

Preparations for Successful Vineyard Mechanization

Fundamental concepts of mechanized viticulture

Increasingly, vineyard operators faced with financial pressures and an inconsistent, costly labor supply are considering mechanization to reduce operating costs, execute timely cultural practices and increase flexibility within their operations. The list of tasks that can be performed by machine has grown extensively over the past decade and now includes pruning, suckering, shoot thinning, shoot positioning, fruit thinning, wire lifting, cordon brushing and leaf removal, in addition to harvesting. Because tasks typically can be performed more efficiently by machine than by hand, using machines not only increases an operator's ability to complete tasks at the appropriate times but also often lowers production costs. Tasks performed by machine also tend to be less variable than those done by hand, which may allow for increased uniformity in fruit maturation. These benefits are significant and attractive to many producers, but they cannot be obtained without investment, and successful mechanization of a vineyard can be limited by many decisions made early in vineyard design and establishment processes.

Producers wishing to mechanize vineyard operations should first develop a working knowledge of the abilities, limitations and requirements of currently available equipment. As the list of mechanizable tasks has grown, so has the size and weight of implements designed to perform them. Growers seeking a high degree of vineyard mechanization need to consider the horsepower, hydraulic supply, lift capacities and stability required by modern vineyard equipment. Although a tractor of 50 to 60 horsepower may be adequate for a simple prepruner or single-head leaf removal unit, larger power units are often necessary for more sophisticated and multirow implements. A tracked power unit may be highly desirable for large implements or for soils prone to rutting or compaction.

Current vineyard mechanization equipment does not completely eliminate the need for hand labor, but it does allow a grower to replace some seasonal labor with

mechanized operations. Reductions in hand labor will vary considerably between vineyards, as some cultivars and sites are more conducive to mechanization than others. Generally, growers will still need seasonal labor for some vine management tasks. In addition, because mechanization relies heavily upon information-based decision-making, growers will need fewer but more-highly skilled personnel to collect and synthesize information, as well as to execute mechanized operations.

Unlike humans, today's machines are nonselective and cannot respond independently to variations in vine growth or productivity. For example, current machines cannot differentiate between high- and low-quality canes, decide which shoots should be retained in the canopy, or differentiate between vines of varying size. Because machines are nonselective, establishing a healthy, uniform vineyard is a key element for successfully mechanizing vineyard operations. Mechanization typically fails to produce desired results in nonuniform vineyard blocks due to increased prevalence of unbalanced vines and associated reductions in fruit quality — problems that, until their causes are identified and mitigated, often become more severe as a vineyard matures.

This publication addresses practical considerations for establishing and maintaining vineyard uniformity for successful mechanized operations. It focuses principally on new rather than mature vineyards, although adapting an existing vineyard for mechanization is also addressed.

Establishing a mechanized vineyard *Site selection and preplant considerations*

Ideally, preparations for mechanized viticulture begin long before vines are planted and even well before the first cover crop is sown. Indeed, some key elements — soil uniformity, blocking strategy, drainage, slope and consistency of grade, and cover crop selection — should be considered during the site selection process.

To maximize uniformity within individual blocks, vineyards must be blocked to consistent soil depth, fertility and water-holding capacity. Thorough investigation of these soil properties must be conducted preplant and the results carefully incorporated into the vineyard design and development plan. This information can be obtained through county soil surveys, on-site soil pits, and ground penetrating radar and other GIS-based applications.

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If on-site soil pits will be used as the primary source of information, areas with high soil variability may require pits at a density of one or more per acre to adequately identify soil boundaries. Where appropriate and spatially efficient, square or rectangular blocks are typically the most cost-effective to install and farm.

Vineyard management is simplified when individual vineyard blocks are planted to a single cultivar or cultivar-rootstock combination. When individual blocks are established based upon measurable soil differences, each block will tend to require somewhat different management even if the cultivar and rootstock of each block are identical. Planting those blocks to multiple cultivars or rootstocks only adds to the complexity of appropriately managing each cultivar or cultivar-rootstock combination.

