in negative (–) bars. The level of water stress as gauged by the midday leaf water potential can be generalized as shown in Table 12.2.

To improve wine grape quality, some growers reduce irrigation prior to véraison until the vines have reached a predetermined “threshold” value. This opens up the canopy for development of color, tannins, and flavor compounds. The threshold can vary from -10 Bars for some white varieties to -15 to -16 Bars in some red varieties. This method can only be used with irrigation systems that allow
Deficit irrigation strategies are commonly employed in growing wine grapes to reduce water consumption, control vegetative growth, and improve fruit and wine quality. In general, moderate water deficit affects a host of fruit quality attributes, such as berry size, seed maturity, acidity, pH, tannins, flavonols, and color. Two irrigation techniques that have been shown to be useful for this are Regulated Deficit Irrigation (RDI) and Partial Rootzone Drying (PRD). These two methods of irrigation do, however, differ fundamentally in two key respects. With regulated deficit irrigation water application is manipulated over time whereas, with partial rootzone drying, irrigation is manipulated over space. With regulated deficit irrigation, a water deficit is applied in a vineyard over a critical period (i.e., after fruit set and up to véraison or harvest). By contrast, partial rootzone drying relies on separating alternating dry and moist roots with an irrigation system that can produce the desired pattern of soil wetting. Partial rootzone drying can be targeted to a particular grapevine growth phase but is usually maintained during an entire growing season.

14.1 Regulated Deficit Irrigation

Regulated deficit irrigation (RDI) is a term used for the practice of regulating or restricting the application of irrigation water until a level of vine water stress is attained in order to improve fruit quality, reduce water consumption, and control canopy growth. RDI can be a consistent reduction (i.e., consistent reduction of planned irrigation volumes over the entire season) or at specific periods (e.g., fruit set to véraison) of the growing season to induce the desired vine response. By inducing controlled moderate water stress, foliage growth and berry size are reduced, ripening is accelerated, fruit quality is enhanced, and sugar accumulation may be unaffected or enhanced. By controlling vegetative growth, the cost of canopy management including hedging, leaf-pulling and shoot removal may be less than budgeted, not to mention the cost savings in controlling for bunch rot diseases. Red grape varieties are more likely to benefit from RDI than white grape varieties (where skin contact during fermentation is minimal).

Timing of Water Deficits

RDI can be applied to wine grapes either from fruit set to véraison, from véraison to harvest or over both periods. The effects of a moderate level of stress from RDI during each of these periods compared with full irrigation throughout the growing season can be summarized as follows.

Fruit Set to Véraison

The RDI period starts when there are no remaining signs of flowering and during the early stages of fruit set. This is the time when RDI offers the greatest potential to reduce excessive shoot growth. Early in the season shoots should have a moderate growth rate and leaves should be normal in size. After reaching full canopy, suspend irrigations or continue to withhold them to arrest shoot growth, which is evident in pale shoot tips, short internodes near the tips, obscuring of the shoot tip by apical leaves, and possibly, slight tendril and petiole wilting during the warmest part of the day (See Figure 14.1). Once shoot growth has been arrested, RDI is practiced to sustain foliage without renewed shoot growth. Basal leaf yellowing or scorching indicate severe water stress and the need for increased irrigation. Before such leaf damage is readily apparent, leaves may appear slightly wilted and exposed leaf tissues may be warm and appear faded. Any reduction in yield may be complemented by an increase in soluble solids, and this is probably related to the reduction in berry size. Water stress before véraison may decrease titratable acid and increase pH levels. Water deficits may be difficult to carry
very wet or flooded conditions. Excess iron can result in dark green foliage, stunted growth of shoots and roots.

**Molybdenum**

**Role and Deficiency Symptoms**

Molybdenum is essential to vine growth as a component of the enzymes nitrate reductase and nitrogenase. It is also involved in enzymatic reactions essential for growth and reproduction in vines as well as plays an important role in grapevine fruit set; seed formation; berry formation and development; and bunch yield. Molybdenum is available to vines as the molybdate ($\text{MoO}_4^{2-}$) ion.

