Developing Mechanized Systems for Producing, Harvesting, and Handling Brambles, Strawberries, and Grapes

Justin R. Morris

ADDITIONAL INDEX WORDS. **abscission layer, fruit maturity, mechanization systems, mechanical harvesting, mechanical shoot positioning, mechanical pruning, processing**

SUMMARY. Mechanization of harvesting, pruning, and other cultural operations on many small fruit crops for the processing market has occurred in response to the scarcity and expense of hand labor. Scientists at the Arkansas Agricultural Experiment Station and other experiment stations in the United States and throughout the world have developed new cultural and fruit-handling systems and have determined the effects of these systems on fruit yield and quality. This research has resulted in the development of prototype and commercial machinery as well as production and handling systems that have assisted in mechanization systems for brambles, strawberries (*Fragaria* × *ananassa* Duch.), and grapes (*Vitis* sp.). Much of this body of work is in commercial use and much is simply available, awaiting circumstances that will be beneficial to implementation.

For some crops, harvest labor accounts for as much as two-thirds of the total labor costs. Fruit producers generally use hand labor as long as it is available at a reasonable cost, since mechanization requires large capital investments and often reduces the producer's flexibility to change from one crop to another. Consequently, the technology for mechanization has usually been developed long before implementation.

Migrant workers have provided much of the harvest labor. Until recently, there was little concern for the welfare of these workers by either the employer or the government. Eventually, concern about the problems of the migrant workers resulted in major changes and improvements in wages, housing, education, and health benefits. These developments increased the cost of harvesting and have led to an increased interest in harvest mechanization so that producers can remain competitive and maintain an inexpensive supply of fruit for consumers. This interest in mechanization has brought about developments for producing and harvesting brambles, strawberries, and grapes.

Brambles

HARVESTERS. Successful mechanical harvesting systems have been developed for many fruit, with brambles and grapes being outstanding examples.

Distinguished professor, Institute of Food Science and Engineering, University of Arkansas, 272 Young Ave, Fayetteville AR 72704.

Published with the approval of the Director, Arkansas Agricultural Experiment Station, manuscript #9703. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

The bramble harvester has, with minor adaptations, been used to pick erect and trellised blackberries (*Rubus* subg. *rubus*), black raspberries (*Rubus occidentalis* L.), red raspberries (*Rubus idaeus* L.), and gooseberries (*Ribes hirtellum* Michx.). By the mid-1960s, there were ≈ 30 commercial machines operating in raspberry plantations in the United States (Dale et al., 1995). The prototype developed in 1964 at the University of Arkansas was one of the first harvesters developed and operated by mechanical shaking of the canes (Morris et al., 1978b). The cane fruit develops an abscission layer at maturation, which allows the more mature fruit to be harvested when shaken. All modern self-propelled commercial pickers work on this shaking principle using sets of horizontal beaters positioned in a vertical plane on each side of the row (Fig. 1). These improved beater arms on the modern commercial harvesters allow for a reduction in the number of strokes needed per minute to harvest the fruit, and cause the least amount of damage to the new canes compared to the original prototype.

The range of 100 to 150 strokes per minute at a ground speed of 1 mph ($1.6 \text{ km}\cdot\text{h}^{-1}$) is adequate to harvest only the ripe fruit. This frequency of stroke also provides a complete shaking throughout the hedgerow. This is important, since berries that are allowed to remain in the interior of the hedgerow often develop mold and contaminate the next harvest. Most self-propelled commercial bramble harvesters should have the feature of being able to be raised, lowered and leveled to fit the plane of the field and the height of the canes. The need for this capability is due to the low fruiting habit of many of the cane fruit crops. The Arkansas harvester collects all fruit above 15.5 inches (40 cm) and is only one of several successful cane fruit harvesters currently in use. The commercial model of the Arkansas harvester, with one operator and four field graders, can do the work of 80 to 85 handpickers.

FRUIT QUALITY. Unlike hand harvesting, machines are able to operate at night to allow for the harvesting of fruit at a lower temperature (Morris et al., 1978b). Research and experience have shown that night harvesting is necessary in warm production regions to maximize fruit quality. The mechanically harvested fruit can be of better quality than hand-harvested fruit when all operations are carried out in a proper and timely manner. Machine-harvested berries are larger and have higher total soluble solids, lower acidity, and superior color compared to hand-harvested berries, which generally do not have uniform maturity (Morris et al., 1978b). By machine harvesting at the lowest possible temperature, fruit quality can be maintained during

subsequent handling before processing.

Treating brambles with the growth regulator ethephon before harvest can improve the fruit quality. Ethephon reduces the number of required harvests, increases color, and lowers acidity of both raw and processed blackberries (Morris et al., 1978a; Sims and Morris, 1982). Most insects can be eliminated from cane fruit before machine harvesting by following recommended spray programs for specific insect problems. Of those that remain, 95% can be removed before processing by a washing technique in which infested berries pass through water containing a dilute nonalkaline, anionic wetting agent. There is no loss of quality with this method (Crandall et al., 1966; Christensen et al., 1973).