Excellent internal soil drainage is necessary in a mechanized vineyard — not only because grapevines are intolerant of saturated soil conditions, but also because mechanized viticulture can require prompt access to the vineyard after rain or snow to prevent delays in operations. In regions where rainfall during the spring and growing season is likely, timely access is guaranteed only by excellent internal soil moisture drainage. Adequate drainage is facilitated by thorough preplant soil evaluation and selection of well-drained soils or by using artificial drainage systems as necessary (Figure 1).

In both hand- and machine-farmed vineyards, slope and elevation are often needed to avoid frost or freeze damage in the spring and fall. Side-slopes of 15 percent or more can be farmed by hand, but equipment operation at and above this grade is dangerous. Seven to eight percent slope is a practical level at which mechanized operations become less difficult. Slopes of 3 to 5 percent are more comfortable and still adequate to promote good air drainage.

To increase a mechanized vineyard's chance of success, seek sites with consistent grade, block the vineyard to uniform grades and soil depths, or employ land-leveling operations as needed to achieve similar conditions. Sites with variable



Figure 1. Even in a tile-drained vineyard, mechanized pruning under wet soil conditions can cause significant rutting. A thicker cover crop stand may mitigate such damage.

grades within blocks often require frequent and sometimes rapid adjustments by equipment operators, increasing the difficulty of executing tasks uniformly by machine. Avoid or level sites with irregular swales or knolls, particularly if transitions in grade are sharp. Swales may collect water, increasing the potential for rutting by equipment and for areas of weak vine growth. Furthermore, variable grades are often accompanied by changes in soil depth, drainage or water-holding capacity, which can increase vine-to-vine variability over relatively short distances.

In areas with significant precipitation during the growing season, dense, durable cover crops in vineyard aisles will reduce soil compaction from wheel traffic, reduce rutting during wet periods and facilitate faster access after rains (Figure 1). Cover crop selection should be based upon soil characteristics, expense, available equipment for seedbed preparation and seeding, and climate. Permanent cover crops typically provide more complete soil cover than annual covers, but the former may not be appropriate for all sites, conditions or management strategies. In vineyards where annual cover crops will be used, stagger planting and incorporation years in alternating rows so that all rows are accessible from a covered, shared aisle.

Design

Several factors need to be considered when designing a mechanized vineyard to ensure the vineyard can be farmed with available equipment. Failure to attend to seemingly minor details can greatly complicate or even prohibit vineyard mechanization.

Rows

A purpose-driven vineyard layout is needed to assure safe and efficient equipment operation. Long, straight rows that are uniformly and adequately spaced are essential. Long rows increase operating efficiency by minimizing time spent turning into and out of rows. Straight rows help minimize vine injury by mechanical pruners and harvesters. Uniform interrow spacing helps maximize efficiency by allowing use of dual-row implements with minimal adjustment by operators. Adequate interrow spacing facilitates equipment operations by providing room for a range of lateral adjustment by operators. Acceptable row spacing will be determined by the trellis or training system selected, implements to be used, and amount of tangential grade that must be compensated for. Carefully consider which implements or power units will be used in any given vineyard block, and provide adequate row spacing for them. Some over-row tractors and implements can be operated in vineyards with row spacing as narrow as 4 feet, but interrow tractor- or trailer-mounted implements can require 6-foot or wider row spacing.

Vine spacing

On sites with consistent soils, uniform vine spacing is essential for the mechanized vineyard. Unlike hand-executed operations, mechanized operations cannot be sensitive to irregular vine spacing. Variable vine spacing can

lead to fluctuations in leaf-area-to-crop-weight ratios and variable maturation at harvest, a known limiting factor in final product quality. Currently available implements are most compatible with single curtain trellis/training systems, so vine spacing that permits use of these systems is advisable where practical. As mechanization often is not conducive to use of specialized techniques for vine size reduction, such as “kicker” or vigor diversion canes, vine spacing in the middle to upper range of acceptable values for a given cultivar is also advisable.

Headlands

Adequately broad headlands of low grade are needed to provide adequate and safe areas for turning equipment. Although headlands of 25 to 30 feet can be adequate for hand-tended vineyards, headlands of 35 to 40 feet are often needed for mechanized operations. Measure headland width perpendicular to fence lines or other obstructions to gain a true measure of available turning space. Even when only moderate grades are present within vineyard blocks, the risk of rollover can be reduced by modifying the headlands to provide a level or low-grade turning area. In adjacent blocks that share a headland, planting vine rows in both blocks in line with one another can facilitate equipment movement between blocks and minimize time spent turning equipment and aligning implements at the start of each row, thereby increasing efficiency.