Only rarely has molybdenum been found to be deficient in vineyard soils. When molybdenum is deficient, necrosis develops and spreads rapidly from the leaf margins inward. The demarcation zone between healthy and necrotic tissue is pronounced, and the unaffected areas appear normal (Figure 16.12). Affected leaves often remain attached to the shoot. Often there are no clear vegetative growth symptoms for molybdenum deficiency prior to flowering. After fruit set the only visible symptoms are “hens and chickens” and “shot” berries. Other factors, such as periods of cold, wet conditions between bud burst and fruit set, and zinc or boron deficiency can also cause poor fruit set and should also be considered when evaluating nutrient deficiencies. Merlot grapevines, in particular, have a critical need for adequate molybdenum concentrations during flowering and reproduction for seed formation and bunch yield.

**Assessing the Need for Molybdenum Fertilizer**

As with most micronutrients, tissue sampling can be used to determine the vines’ molybdenum status. Tissue analysis results coupled with visual observations should indicate whether to apply molybdenum. Soil analysis does not adequately represent molybdenum availability throughout the soil and root profile for mature vineyards.

**Time Application**

Molybdenum fertilizer can be applied late winter to early spring for soil surface applications. If molybdenum fertilizer is applied via drip irrigation it should be completed 2 or 3 weeks prior to bloom. This allows enough time for vine uptake by bloom. The optimal time for foliar application is 2 weeks prior to bloom to full bloom in order to improve fruit set and berry development.

**Application Methods**

**Direct Soil Surface Application**

Soil surface applications of molybdenum are not very effective because it is not an effective short-term measure in the current season in overcoming molybdenum deficiency before fruit set.

**Fertigation**

Molybdenum applied to vineyards with the drip system is effective and feasible. Drip irrigation is effective since nutrients are placed where roots are highly concentrated, and uptake is supported by continuous high soil moisture beneath emitters.

**Foliar Application**

Most molybdenum deficiencies can be corrected with foliar sprays. Except in severe cases, repeated foliar spray treatment is probably the most economical way to correct most molybdenum deficiencies. Foliar sprays of sodium molybdate and ammonium molybdate are effective on grapevines when molybdenum deficiency is identified.

**Soil Factors Affecting Availability**

Molybdenum deficiencies are found mainly on acid, sandy soils in humid regions. Soils high in iron/aluminum oxides will absorb molybdenum strongly, reducing molybdenum availability. High levels of phosphate increase molybdenum availability because phosphorus and molybdenum are so similar that phosphorus will compete for the same sorption sites as molybdenum, resulting in molybdenum desorption. Generally, growers’ correct molybdenum deficiencies by applying lime to the soil, thus increasing the soil pH and thereby increasing molybdenum solubility.

**Molybdenum Toxicity**

Marginal leaf scorch and abscission as found in typical salt damage are typical symptoms. Because of the intensity
Fertilizer Formulations

Fertilizers applied in irrigation water may be purchased dry granular or as liquids. Preparation of nutrient stock solutions from dry fertilizers may require considerable time and effort and can generate sediments and scums as waste products. Therefore, commercially prepared liquid fertilizer solutions (true solutions, not suspensions) that are completely water soluble are often used. Liquid fertilizers are available in a variety of grades and can be purchased with or without micronutrients.

Liquid Fertilizers

Liquid fertilizers are available as fertilizer solutions and suspensions, both of which may contain multi-nutrient or single nutrient materials. Solutions are defined as liquids that have all the plant nutrients in a solution while suspensions hold part of the plant nutrients suspended in the liquid by a suspending agent. Suspension fertilizers contain undissolved constituents, whereas the constituents of solution fertilizers are completely dissolved. Dry or suspension fertilizers are mixed with enough irrigation water prior to application to ensure that the fertilizer material dissolves completely and forms a solution (no undissolved constituents).

Advantages of Liquid Fertilizers

- Liquids are especially suited to application through a drip or sprinkler irrigation system.
- Liquids are excellent carriers of micronutrients. If applied through a drip irrigation system, liquid fertilizers allow for accurate placement of the micronutrient at the desired location for efficient fertilizer use.
- Plant utilization of the nutrient is more efficient as the nutrients are in a form that is readily available to the roots.
- They eliminate the problems caused by insoluble materials found in some dry fertilizers.
- Although transportation costs make liquid formulations a little more expensive, they save time and labor and help prevent problems associated with poorly made “stock solutions” made from dry, granular fertilizers.