CULTURAL SYSTEMS. In many cases, modifications of old cultural systems must be made to successfully machine harvest brambles. A mechanical pruner, developed at the University of Arkansas, properly shapes the hedgerow for maximum harvesting efficiency of erect cane fruit (Morris et al., 1978b) and reduces the labor necessary for pruning. Old canes left in the hedgerow, do not affect yield or fruit quality.

Hedgerow culture of erect blackberries is conducive to mechanical harvesting. Five to seven harvests at 4- to 5-d intervals may be required to harvest the entire crop mechanically; therefore, it is desirable to breed for concentrated maturity to reduce the number of harvests. Breeding programs on brambles

Fig. 1. Commercial model of University of Arkansas cane fruit harvester, manufactured and sold by Blueberry Equipment Co., Inc., South Haven, Mich.

at some land-grant institutions, at the USDA, and in Canada have developed cultivars of erect blackberries that adapt well to mechanization (Moore, 1979, 1984). These breeding programs remain active and should continue to produce more cultivars better adapted to mechanical harvesting.

Most blackberry plantings need to be renovated after 5 or 6 years. Renovation can be accomplished by mowing the entire hedgerow to 3 to 4 inches (8 to 10 cm) immediately after the final harvest. All mowed canes should be removed from the field. A mechanical harvester cannot be used in the year following this renovation. However, the fruit from these shorter vines can be hand harvested if an economical supply of labor is available.

The Pacific Northwest has adapted well to mechanical harvesting of brambles. Growers in Oregon machine harvest most of their 1500 acres (600 ha) of black raspberries and most of 8000 acres (2800 ha) of trailing blackberries and hybrid berries (Dale et al., 1995). The lack of rain in harvest season in the Pacific Northwest makes mechanical harvesting feasible. Where rainfall at harvest time is common, harvest days are reduced, and the softer fruit is more easily damaged, as are the primocanes, which then easily succumb to cane death by the fungus *Leptosphaeria coriothyrum* (Fckl.) Sacc. (Dale et al., 1995).

Strawberries

At the University of Arkansas, several harvesting principles had to be evaluated in the process of developing a mechanical harvester for strawberries since, historically, strawberries have been considered one of the crops least adaptable to mechanization (Morris et al., 1978c; Nelson and Kattan, 1967; Nelson et al., 1978).

HARVESTERS. A tractor-drawn prototype of a mechanical strawberry harvester was developed at the University of Arkansas in 1967, and since then it has undergone continual revision (Fig. 2) including development into a self-propelled machine. This prototype was a stripping harvester. It used a reel with alternating brush and comb that raked through the crop. Air suction lifted the berries and foliage (Fig. 3). An airlock berry removal system evacuated the debris while the berries dropped through the airlock valve onto the conveyor. A grower in Copemish, Mich., purchased this machine and suggested that it be built to accommodate two rows for better commercial acceptance. Subsequently, Blueberry Equipment Co., Inc. (BEI), of Michigan modified and produced the University of Arkansas harvester as a two-row hydraulic-powered machine for commercial sale. In those early years, researchers working with the harvesters mentioned and other types of mechanical strawberry harvesters reported picking efficiencies from 31% to 87% (Denisen and Buchele, 1967), 91% to 97% (Morris et al., 1978c), and 24% to 92% (Booster et al., 1970a, 1970b; Booster, 1973.)

In addition to the University of Arkansas harvester, several others have been developed for strawberries. Three different stripping type machines were developed in Italy during this same period (Di Ciolo and Zoli, 1975; Lucignani, 1979; Rosati, 1980), and researchers in Denmark produced a commercial machine called the Danpluck harvester, which uses 62-inch-wide (160-cm) rakes on a sloping belt to lift the berries. A unique finger reel plucks the leaves from the berries as an air ejector expels them. (Thuesen, 1988).

Quick and Denison (1970) described a stripping-type harvester that used a bank of diverging, vibrating ramps instead of a reel. Shikaze and Nyborg (1973) developed a variation on this design by replacing the vibrating action with a bank of small belts. However, there has been no commercial use of these machines. More recently, H. Lee of the University of Guelph, Canada, and Bragg Enterprises in Canada have developed another version of the stripping harvester (Swinkles and Murray, 1991). Their machine uses a reel with cam-controlled finger bars that work through the plants, stripping the strawberries from their peduncles and dumping them through the cam mechanism onto a conveyor system.