Trellising

Trellising is a critical consideration for vineyards seeking a high level of mechanization. All trellis and training systems can be mechanized to at least a limited extent, but some can be more easily and completely mechanized than others. At present, single curtain, cordon-trained systems are the most conducive to full vineyard mechanization. Examples include the high bilateral cordon, midwire cordon with vertical shoot positioning (VSP), and the Smart-Dyson and Ballerina systems. Of these, the former two are often preferred for their simplicity in management, and selection of either should be based upon cultivar growth and bearing habit, anticipated vine size and revenues, and other site or regionally-specific considerations.

In general, mechanization is most easily and cost-effectively employed when the fewest possible trellis systems and training configurations are used. Different trellis or training systems may require different implements, attachments, or adjustments, so using multiple systems will likely increase not only the number of implements required to farm mechanically but also the amount of time required to mount, adjust and maintain equipment.

Stout, high-quality trellises that can withstand strains associated with significant crop loads and occasional equipment impact are needed in a mechanized vineyard. Trellis wires must be kept taut and not allowed to sag between line posts or vine stakes to maintain consistent working heights for equipment (Figure 2). Sag can be avoided by using adequate end assemblies that won't



Figure 2. This mechanized Midwest vineyard trained to high bilateral cordons features long rows of vines with straight trunks, which facilitate mechanization. The consistent height and tautness of the cordon wire are also highly advantageous.

shift over time. Well-constructed tie-back end assemblies typically are adequate for moderate row lengths (up to about 500 feet) and single curtain trellis systems, but internally braced configurations such as H or diagonal thrust assemblies generally are needed for longer rows, divided canopies and high-yielding blocks. Bracing requirements can be reduced through use of spaded end posts, but growers inclined to use them should seek experienced guidance to incorporate them into adequate end assemblies.

Line post spacing and wire gauge also play important roles in minimizing sag. Install line posts or vine stakes at distances of 16 feet or less and use comparatively large-diameter high-tensile wire (11 or 10 gauge) for cordon supports to maintain consistent height.

Metal trellis posts are being used increasingly in mechanically farmed vineyards because of their durability and longevity, and because they ease mechanical harvest. End posts with a narrow in-row profile help assure mechanical pruning operations can be executed without obstruction. Wires must be tensioned adequately, but not excessively. Crimped or “wavy” wire is an excellent choice for mechanized vineyards because the crimps help maintain consistent wire tension throughout the season, thereby minimizing wire sag.

High cordon trellises that place the cordon wire at or as near the top of posts as possible facilitate precise mechanical pruning (Figure 3). Low or mid-wire cordon systems that position catchwires at heights compatible with pruning and canopy management implements, and allow the wires to be placed below the cordon wire during the dormant and early growing season will improve implement access to the working area and increase precision.

Other trellis configurations and components also may be compatible with mechanized vineyard operations. As a full discussion of trellising options is beyond the scope of this publication, advice from a qualified, experienced source should be sought to determine the optimal trellis structure.



Figure 3. In vineyards trained to high cordons, posts or stakes that extend well above the cordon are hazardous to implements and increase the amount of follow-up hand-labor required. Note the rising height of cut made by the pruning machine operator to avoid the abnormally tall vine stake.

Irrigation

The design and installation of systems for irrigation, frost-avoidance or both in a mechanized vineyard should incorporate these recommendations:

- Position drip irrigation tubes and supporting wires at heights where they will not interfere with harvester “fish plates” or working components of other implements.
- Position irrigation riser tubes directly in line with the vine row and in locations where implement impact is improbable to minimize damage by harvesters, pruners and other implements.
- Use flexible tubing for irrigation risers to avoid damage or simplify repairs from accidental equipment impact.
- Position sprinkler heads where injury from equipment impact is unlikely.

In keeping with the desire for high vineyard uniformity, design irrigation zones to irrigate blocks with unique needs separately. At a minimum, the well and pump assembly should be large enough to comfortably irrigate the largest block on the property on a reasonable interval. Electric variable frequency drive (VFD) or petroleum-based fuel engines can efficiently address nonuniform block size and pumping requirements.