Granular Fertilizers

As mentioned, dry granular formulations must be mixed with water to form a stock solution. When mixing granular fertilizers, it is better to start with about half the required amount of water in the tank. Then, while continuously

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**Figure 18.5 Fertilizer compatibility chart**

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<thead>
<tr>
<th>COMPARABILITY CHART</th>
<th>Urea</th>
<th>Ammonium nitrate</th>
<th>Ammonium sulphate</th>
<th>Mono-ammonium phosphate MAP</th>
<th>Mono-potassium phosphate MAP</th>
<th>Potassium nitrate</th>
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<th>Potassium chloride</th>
<th>Calcium nitrate</th>
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to be “organic” even though they are concentrated by man-made processes. Also, salts of copper and iron are found in nature, processed for use, and termed ‘synthetic’ but are allowed to be used with some restrictions (used in a manner that minimizes accumulation in the soil) and are considered to be “organic.” Organic production is regulated through the USDA National Organic Program which defines what inputs are allowed for pest management. Some, but not all, biorationals are approved for use on crops that are certified organic under the National Organic Program. For a given active ingredient, some products or formulations may be approved for use in certified organic crops, while others are not. Products that are generally approved for organic production are designated “OMRI” or “OMRI listed,” which indicates they are listed by the Organic Materials Review Institute. Growers should consult with their certifying agency to be sure which products are approved for use.

**Biopesticides**

Biopesticides, as defined by the EPA, are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. Categories of biopesticides include: (1) biochemical pesticides, which are naturally occurring substances that control pests by non-toxic mechanisms, such as sex pheromones that interfere with mating and scented plant extracts that attract insect pests to traps; (2) microbial pesticides, which consist of a microorganism (e.g., a bacterium, fungus, virus or protozoan) as the active ingredient; and (3) plant-incorporated-protectants (PIPs), in which pesticidal substances are produced by crop plants as a result of genetic material being added to the plant (e.g., _Bt_ insecticidal protein). With plant-incorporated protectants, the toxin and its genetic material, but not the plant itself, are regulated by EPA.

**Biorationals Approved for Organic Crop Production**

Most biorationals are approved for organic crop production, thus they are a logical fit for managing pests in organic crops. However, some formulations are not approved, which can be due to inert materials or synthetic additives. Some biorationals are not allowed under National Organic Program (NOP), for example phosphorus acids and genetically engineered PIPs. It is important to verify that a biorational, like any other product is approved for organic production and registered in your state prior to any application. A synthetic substance, as defined by the NOP, is formulated or manufactured by a chemical process or by a process that chemically changes a substance extracted from naturally occurring plant, animal, or mineral sources, except that such term shall not apply to substances created by naturally occurring biological processes. Those few synthetic additives that allowed can be found on the National List under § 205.601.

**Chemical Pest Control**

Conventional pesticides (i.e., synthesized by the agrochemical companies) are man-made and are the largest

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**FIGURE 20.7**

Historically, pest control in vineyards was based on broad-spectrum pesticides, which were associated with a diversity of problems, traditionally including environmental effects, beneficial organism extinction, and pesticide resistance. More recently, growers have began adopting and promoting a concept “Integrated Pest Management” (IPM).
Green June Beetle

Green June beetle (*Cotinis nitida*) is a serious pest most commonly found throughout the southern U.S. in vineyards but also this native beetle can be found from Connecticut south to Florida and as far west as Texas and Oklahoma.

**Symptoms**

Green June beetle is a serious pest of grapevines feeding on petioles, leaves, and berries (See Figure 22.18). Green June beetle is attracted to the ripening clusters as the berries soften and the sugar content increases. As the beetles feed, they emit pheromones, which attract other green June beetles. Unpleasant green June beetle excretions can give the final wine product an objectionable flavor. Fruit injury is more common than with the Japanese beetle.