The British National Institute of Agricultural Engineering developed a mower-type harvester that was modified by Michigan State University and then commercialized in somewhat different forms by two machinery companies, Smallford Planters of Silsoe, England, and Conners Machinery, Inc. (CMI),

Fig. 2. First commercial single-row mechanical strawberry harvester developed by the University of Arkansas and manufactured by Blueberry Equipment Co., Inc., South Haven, Mich. A two-row harvester was successfully tested and used commercially in Oregon.

of Simcoe, Ontario, Canada (Hansen et al., 1983). The Smallford machine used a cutter bar with fingers that lifted the berries above the bar (Kemp, 1976). The berries were conveyed to a belt where cutting blades clipped the trusses, and debris was blown back into the field. The CMI harvester employed a more effective air-blast system to separate the debris from the berries and used reciprocating clippers to cut berry trusses. The heavy output of this harvester led to the development of mechanisms that would support and allow easy handling of shallow bulk bins and a suitable box-filling system (Lauro and Hergert, 1987). Researchers in Arkansas (Booster, 1973), Oregon (Hecht, 1980) and Germany (Fiedler, 1987) developed similar harvesters, although the German machine used people seated on the harvester to sort and destem the fruit.

Research at the University of Arkansas has shown that certain strawberry cultivars are more adapted to machine harvesting, cleaning, and sorting without loss of quality (Morris et al., 1978c, 1979c, 1980; Nelson et al., 1979). Quality of machine-harvested fruit from certain strawberry cultivars is improved by prior handpicking (Morris et al., 1979c, 1980). Once-over machine harvested strawberries, after one or two hand harvests, have had a higher percentage of ripe berries than fruit machine harvested without a previous hand harvest. The percentage of total soluble solids, firmness, and color intensity of the once-over harvested strawberries after one or two hand pickings was the same or higher than that of hand-harvested fruit (Morris et al., 1980). Sensory quality of fruit puree from both machine-harvested and handpicked fruit was rated as acceptable.

One of the most objectionable aspects of machine-harvested strawberries is the presence of green, immature fruit. Many immature berries can be separated from mature fruit in the processing plant, based on fruit size. However, large green fruit that is sorted with the large ripe fruit eventually ends up in the processed product. Research has shown that strawberry products made from cultivars containing high anthocyanin levels can tolerate as much as 50% immature fruit in the production of commercially acceptable jam (Morris et al., 1979a; Sistrunk and Morris,

1978). Strawberry jam made from 'Cardinal' strawberries, which have extremely high anthocyanin levels, can contain as much as 75% large immature fruit and still be rated acceptable (Spayd and Morris, 1981).

Strawberries are highly perishable. Research has shown that extremely firm-fruited strawberries for processing can be mechanically harvested, properly cleaned and handled, and then held for up to 48 h at 75 °F (24 °C) and up to 7 d at 35 °F (1.7 °C) without excessive quality loss (Morris and Cawthon, 1979). It also showed that fungicide dips before storage suppress mold growth and reduce loss of soluble solids. An acetaldehyde atmosphere and a combination of atmospheres and dips are effective in maintaining good color, freedom from browning and product acceptability of machine-harvested strawberries held for 72 h at 75 °F (24 °C) (Morris et al., 1979a, 1979c). However, these techniques have not been commercially implemented since it has never been practical to use machine-harvested fruit for the fresh market, and berries are usually processed immediately.

Currently, only one strawberry harvester is operating commercially in Oregon. This harvester was developed by the University of Arkansas and manufactured by BEI (Figs. 2 and 3). The machine is used to strip the mature fruit remaining after one or two hand harvests. This fruit is being processed in a puree product. Improvement in strawberry cultivars that would make them better suited for once-over harvest or better suited for multiple harvest, or improvements in harvesting machines will be required before large scale mechanization of strawberries will be used.

Fig. 3. University of Arkansas mechanical strawberry harvester: (a) mowing sickle bar, (b) comb-brush picking and conveying system, (c) fan, (d) airlock valve, and (e) fruit transporting conveyor.

Grapes

Major developments in juice and wine grape harvest mechanization occurred in the early and mid-1960s (Olmo, 1980; Shepardson and Miller, 1962; Shepardson et al., 1969; Studer and Olmo, 1969), and mechanization was practiced commercially by the late 1960s (Johnson, 1977; Marshall et al., 1972). Mechanically harvested grapes can have better quality than hand-harvested grapes when delivered promptly to the processing unit (Whittenberger et al., 1971). Trellising systems suited for mechanical harvesting and other mechanical operations continue to be a major prerequisite to successful harvesting of grapes.

HARVESTERS. Basically, there are two configurations of mechanical harvesters, tractor drawn and self propelled. Cattell (1994) reported that the towed models cost between \$40,000 and \$75,000. These units can generally be justified when the price of hand harvesting is between \$8,000 to \$10,000 a year. These towed units can easily handle 120 acres (48.6 ha) per season. Often, the overriding factor in a decision to purchase a harvester is to have total control over when grapes are harvested.

The self-propelled machines straddle the row and cost between \$120,000 and \$150,000. They can harvest over 247 acres (100 ha) in the course of a season. Grape growers with more than 100 acres (40.5 ha) usually consider the self-propelled units. Since these units have a larger capacity, some growers do custom harvesting as a side line. In the large grape-producing ar-

reas of California, some companies do nothing but custom grape harvesting. These companies use only the over-the-row harvesters. These harvesters can be converted to harvest either a single-wire trellis or a divided double-curtain trellis, which contains two separate foliage canopies.