Cultivar selection

Cultivars selected for mechanized vineyards should meet the standard criteria of being marketable, adequately profitable, and adapted to prevailing soil and climatic conditions. The latter criterion is particularly important to avoid the risk of winter injury and a subsequent need for retraining, along with potential loss of uniformity in the vineyard.

A high degree of mechanization is possible only with cultivars that can be trained successfully to straight trunks



Figure 4. The second crop (right) cluster on this Chardonal vine will contribute undesirable, immature flavors to the finished product.

and permanent cordons under typical local conditions. Mechanization will be more easily achieved if the selected cultivars possess several additional characteristics, described below.

Short bearing units

Cultivars that yield adequately on relatively short bearing units will likely be easier to mechanize with currently available equipment, which can be adjusted to prune to nearly any desired cane length but cannot prune individual canes within each vine to alternating lengths or adjust cane density within the canopy. This limitation is relatively insignificant for cultivars that bear adequately on short (two-to-three-node) spurs, but for cultivars that require pruning to longer bearing units, it can create a conflict between the need to prune long for productivity but sufficiently short to provide adequate renewal near the cordon for subsequent seasons. Strategies to address this conflict are being developed but need to be refined; the best approach may vary by cultivar. For now, growers pursuing mechanization are encouraged to select cultivars that produce adequately on short bearing units where possible and to perform follow-up hand-pruning as necessary to maintain appropriate renewal spur positions.

Noncount shoots

Grapevine cultivars vary significantly in their tendency to produce fruit on noncount shoots (those emerging from sources other than nodes purposefully retained at pruning). This tendency can be a distinct advantage in terms of maintaining yield after adverse winter or spring weather, but it can also be a disadvantage because fruit from noncount shoots may display delayed maturity relative to fruit borne on count shoots. Additionally, as the nonselective nature of current implements causes them to farm a combination of count and noncount shoots, mechanized crop load management of cultivars producing fruitful noncount shoots can often be more complicated

because of varying numbers of clusters per shoot and varying cluster size between the two shoot types. If minor variations in fruit maturation are unacceptable, select cultivars for mechanization that either produce little noncount crop or mature both crops equivalently.

Second crop

Cultivars producing significant second crop may be problematic for growers seeking a high degree of mechanization. Shoot thinning, positioning and leaf removal machines typically cause at least minimal damage to shoots on the vine. In some cultivars, these injured shoots produce significant lateral shoot growth that bears second crop, which may not mature fully and may subsequently produce unripe flavors in finished products (Figure 4). Selection of cultivars that produce limited amounts of second crop will minimize the amount of hand labor required to thin unripe fruit from the canopy before mechanical harvest. Conscientious mechanical harvester adjustment and operation will also minimize removal of immature fruit that has lower mass.

Vine training

As indicated above, currently available implements for vineyard mechanization are most compatible with cordon-trained vines. The quality and uniformity of vine training employed to establish the semipermanent framework of the vines (trunks and cordons) are important for mechanization of viticultural practices.

Uniform training; straight trunks and cordons

Uniform vine training with straight trunks and cordons is absolutely essential for the mechanized vineyard (Figure 2). Uniform training helps ensure all vines produce similar yields and fruit maturation under mechanized practices. Straight trunks and cordons help minimize vine injury and yield loss from accidental equipment impact. If vines are trained to a trellis with wires attached to the sides of



Figure 5. Training vines to the “post” (left) side of the trellis reduces the width of the trunk/post profile thereby reducing the likelihood of injury from equipment impact.

the posts, trunks should be trained to the post side of the trellis so that the posts afford the trunks some protection from implement impact (Figure 5). Tight heads, where transitions from trunk to cordon are as small and neat as possible, also help reduce impact injury and maximize efficiency of mechanized operations. For bilateral cordon systems, training vines so that cordons cross in the head region helps prevent splitting of cordons should impact occur (Figures 6, 7 and 8). Vineyards established to trellis or training systems requiring mechanical pruners to operate around and between vine trunks will benefit if the vines are trained closely and tied to individual vine stakes (Figure 9).