**Life Cycle**

The larvae overwinter just below the soil surface. In the spring, they tunnel near the soil surface, pupate and emerge as adults in the summer months feeding on leaves and berries. Adult populations usually peak with grape berry maturation. Mating occurs at this time and eggs are laid in sites containing organic matter, which hatch in 2 to 3 weeks. After the eggs hatch, the young larvae burrow into the soil. During the day, larvae hide but at night, they emerge and feed on decaying organic matter. During the winter, larvae are inactive but may crawl from their tunnels to feed on warm days. There is one generation each year. Sandy soils high in humus or organic matter are preferred.

**Monitoring**

Management of green June beetle requires frequent scouting to detect its presence in the vineyard at the time they are most active. Traps are available for monitoring green June beetle though not too effective, but still can be used to indicate initial adult emergence. Direct fruit counts are the most effective way of assessing damage. Depending on the location of the vineyard, adults generally emerge in the summer months, so repeated scouting may be necessary. Typically green June beetles are most abundant in the vineyard during the period when wine grapes accumulated sugars are high and until grapes are ready to harvest.

**Cultural Pest Control**

Growers might consider burying the pupae by mounding soil up under the vines early in the season. This form of cultural control might prevent adults from reaching the soil surface. Reportedly removing decaying vegetation (compost) may minimize the number of attractive egg laying sites.

**Biological Pest Control**

Parasitic wasps and flies have also been used to control green June beetle. Two species of tiphiid wasps (*Tiphia vernalis* and *T. popilliavora*) have been introduced to control green June beetle larvae. The tachinid fly, *Istocheta aldrichi*, is known to parasitize adult beetles. Another biological control method is to trap and release native pests into the vineyard.

**Biorational Pest Control**

**Microbials**

Milky spore disease (*Bacillus popilliae*) is available for the control of green June beetle, but it is only effective in protecting grassy areas from large larval populations; winged adults will continue to enter vineyards from untreated areas.

**Chemical Pest Control**

Standard chemicals for controlling green June beetle include Imidan (phosmet), Danitol (fenpropathrin), Guthion (azinphos-methyl), Sevin (carbaryl), and Sniper (bifenthrin). Insecticides used for controlling green June beetle in vineyards are presented in Appendix K, *Insecticides Registered for Use in Vineyards.*
Weed germination is greatly impeded and growth diminished.
- Some mulches (e.g., partly composted green waste) are a useful source of nutrients.
- Mulch adds organic matter to the soil.
- Vine roots concentrated directly under the vine are protected from excessive heat.
- Mulch greatly reduces evaporation, thus conserving soil moisture.
- Mulching helps avoid vine damage from cultivation.

Disadvantages
- Partly decomposed mulch may create an ideal seedbed for weeds.
- Mulches may provide a good habitat for pathogens, gophers, voles, and field mice, or be a source of new weed seed that came with the mulch.
- The cost may be prohibitive when considering the need for application of organic mulches.
- Mulch can enhance the risk of frost damage due to the slower upward movement of heat.

Plastic Mulches
Plastic mulches have proven particularly useful in establishing vineyards not only for controlling weeds but to maintain higher moisture levels and promote faster root development. Plastic mulches may consist of either impermeable or porous woven sheets of polyethylene. Porous sheeting has the benefit of better air and water permeability, but it increases evaporative water loss. Polyethylene sheets can be designed to exclude photosynthetically active radiation (retard weed growth), but allow penetration of far-red radiation (permit soil warming).

24.3 Controlling Weeds by Mowing
Mowing is another option used by organic growers in controlling weeds and in orchards and vineyards. It is a relatively fast operation that causes minimal soil disturbance, although soil compaction may become an issue where mowing is frequent. Mowing weeds or cover crops can be used to produce mulch material for weed suppression in the inter-row or intra-row areas. Growers should consider a program of mowing alternate rows, allowing the uncut rows to provide habitat and food sources for beneficial insects in the orchard or vineyard.

Mowing can be effective for perennial weed control. Success depends on repeated mowing to deplete the plant’s food reserves. For annual and biennial weeds, mowing should occur before flowering to prevent any seed production. Some annual and biennial weeds will not recover after one cut. However, others may survive and continue to flower below the cut line. One strategy to correct this is to cut the plant as high as possible and still remove flowers in the first and any subsequent cuts, lowering the height of the mower with each successive cut. High mowing will reduce or prevent seed set in medium to tall weeds while allowing useful species, including non-grasses, to regenerate. Low mowing tends to favor grasses over many other desirable plants, because the regeneration point for grasses is low. For the same reason, low mowing is not effective against weeds with very low crowns, like capeweed and caltrop.