Many of the commercial harvesters use pivotal strikers, arranged as a double bank of flexible horizontal rods, that strike and shake the vine to remove fruit. They can be operated as in phase or out of phase. In phase means both the front and rear strikers move in the same direction at the same time. This can cause vibrations, which need to be balanced by counter weights. Vibrations are not a problem with the out-of-phase pivotal strikers (the type on most older models). However, depending on the vine growth, they may not pick as well. Conversion kits are readily available to convert the out-of-phase to an in-phase system.

Another principle used in California is the trunk shaker in which two parallel rails impart horizontal vibration to the upper trunk and/or cordon. The trunk shaker is most effective in removing fruit located close to a rigid trunk or cordon, and much less material other than grapes, such as bark, canes, leaves, and petioles, is harvested compared to that with the pivotal striker. Some machines have combined the two principles and reduced the number of horizontal rods.

Another picking head is the bow head or bow rod unit. Construction may vary from manufacturer to manufacturer, but the shaking elements are round commercial plastic bar stock 1 to 1.5 inches (2.5 to 3.8 cm) in diameter and $\approx$ 5 ft (1.5 m) long having the general shape of a closed shepherd's staff (Fig. 4). These horizontally oriented bars move transversely and shake the vine. The shaking action on the leaves is more gentle than with pivotal striker rods, and the longer striking distance results in less defoliation. The bow head also allows for greater harvesting speed. Because of the introduction of the bow head, the trunk shaker is not as popular in California vineyards as it was in the 1980s.

GRAPE QUALITY. The mechanical harvester makes it possible to harvest at night and the advantages of night harvesting cannot be over emphasized. Grapes harvested at night when temperatures are more favorable for deliv-

ery of cooler grapes, result in better quality than grapes harvested in the heat of the day. Research has shown that any type of grape harvested when fruit temperature is high (86 °F or 30 °C and above) will have poor color and produce high levels of alcohol and acetic acid, both of which are signs of microbial spoilage (Morris et al., 1972). The alcohol and acetic acid levels of mechanically harvested grapes begin to rise after 12 h from the time of harvest if grape temperature at harvest is as high as 85 °F (29 °C). Decreases in soluble solids, flavor, and color quality parallel the increases in alcohol and acetic acid (Benedict et al., 1968; Morris et al., 1979b). Off-flavors are present in the processed juice product when alcohol levels reach 0.05%. These studies suggest that grapes produced in hot areas, such as the San Joaquin Valley of California and the southern United States, should be harvested during cool periods of the day or at night to minimize loss of quality (Benedict et al., 1968, 1973; Johnson, 1977; Morris et al., 1979b.)

Adding sulfur dioxide (SO₂) to machine-harvested wine grapes minimizes quality loss during holding (Benedict et al., 1973; Bourne et al., 1963; Christensen et al., 1973; Morris et al., 1972, 1979b; O'Brien and Studer, 1977). An applicator is commercially available that will meter a spray solution of SO₂ onto the grapes before they enter the bins and is employed principally on wine grapes. Addition of 80 to 160 ppm SO₂ immediately after harvest has been shown to slow postharvest deterioration of machine-harvested juice grapes by reducing browning and delaying alcohol accumulation and loss of soluble solids for 24 h (Morris et al., 1979b).

COLLECTION AND HANDLING. Mechanical harvesters have two basic kinds of mechanisms for collecting the grapes: a belt system and a bucket system. Grapes that are juiced during harvesting are better handled with the bucket system. However, the bow rod picking head harvests more intact fruit causing less juicing than the fiberglass rods of the pivotal striker head.

The initial containers used for hauling 'Concords' and other juice grapes to the processing unit were 1 ton (0.9 t) capacity wooden bins with food-grade plastic liners. Many operations have switched to the west coast method, where a 4 to 5 ton (3.6 to 4.5

Fig. 4. Bow rods inserted horizontally in the picking field.

t) capacity, hydraulic, self-dumping vineyard gondola is used to transfer harvested wine or juice grapes into open-top, bulk tank trucks.