Wrapping vs. tying cordons

Some growers with mechanization experience suggest cordon renewal may be required more often in mechanized vineyards than hand-farmed vineyards due to the nonselective nature of mechanized operations, but opinions and experience vary. Most growers agree, however, that although cordons must be firmly attached to fruiting wires, excessive wrapping of canes during the establishment phase complicates the task of cordon renewal when it becomes necessary (Figure 6). The three practical means of establishing cordons are to forego wrapping canes and simply tie adequately to develop straight cordons, to wrap loosely (about one turn of the cane for every 1.5 feet of row) and tie intermittently, or to wrap tightly and be prepared to replace both the cordons and fruiting wire when cordon replacement becomes necessary. The aggravation and cost of removing tightly wound cordons may be partially offset by the reduced possibility of the cordons sliding along the fruiting wire, as both mechanical pruners and harvesters can cause significant damage in vineyards where this occurs. Furthermore, cordons that grow tightly around support wires increase rigidity of the trellis/vine structure, which eases harvest and other operations executed through mechanical means.



Figure 6. Cordons crossing tightly and neatly in the head region of the vines are spatially efficient and stabilize one another in the event of equipment impact. However, the tight wraps of cordon around the fruiting wire will complicate cordon replacement, and the training of the trunk to the adjacent vine stake is suboptimal.



Figure 7. The open head of this vine increased its propensity for injury from equipment impact. Note the split trunk (see close-up in Figure 8).



Figure 8. Close-up of the split trunk in Figure 7. Half of this vine will be temporarily lost because the cordons separated during a mechanical pruning incident. The wound is an ideal entry point for pathogens.

Arm formation

Arm formation in the year of cordon establishment must be considered because current mechanized pruning implements cannot adjust cane density in the vine row. This inability can necessitate compromises between bearing unit number (per unit row length) and numbers of retained nodes per unit to achieve desired numbers of retained nodes. In vineyards (and cultivars that bear well from basal nodes) that will be pruned to short bearing units, a relatively high cane density (e.g., 5 to 6 per foot of cordon) may

be advantageous to facilitate tight mechanical pruning with minimal hand follow-up to retain adequate node numbers. Conversely, in vineyards that will be prepruned mechanically to longer bearing units (e.g., 4 to 6 node canes) and subsequently hand-pruned to thin canes and select renewal positions, maintaining a relatively low shoot density (e.g., 3 to 4 per foot of cordon) during the year of cordon formation may minimize hand-labor demands. Growers need to examine their sites, cultivars and principal management objectives to develop the most economical production strategies for their operations.

Information collection and management

Efficient collection and management of significant amounts of information facilitates successful vineyard mechanization. Currently, most data collection activities



Figure 9. This vine trunk was nearly cut off during mechanical pruning. Its position away from the stake and lack of ties to hold it in the appropriate position predisposed it to this injury.

and equipment adjustments are performed manually, so appropriate staffing will be required. Personnel capable of collecting unbiased data, accurately interpreting the resulting information, and monitoring or adjusting implements in response to the information are imperative. In addition, block-specific reference information (such as acreage, row lengths, spacing, pruning weights, shoot counts, historical cluster or berry weights, and desired crop loads) and block maps need to be readily available to aid in making accurate and efficient in-field decisions and adjustments. An electronic data management system using field-ready computers is highly desirable for large operations with numerous blocks or vineyards.

Preparing an existing vineyard for mechanization

As previously mentioned, not all vineyards can be mechanized. Some established vineyards can be mechanized with limited improvements, others will require full retraining and trellis conversion — operations requiring significant capital investment, and yet others may be in such condition that the cost to mechanize would exceed any foreseeable savings. Accordingly, a producer must conduct extensive surveys to determine whether mechanization of an existing vineyard is possible, prudent and likely to be profitable. The primary criteria to consider are vineyard uniformity, vine and vineyard condition, vineyard maturity, and future demand and profitability of the cultivars in the vineyard.

If the vines and vineyard are in good condition, preparations for mechanized operations may be minimal and inexpensive. The following are examples of vineyard characteristics to examine:

- Check the condition of the vines' trunks and cordons and the density of canes and spurs on the cordons. If the trunks are bowed and aging, consider trunk renewal to alleviate potential implement impact problems. If the cordons have numerous dead arms or poorly spaced

Table 1. Checklist for determining established vineyard suitability for mechanized operations.