Types of Mowers
There are three basic types of mowers: the sickle-bar, rotary, and the flail. The sickle-bar consists of a cutting bar with attached guards and a knife (sickle) that is driven back and forth in a horizontal direction. Rotary mowers have blades that rotate parallel to the ground, which coarsely chop and cut weeds that are growing on the orchard or vineyard floor (See Figure 24.3). They can be mounted on the front or back of a tractor. Flail mowers have numerous small blades that rotate perpendicular to the soil surface, which cut the weeds into smaller pieces. Flail mowers are often mounted in the rear of the tractor. Mowers are often the preferred method for managing weeds, especially on hillside orchards and vineyards, where growth is very vigorous, and in no-till systems. Flail and rotary mowers with side-delivery chutes can be operated to place the clippings as a mulch within tree/vine rows, helping to move nutrients from the row middles to the tree/vine row and suppress weed growth.
uniform than with a conventional air-blast sprayer with a single fan operated from the vineyard floor.

Directed Air Duct Sprayers

Low volume, low velocity air is produced by a relatively small fan with separate ducts delivering the air past each nozzle (See Figure 26.4). Each outlet incorporates a hydraulic or air shear nozzle surrounded by a stream of air. Each duct can be individually adjusted, depending upon growth stage, shape, and density of the vine canopy. The air flow is convergent and creates excellent turbulence within foliage giving good coverage resulting in reduced drift.

Multi-Head Fan Sprayers

Multi-head sprayers (See Figure 26.5) utilize a number of shrouded small axial fans which can be independently adjusted to direct high volume, low velocity converging air streams to the canopy. Atomization is either by rotary atomizer or conventional hydraulic pressure. Rotary or hydraulic nozzles are arranged behind or around the fans so that spray droplets are caught up in the airstream and transported to the canopy. The location of the fans means that the point of atomization (the point of emission of the spray-laden air) is relatively close to the target. The arrangement of fans overcomes many of the geometric limitations of a radial fan near the ground. The fans should be adjusted so that they are not directly opposite each so adjustments should be made so that the fans are facing at least 5 to 10 degrees backwards. Hydraulic nozzle versions allow the growers to change droplet size by changing nozzle size or system pressure whereas with rotary nozzles droplet size is controlled by the speed of the rotary nozzle. Multi-head sprayers have the flexibility for high or low volume spraying, with some grape growers achieving excellent control of diseases and insect pests.

Electrostatic Sprayers

Electrostatic sprayers (See Figure 26.6) use air-shear nozzles, whereby the solution (chemical and water) is combined in a “shearing” action, which atomizes the particles down to extremely fine water droplets (< 50 µm). Then, just before the mist exits the nozzle, it is exposed to a high voltage/low current charge, usually at or near the nozzle outlet producing electrically charged (negative) spray droplets, which are carried into the vine canopy in a high-speed air stream. As the negative charged droplets enter the canopy they are attracted to the positively charged plant surface (opposite charges attract). This charge is small, but the force attracting the spray to the “target vine” is up to 75 times the force of gravity. This results in much improved droplet deposition over the canopy surface with the increased chance of the pesticide finding its target. The particles actually reverse direction and coat the back sides of the vines throughout the entire canopy. This is referred to as “electrostatic wraparound.” Since all of the spray particles leaving the nozzles have the same charge, they cannot collect into large droplets.
Over-Vine Sprinkler Systems

Over-vine sprinkler systems remains among the most reliable methods of frost-protection, since it does not rely on access to warm air above the vineyard, and provided sufficient water is applied, is able to protect against severe frosts. Over-vine sprinkler systems involve spraying the vines with a fine mist of water as the temperature falls to freezing. This water then freezes encasing the canes and buds in ice (See Figure 28.6). As the water changes to ice on the surface of the vine, it releases a small amount of heat (known as latent heat) that protects the vine from any damage. Latent heat prevents the surface temperature of the vine tissue from falling below 32 degrees F (0°C). Conversely, when ice melts, or water evaporates, the temperature around the water is cooled. Water evaporating from the surface of a vine will draw heat from that vine.