GUIDELINES FOR EFFICIENT MECHANICAL HARVESTING. Researchers at the University of Arkansas in cooperation with commercial grape growers have developed guidelines for efficient mechanized harvesting and handling: 1) Select the proper revolutions per min (rpm) of the shaking mechanisms or strikers and the proper ground speed for each cultivar and crop load situation. 2) Establish a time limitation for each cultivar from harvesting to processing plant delivery. 3) Optimize fruit temperature and SO₂ usage. 4) Eliminate problems of material other than grapes (MOG). 5) Cease cultivation sufficiently before harvest to minimize dusty conditions. 6) Inspect the vineyard for foliar-feeding insects and, if necessary, apply sprays sufficiently ahead of harvest. 7) Provide a bin or conveyor inspector as part of the harvesting crew to remove MOG, to watch for plugging of cleaning fans, hydraulic leaks and mechanical failures, and to monitor SO₂ application. 8) Cover harvested grapes at all times and clean the bin after each dumping. 9) Clean mechanical harvesters thoroughly with approved detergent and sanitizer as needed. 10) Install a magnet on the machine's discharge conveyor to collect staples and other iron-containing objects. These guidelines were developed for commercial harvesting of *Vitis labruscana* L. in the eastern United States. Similar guidelines have been or should be developed for each region depending on standards established by the processors.

Specialty grapes

MUSCADINE GRAPES. Muscadines, *Vitis rotundifolia* Michx., are used primarily for wine, and most of these muscadine wine grapes are machine harvested. Muscadines are also sold fresh and as juice, jams, and jelly. Muscadine grapes present a challenge for mechanical harvesting since they grow in small clusters that usually contain 6 to 24 large berries. Mature berries of most muscadine cultivars do not adhere to their pedicel as do those of the bunch grapes. This makes muscadines easy to remove, but can cause the problem of fruit dropping in advance of the mechanical harvester. To prevent the loss of this over-mature fruit,

an extended collecting unit has been designed that is adaptable to the front of any conventional commercial harvester (Morris, 1994). When using the over-the-row mechanical harvesters that have four sets of beater rods, the front two sets can be removed. This allows the beating action to start after the fruit to be removed has completely entered the harvester.

Machine-harvested muscadines may be sorted effectively according to their density, with the denser berries falling into the riper categories (Lanier and Morris, 1979). Density sorting is a rapid and inexpensive method of removing fruit of undesirable maturity. In the 1980s, when North Carolina had a significant commercial muscadine grape industry, one grower built and successfully used this density separation system. However, today the system is used primarily by scientists to evaluate cultivars and cultural systems for their suitability for once-over harvesting from the standpoint of uniform maturation.

RAISINS. Mechanization of raisin harvest has been more difficult than that for other grapes. A severed-cane or harvest-pruning technique to facilitate the mechanical harvesting of 'Thompson Seedless' raisin grapes was reported by Studer and Olmo (1971, 1974). Cutting the fruiting cane near the base and leaving the fruit on the trellis wires for 4 to 8 d until the pedicels dry allows the grapes to be harvested as single berries by any type of vibrating harvester. The individual berries are conveyed into a hopper and then metered and spread evenly on a continuous paper strip. The single berries will dry uniformly without being turned. The dried raisins are picked up by another machine, with metal fingers that run under the paper strip to guide it to revolving brushes, which sweep the raisins onto conveyors that transport them into bulk bins.

Dried-on-the-vine (DOV) raisin production research began in Australia in the late 1950s and early 1960s (May and Kerridge, 1967). Parallel efforts were under way in California where the method was used on 'Black Corinth' and 'Thompson Seedless' cultivars. The efforts on DOV Zante currants (from 'Black Corinth' grapes) were successful (Christensen et al., 1970), but the results with 'Thompson Seedless', the primary raisin grape, were disappointing due to their later

maturity, higher vigor, and larger berry size (Studer and Olmo, 1973). Harvest-pruned 'Thompson Seedless' grapes dried to 25% to 35% moisture after 6 to 9 weeks of vine drying on their standard trellis systems. Attempts to speed up the DOV process included oleate sprays (Petrucci et al., 1974), but as in Australia, adequate emulsion spray coverage was difficult to achieve, and the final product was different from the natural 'Thompson Seedless' raisin (Striegler et al., 1996). The DOV 'Thompson Seedless' raisin sprayed with oleate was not embraced by the consumer. In 1984, the raisin industry enthusiastically embraced the sprayed-on-the-tray (SOT) method of raisin production after shallow consumer testing. That year the industry produced 7,745 tons (7,048 t) of SOT raisins, only to have that production fall to 38 tons (34.6 t) in 1988, because consumers did not buy them. Producers were anxious not to repeat this mistake (Malcolm, 1993).

Although the concept of DOV raisins is an old one, DOV has been given new life through research developments. In the new DOV method, raisins are not sprayed with oil. New trellising systems and newly introduced seedless grape cultivars have made the spraying step unnecessary. Traditionally, in California, raisins are harvested in September and boxed 12 to 21 d later, depending on drying conditions. With the present DOV system, canes are cut in August so the chance of rain is very low.

New trellis systems have been developed for DOV production. These trellis systems follow the general principle of separating the vine canopy into fruiting and nonfruiting zones and are designed also to facilitate mechanization of harvest pruning, the cutting of fruiting canes for drying on the vine. Generally, this year's canes are on the south side of an east-west row and next year's canes are in a catching trellis system that provide for maximum sun exposure. The southern exposure gives adequate sunlight exposure and optimum drying conditions. Australia is also actively reviving the DOV system. They have introduced specialized trellising systems along the above described lines: the Irymple system (Gould and Whiting, 1987), the Shaw system (Shaw, 1986), and the swing-arm system (Clingeffer and May, 1981).