Vineyard attribute	Desired condition	Potential corrective actions if necessary
Vine uniformity		
Within and between rows	High	Divide block into homogenous units; adjust irrigation zones to match high/low vine size areas; corrective pruning, retraining and crop load adjustment to reestablish uniformity
Vine condition		
Trunks	Straight and healthy	Retrain trunks from scion suckers near graft union or ground level
Cordons	Established, straight and healthy	Establish or retrain cordons from water sprouts near the head
Bearing unit density	Adequate	Corrective pruning if too dense; cordon replacement if too sparse
Cordon arms	Short and of uniform length	Corrective pruning or cordon replacement if too long
Vine size	Moderate to high for vine spacing and trellis	Adjust vine spacing, crop load and/or nutritional and water status as necessary to establish desired vine size
Pathogen/pest status	Free of organisms expected to appreciably shorten vineyard longevity (viruses, phylloxera, etc.)	Retrain or replant vineyard
Training	Uniform	Retrain as necessary
Cultivar		
Market potential	Acceptable to high	Replant or regraft vineyard to marketable cultivar(s)
Cold hardiness	Adequate to escape significant freeze injury in about five out of seven years	Replant vineyard
Bearing habit	Amenable to cordon training and spur pruning	Not applicable (although high retained node numbers can partially compensate for low fruitfulness at basal nodes)
Fruit maturation	Comfortable for available growing season length (crop not maturing at limit of growing season)	Maintain tight control of crop load while transitioning to mechanized operations; replant vineyard to cultivar(s) with appropriate maturity dates
Trellis		
System	Simple and amenable to mechanization	Retrellis and retrain vineyard
End assemblies	Stout and intact	Repair existing assemblies or install improved replacement structures
Line posts	Stout, intact, and spaced to minimize wire sag	Replace failed or weak posts; increase post density to improve trellis rigidity and wire height uniformity
Wire(s)	Uniform height and appropriately tensioned to minimize sag	Repair or replace end assemblies; increase line post density to improve wire height uniformity; tension wires adequately
All components	Compatible with necessary or desired implements	Replace components as necessary or retrellis
Irrigation system		
Zones	Matched to vines of a single cultivar, size and age	Modify irrigation zones
Water supply	Adequate to irrigate all zones on a reasonable cycle	Increase water supply as necessary
Vineyard layout		
Slope	Below 10 percent if rows are perpendicular to slope; below 15 percent if rows are parallel with slope	Terrace inter-row area or replant vineyard
Headlands	Sufficient width for equipment access and turning	Remove vines and reestablish end assemblies as necessary
Vineyard soil		
Moisture drainage	Excellent	Fill swales to establish consistent grade; install artificial drainage
Cover crop	Dense and appropriately competitive (in regions with frequent precipitation during growing season)	Interseed or replace

cane bearing positions, replace cordons in a way that achieves the desired spur density and distribution. If the vines show significant symptoms of crown gall, nematodes, virus or phylloxera, estimate the longevity of the vineyard and the probability that any investment would be lost.

- Be certain the trellis is in good condition and appropriate for the existing cultivars and their size. If it is not, investigate the costs of repairing or retrofitting the trellis.
- If wires are sagging between line posts, look for the cause. Failing end assemblies, excessive line post spacing and inadequate initial tension prior to cordon establishment are likely causes and can sometimes be corrected, often most successfully when done at the same time as trunk or cordon renewal.

Table 1 presents a checklist to help growers determine the suitability of an established vineyard for mechanized operations and the cost-effectiveness of making necessary corrections.

Summary

Vineyard mechanization may offer the grape producer many benefits, such as lower costs of production, reduced reliance on hand labor, increased efficiency through more timely execution of vineyard management operations, and improved fruit quality. These benefits are achievable, however, only for growers who develop a keen understanding of the requirements and limits of vineyard mechanization and of sustainable strategies to succeed within these constraints. Growers wanting to use a high degree of mechanization will find long-term value in well-engineered, purpose-built vineyards with high rates of uniformity.

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