Over-vine sprinkling is continued until the temperature of the surrounding air is above 32 degrees F (0°C) and ice on the vines has begun to melt; this is usually after sunrise. If the grower ends the application before temperatures warm up, unintended damage can occur. Use of sprinklers can protect vines when temperatures fall to 22 degree F (-5.6°C), if conditions are ideal (Sugar et al., 2003).

The main disadvantages with using sprinklers are the high installation cost and the large amounts of water needed requiring wells with sufficient capacity and/or building large holding ponds for supplemental water. In many instances, limited water availability restricts the use of sprinklers. In other cases, excessive use can lead to erosion, soil waterlogging, which could cause root problems as well as limit access to the vineyard. So the method is mainly confined to those areas where adequate water is available, and soils are free draining. Nutrient leaching (mainly of nitrogen) is a problem where sprinkler use is frequent.

Start-Up and Shut-Down Temperatures

When frost is expected, the usual practice is to start the sprinklers when the temperature drops to 34 degrees F (1°C), thus providing a margin of safety (Weaver, 1976). However, it may be necessary to start the sprinklers at a higher temperature than 34 degrees F (1°C) when very dry atmospheric conditions prevail (low dew-point temperature) in order to increase the relative humidity before frost occurs.

When using sprinklers for frost protection, the sprinklers should be started and shut-down when the wet-bulb temperature (Tw) is at or above the critical damage temperature (Tc) for the vines. Starting the system when the wet-bulb temperature is below the critical temperature may create evaporative cooling conditions that could cause frost damage in itself. The air temperature (T) to start the sprinklers is estimated by first measuring the dew point (Td) temperature, which can be determined indirectly by determining the wet- and dry-bulb temperatures with a sling psychrometer and a psychrometric chart.

Wet-Bulb Temperature

The wet-bulb temperature represents the temperature a wet surface will cool to as the water evaporates. If wet-bulb temperate is very low, water will evaporate quickly, causing
the spring when the ground can be easily cultivated, and then mowed and tilled into the soil. This operation is often timed when the cover crop is flowering, as it will decompose easily at this stage. This system is best suited for relatively flat vineyards in which soil erosion is not a serious hazard. This farming system is tillage-intensive, and soil is exposed to sunlight during the summer. Loss of soil structure and organic matter occurs if tillage is excessive. Cover crop species typically used in this system include annual small grains (barley, oats, triticale), winter peas, common vetch, bell beans, daikon radish, Persian clover, and other annuals that grow well during the cool months. Legume cover crops can improve the nitrogen status of low-vigor vineyards. Including grasses, in the sward can also improve the soil’s physical structure, water and air filtration, and moisture storage.

No-Till Cover Crop Floor Management Systems

No-till practices were first introduced as a soil conservation tool and to decrease labor requirements and fuel use. Another benefit is firm footing in wet weather. Numerous studies have shown that soil is more protected from erosion and run-off in no-till systems and that yields in no-till systems can be as good or better than with conventional tillage. Soil carbon and other soil quality parameters (aggregate stability, microbial activity, earthworm populations) can increase significantly after switching from annual tillage to no-till. Potential disadvantages of no-till cover cropping systems include possible competition between the cover crops and vines. Dryland vineyards on shallow soils are not good candidates for no-till cover cropping systems due to excessive competition.

Non-Tillage Floor Management with Annual Cover Crops

In a no-till system with annual cover crops, the vineyards are tilled initially and seeded with species that will reseed themselves on an annual basis. Thereafter, the vineyards are mowed in spring and early summer. Tillage is restricted to only beneath the vines. Subterranean clovers, rose clovers, crimson clover, red clover, berseem clover, bur medic, bolansa clover, and Persian clover are all suited for this farming system. Grasses that can be used include Bland brome and Zorro fescue. Another no-till approach is planting annual cover crops that are not self-reseeding just before fall rains, such as oats, barley, peas and vetch, with a no-till drill. This approach is useful when tillage could cause erosion, and it is desirable to keep tillage to a minimum. The cover crop is simply mowed and left to lie on the soil surface.