Another manner in which to improve the DOV system is to use specially designed seedless cultivars. Three cultivars are being investigated for use in DOV raisin production. 'Thompson Seedless 2A' is a heat-treated, virus-free clone of 'Thompson Seedless'. It has a proven track record of productivity and is preferred for new plantings of 'Thompson Seedless' for raisins and crushing. 'Fiesta' is a result of a complex cross made in the 1960s at the USDA Horticultural Field Station in Fresno, Calif. It ripens 10 to 14 d earlier than 'Thompson Seedless', produces high quality raisins and, after initial concerns over seed traces were laid to rest, has gained supporters in the last several years [3,840 acres (9,489 ha) in 1996] (Christensen, 1997). 'DOVine' is a recent (1995) release by David Ramming (USDA) as an early ripening (2 to 3 weeks before 'Thompson Seedless') cultivar that is suitable for DOV production (Christensen, 1997). 'DOVine's' high vigor provides potential for a large vine framework and a canopy adapted to more expansive trellising and the demands of cane renewal for DOV. In fact, its greatest potential is with large, expansive DOV trellis systems where the canopy can be spread. Vigor control through controlled drip irrigation and nitrogen fertilization will be necessary in most sites. Vertical or south side systems may not handle the vigor unless these control measures are taken.

All three of these cultivars show appropriate fruitfulness characteristics for DOV. In comparative studies done at the California Kearney Agricultural Research and Extension Center, raisin yields were statistically similar among the cultivars. Berry weights were heaviest with 'Fiesta', followed by 'DOVine' and 'Thompson Seedless 2A'. Airstream sorter raisin grades were similar, except the percentage of substandard berries was higher in 'DOVine' than in 'Thompson Seedless 2A'. Researchers concluded that 'Thompson Seedless' (the 2A clone) will continue to be a dominant cultivar because of its adaptability, versatility,

familiarity, and longevity (Christensen, 1997).

Industry leaders believe the DOV technique has potential for saving money while improving their operation and producing high-quality raisins. The new DOV systems eliminate pickers, turners, rollers, the traditional boxing crew, and even paper trays. There will be savings in crop insurance as it is presently written and on workers' compensation. Estimates of savings run as high as \$300/acre (2.5 ha) with DOV production (Malcolm, 1993).

In 1992, one prototype harvester for DOV production was designed and manufactured by Ag Right Enterprises of Madera, Calif. The unit is operated by hydraulics and uses a radial-forced balanced shaker unit that gently knocks the raisins off the canes into a catcher with a conveyor belt that takes it up to another conveyor unit that deposits the raisins into a bin trailer running in the adjacent row, parallel to the machine. Another prototype harvester system that is currently being evaluated is manufactured by Korvan Industries, Inc., Ore.

More time is needed to evaluate the most cost effective trellis systems, handling, and processing. However, industry is concerned about market analyses and the public's acceptance of the characteristics of DOV raisins. In 1993, one raisin board adopted a long-term policy of gradual market development (Malcolm, 1993).

Other mechanization practices for grapes

PRUNING AND THINNING. Along with mechanical harvesting, other mechanized processes can improve efficiency in grape production. Mechanical pruning can reduce hand labor by as much as 50%. Studies in Arkansas on shoot-positioned 'Concord' grapevines trained to Geneva Double Curtain (GDC), (a system with two adjacent wires $\approx$ 4 ft (123 cm) apart with vines trained on them to form a double curtain of foliage) or bilateral cordon systems (which have one wire with vine cordons running up and down forming a single curtain of foliage) examined the effects of mechanical pruning on yield, vine size, and juice quality. The results showed that continual mechanical pruning of 'Concord' grapes is recommended only in shoot-positioned vineyards where cane selection and adequate node, shoot or fruit limitation follows pruning. Recent data from the author show that mechanical fruit thinning also eliminates the problem of overcropping without the need for hand thinning. Data collected in a commercial vineyard in New York in 1997 showed that it was possible to mechanically thin a machine-pruned vineyard with the Morris-

Table 1. Effect of thinning double curtain 'Concord' grapes grown at Merritt Vineyard, N.Y, 1997. Source: Joint research by Morris, Main, and Dunst funded by New York State Agricultural Experiment Station Viticulture Consortium Research Grants Program.

Treatment	Yield (tons/acre)	Soluble solids (%)	pH	Red pigment (520 nm)
Control	13.5 a ^z	12.7 c	3.24	4.04 c
C-R ^y 250 rpm	9.9 bc	14.2 b	3.27	6.01 b
M-O ^x 200 rpm	11.5 ab	13.7 b	3.28	4.71 bc
M-O 225 rpm	11.0 bc	14.4 b	3.27	6.08 b
M-O 250 rpm	9.2 c	15.2 a	3.25	8.15 a

^zMeans within the same column having the same letters are not significantly different at $\alpha \leq 0.05$.