Non-Tillage Floor Management with Perennial Cover Crops

Perennial species are most commonly used in vineyards planted on fertile sites. Many of the perennial grasses are very competitive with grape vine roots, and will have a devigorating effect on the vineyard. This may be desirable if the vineyard is seriously out of vegetative balance. Some perennials are attractive to gophers, voles, and other rodents that can damage grapevines. It is important to let these grasses flower late in the spring, in order for them to accumulate carbohydrates in their root systems, which improves their persistence and competitiveness with weeds.

There is a range of cover crops that vary from being slight to very competitive. The fine fescues (hard fescue, creeping red fescue, and sheep fescue) are the least competitive, grow very short, and survive well. Turf selections of perennial rye grass and tall fescue are intermediate in their competitiveness. They have fairly low stature, and require mowing only once or twice per year. Pasture selections of perennial rye grass, tall fescue, and orchard grass are the most competitive, and can have a tremendous impact on vineyard vigor. They should be planted on only the most vigorous sites with deep soils.

Some growers have had success planting perennial grasses alone, and then, after two or three seasons, planting annual legumes into the sward such as white clover, strawberry clover, alsike clover, and birdsfoot trefoil in a perennial mix. These species provide not only nitrogen for the grasses, but also habitat for generalist predator and parasitoid insects. If the annual legumes and perennial grasses are initially planted together, the legumes will shade the grasses out, and a poor stand of perennial grasses is likely to occur in the sward.
There are many aspects in evaluating wine grape maturity that determine the best time to harvest wine grapes. Some of these are quantitative and can be determined to a high degree of numerical accuracy, and others are qualitative and are more subjective. Some of the quantitative measures include soluble solids content, titratable acidity, and pH for the intended type and style of wine. Of equal importance are the grower’s observations of the qualitative indicators—integrity of fruit, color intensity of skins, seed coat color, the degree of tannin “ripeness” when the skins are chewed, degree of lignifications of the cluster peduncle development, and observations of the physical condition of the vines. Practical and economic considerations play a role too and may include availability of labor and weather conditions.

32.1 Determining Wine Grape Ripeness

Quantitative Parameters

The greatest potential of any wine grape variety is realized only when it is harvested at the right time in order for the wines to possess the characteristic varietal aroma, flavor, and balance intended for its use. The date of previous harvests can be used as a guide when trying to determine the projected harvest date. However, such dates alone should never be relied upon exclusively given management practices and environmental influences that come into play. The maturity of grapes is usually based on three parameters: sugar content, titratable acidity, and pH. All of these parameters change over time, and the rate at which they change depends on conditions during the growing season. Therefore it is critical to properly monitor and assess the fruit quality and maturity to make the appropriate management, harvesting, and winemaking decisions to produce the best quality grapes and wine possible.

As grapes ripen, sugar levels rise and acid levels fall. Thus, the object in assessing wine grape ripeness is to get to the optimum cross-over point, where sugars are high enough as well as acid numbers allowing for good wine-making. Table 32.1 gives the recommended sugar, acid, and pH levels for harvesting grapes for different styles of wine. In some cases, all the parameters will be in acceptable ranges at harvest. In other cases, harvest date is determined by one parameter, even though other indices may be outside the ideal range.

Table 32.1 Approximate Ranges of Sugar, Acid, and pH for Must at Harvest

<table>
<thead>
<tr>
<th>Type of Wine</th>
<th>°Brix</th>
<th>Titratable Acidity g/100 mL</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparkling</td>
<td>18.0–20.0</td>
<td>0.70–0.90</td>
<td>2.8–3.2</td>
</tr>
<tr>
<td>White table</td>
<td>19.5–23.0</td>
<td>0.70–0.80</td>
<td>3.0–3.3</td>
</tr>
<tr>
<td>Red table</td>
<td>20.5–23.5</td>
<td>0.65–0.75</td>
<td>3.2–3.4</td>
</tr>
<tr>
<td>Sweet</td>
<td>22.0–25.0</td>
<td>0.65–0.80</td>
<td>3.2–3.4</td>
</tr>
<tr>
<td>Dessert</td>
<td>23.0–26.0</td>
<td>0.50–0.75</td>
<td>3.3–3.7</td>
</tr>
</tbody>
</table>