^yChisholm-Ryder harvester for thinning.

^xMorris-Oldridge thinning unit.

Fig. 5. A Geneva double curtain over-the-row mechanical shoot positioner developed by Tom Oldridge, Lowell, Ark. Adding cutter bars behind converts the machine to a mechanical pruner. These units are used as part of one of the 12 Morris-Oldridge vineyard mechanization systems.

Oldridge thinning unit at 250 rpm and obtain high quality (15.2% soluble solids) 'Concord' juice grapes (Table 1).

SHOOT POSITIONING. Shoot positioning allows for effective mechanical pruning. Shoot positioning of the canes to avoid shading exposes the lower nodes on the bearing units to sunlight, making these basal nodes more productive, and improving fruit quality (Morris et al., 1984). Positioning is particularly effective on the vigorous *V. labruscana* cultivars. Vines are usually shoot positioned for the first time at first bloom, but complete shoot positioning usually requires a second and possibly a third pass (Fig. 5). A properly shoot-positioned GDC system with two separate foliage canopies is more efficient to harvest mechanically than a nonpositioned canopy. A bilateral or single-curtain system that has been shoot positioned is easier to mechanically prune and mechanically harvest

with less damage to fruit and canes.

COMPLETELY MECHANIZED SYSTEMS FOR GRAPES. In a cooperative research effort the author and Tom Oldridge, grape grower and inventor from Lowell, Ark, have developed systems for vineyard mechanization, and we have a pending patent on vineyard machinery and systems. The Morris-Oldridge Sys-

tems provide machines that allow for almost complete mechanization of all vineyard operations. The patent describes a method for complete vineyard mechanization of 12 different trellising systems and methods to modify, trellis, and train grapevines. These developments eliminate expensive hand operations, and production can be economically mechanized without any substantial loss of yield or fruit quality. This patent is the result of studies at the University of Arkansas over the last 32 years that have involved the evaluation of trellising and training systems suitable for complete vineyard mechanization, mechanical shoot positioning, mechanical pruning, mechanical thinning (Tables 1 and 2), mechanical harvesting, and the postharvest handling and use of mechanically harvested grapes (Cawthon and Morris, 1977; Morris, 1985; Morris and Cawthon, 1980a, 1980b, 1981; Morris et al., 1975, 1984).

Currently, two trellising systems can be completely mechanized—the GDC and the single curtain system. In addition, variations of these systems can also be completely mechanized. We have designed a complete mechanization system with the apparatus and methods for the mechanization of, not only the juice grapes of *Vitis labruscana* species, but

Table 2. Effect of thinning and pruning methods on yield and fruit quality of 'Cabernet Sauvignon' grapes grown at Vino Farms, Inc., Lodi, Calif., 1997.

Pruning treatment	Thinning treatment	Yield (tons/acre)	Soluble solids (%)	pH	Tartaric acid (%)	Anthocyanin (mg/cm ³)
Spur pruned control	None	11.4 b ^z	25.2 bcd	3.78	0.54 abc	0.30 bc
Machine	None	15.0 a	23.7 de	3.60	0.57 a	0.31 bc
Machine	M-O ^y (400 rpm)	8.5 c	26.6 ab	3.72	0.51 bc	0.39 ab
Minimal	None	15.2 a	22.4 e	3.52	0.59 a	0.26 c
Minimal	M-O (600 rpm)	10.8 bc	25.2 bcd	3.63	0.55 ab	0.37 ab

^zMeans within the same column having the same letters are not significantly different at $\alpha \leq 0.05$.

^yMorris-Oldridge thinning unit.

Table 3. Effect of leaf removal method on rot, yield, and quality of 'Chardonnay' grapes grown at White Hills Vineyard, Santa Maria, Calif, 1997. Source: Striegler and Berg, Viticulture Enology Research Center, California State University, Fresno.

Treatment	Rot (%)	Yield (tons/acre)	Soluble solids (%)	pH	Tartaric acid (%)
No Leaf Removal	26.5 a ^z	4.4	23.3	3.51	0.85
Hand Removal	10.6 b	5.7	22.8	3.52	0.77
M-O ^y no hand followup	12.4 b	5.5	23.3	3.56	0.79
M-O hand followup	16.1 b	5.4	23.7	3.52	0.92

^zMeans within the same column having the same letters are not significantly different at $\alpha \leq 0.05$.

^yMorris-Oldridge thinning unit.

also *Vitis vinifera* L. and French-American hybrids (*Vitis* interspecies hybrids). The French-American hybrids are interspecific hybrids that vary a great deal in their vine characteristics. Almost all hybrids tend to be extremely fruitful. This fruitfulness is due primarily to the high number of clusters per node and the extremely fruitful basal nodes. These basal nodes are seldom, if ever, fruitful with *V. labruscana* and *V. vinifera* species.