Source: Boulton et al., 1996

The complexity in trying to correlate wine quality to the above mentioned measurements will likely vary from variety-to-variety, from vineyard-to-vineyard, and from year-to-year. In addition, what is desirable from one wine style will almost certainly be different for another. For example, Pinot Noir intended for sparkling wine production will have a very different ripeness target compared to that for a Pinot Noir for still wine. Lower sugar, higher acidity and more neutral flavors are desired for sparkling wine compared to still wine, so “ripeness” and harvest for sparkling wine occurs earlier. In hot, early ripening years, it may be desirable to harvest the grapes at
advantages when used for commercial mapping. The mission set-up is simple; there is no need to plan takeoffs and landings into the wind as must be done with a fixed-wing. For inexperienced operators, they are the easiest way to get up and running quickly. There’s a preconception that multi-rotor drones don’t have the range necessary to cover large row crops, and historically, people looked at fixed-wings for that reason. Multi-rotors actually have many advantages: they’re easier to operate, require no advance wind planning, and have the ability to fly more precisely (for example, to turn sharply where fields abut adjacent highways). There are a number of exciting data products in development which will require low altitude flight to capture extremely detailed images; here again, the multi-rotor has the advantage. Furthermore, range is no longer a practical issue. Under new FAA rules, operators can only fly to edge of line of sight, effectively negating the argument for long-range fixed wings.

Advantages

- **Greater Maneuverability.** Unlike fixed wings, multi-rotor aircraft can perform vertical takeoffs and landings. This means that they require less space to take flight, can hover mid-flight, and maneuver above and around objects for easy inspection, mapping, and modeling. This also makes them ideal for area mapping due to the number of flight legs often required to get sufficient overlap to make a quality map.

- **Lower Price.** In the current market, multi-rotor vehicles come with a lower price tag than their fixed wing counterparts. There is of course a wide price range, but you can purchase a professional quadcopter for as low as $1,500, whereas a professional fixed wing drone of similar quality can easily be 5 to 7 times higher.

- **More Compact.** Multi-rotor vehicles don’t require the surface area or wingspan that fixed-wing aircraft do because they use propellers to maneuver. They are easier to break down, fold up, and pack away into smaller cases—making them convenient to transport. Even the larger hexacopters and octocopters fold down to a portable size.

- **Ease-Of-Use.** Multi-rotor aircraft are easier to fly for both humans and autopilots. Quick to maneuver, and capable of making movements in any direction, copters have a shorter learning curve for beginners taking flight for the first time.

Disadvantages

- **Shorter Range.** One limitation of multi-rotor craft is the flight range on a single battery. Most multi-rotor drones can fly for about 30 minutes in ideal conditions before returning home for battery replacement. You can offset this downside by purchasing additional batteries.

- **Less Stable in Wind.** The aerodynamics of multi-rotor aircraft leaves them more vulnerable to wind. This means that for use cases where high winds are expected, you may have to purchase a heavier, more stable and more expensive multi-rotor vehicle.

Sensors

Today, a wide range of optical imaging systems are available which can be integrated with unmanned aerial systems (UAS). In general, optical sensors are classified based on the form of data acquired and source of electromagnetic radiation (EM) used to measure the response. A range of active and passive sensors can be integrated with small UAS. Georeferenced and processed data from such sensors can be used for decision support in crop management. Overall, the integration of a typical sensor with a small UAS depends on the specific agricultural application and the UAS platform payload lift capabilities.

**RGB Sensors**

RGB sensors are the least expensive of all the cameras but also provide the least amount of information and uses. They only capture visible light (red, green, and blue). Applications for RGB sensors include agriculture, inspection, and terrain modeling. A major advantage of visual imagery captured by a UAV is the aerial perspective of a specific area. The grower is able to get a birds-eye-view high-resolution picture without putting in extra effort for the vantage point.

**Multispectral Sensors**

The multispectral sensor is one of the most commonly used scanning systems. Multispectral sensors allow specific ranges of the electromagnetic spectrum to be captured. They normally capture 4 to 7 bands. Multispectral
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