Hand thinning of French-American hybrid vineyards is conducted in the traditional manner to ensure a sustainable fruit load that produces consistently high quality fruit from these cultivars. However, hand thinning is expensive and one of the greatest challenges in producing these cultivars. Mechanical thinning is both economical and successful on these hybrids. Mechanical removal of basal leaves in *V. vinifera* has successfully reduced fruit rot (Table 3) from 26.5% to 16.1% on 'Chardonnay' grapes at Santa Maria, Calif., in 1997. Removal of leaves by hand did not significantly reduce rot over machine removal, and the cost of hand removal was estimated at \$120/ acre (2.5 ha).

Most premium wines produced in the world comes from *V. vinifera* grapes. Wineries pay premium prices for high quality *vinifera* grapes. In some regions, the crop must be limited, and leaf removal is practiced to produce a specific quality, and in others, the crop must be limited to ensure maturity due to a shortened growing season. Also, crop adjustment is used in many grape regions of the world and is even enforced by law in some. These are expensive operations when carried out with hand labor. By mechanizing these operations, grape production for premium wine production should become more profitable.

Conclusions

In brambles and strawberries as well as grapes, mechanization can improve efficiency, but wise use of such mechanization requires careful adaptations to specific crops and sometimes to specific cultivars. For example, although complete vineyard mechanization systems and methods provide the viticulturist with a wide array of tools, careful use and intelligent implementation of each of these tools must be understood for the systems to be successful. Further research and continued improvement in mechanized practices will make completely mechanized systems more efficient. Adoption of completely mechanized systems can potentially mean more reliable, more stable and more economical production of premium quality fruit that will be competitive for the local, regional, national and global markets.

Literature cited

- Benedict, R.H., J.W. Fleming, and M.D. Jones. 1968. Quality of machine-harvested grapes. *Ark. Farm Res.* 17(2):10.
- Benedict, R.H., J.R. Morris, J.W. Fleming, and D.R. McCaskill. 1973. Effects of temperature on quality of mechanically harvested 'Concord' grapes. *Ark. Farm Res.* 22(1):2.
- Booster, D.E. 1973. The mowing method of harvesting strawberries. *Amer. Soc. Agr. Eng. Paper* 73-109.
- Booster D.E., D.E. Kirk, G.W. Varseveld, and T.B. Putnam. 1970a. Mechanical harvesting and handling of strawberries for processing. *Amer. Soc. Agr. Eng. Paper* 70-670.
- Booster D.E., G.W. Varseveld, and T.B. Putnam. 1970b. Progress in the mechanization of strawberry harvesting. *Oregon State Univ. Agr. Expt. Sta. Spec. Rpt.* 305.
- Bourne, M.C., D.F. Splittstoesser, L.R. Mattick, W.B. Robinson, J.C. Moyer, N.J. Shaulis, and E.S. Shepardson. 1963. Product quality and me-

chanical grape harvesting. *Proc. N.Y. State Hort. Soc., Geneva.* p. 227-230.

Cattell, H. 1994. Considerations in buying a mechanical harvester. *Wine East's 1994 buyer's guide to winery and vineyard equipment and supplies.* p. 26-28.

Cawthon, D.L. and J.R. Morris. 1977. Yield and quality of 'Concord' grapes as affected by pruning severity, nodes per bearing unit, training system, shoot positioning, and sampling date in Arkansas. *J. Amer. Soc. Hort. Sci.* 102:760-767.

Christensen, L.P. 1997. How do Thompson Seedless, Fiesta, and DOVine compare in new raisin vineyard planting decisions? *Proc. San Joaquin Valley Grape Symp. Univ. of Calif, Fresno.*

Christensen, P., C. Lynn, H.P. Olmo, and H.E. Studer. 1970. Mechanical harvesting of Black Corinth raisins. *Calif. Agr.* 24(10):4-6.

Christensen, L.P., A.N. Kasimatis, J.J. Kissler, F. Jensen, and D.A. Luvisi. 1973. Mechanical harvesting of grapes for the winery. *Calif Agr. Ext. Bul.* AXT-403.

Crandall, P.C., C.H. Shanks, Jr., and J.E. George, Jr. 1966. Mechanically harvesting red raspberries and removal of insects from the harvested product. *Proc. Amer. Soc. Hort. Sci.* 89:295-302.

Clingeffer, P.R. and P. May. 1981. The swing-arm trellis for Sultana grapevine management. *S. Afr. J. Enol. Viticult.* 2(2):37-44.

Dale, A., E.J. Hanson, D.E. Yarbrough, R.J. McNicol, E.J. Stang, R. Brennan, J.R. Morris, and G.B. Hergert. 1995. Mechanical harvesting of berry crops, p. 255-367. In: J. Janick (ed.). *Horticultural reviews.* vol. 16. Wiley, New York.

Denisen, E.L. and W.F. Buchele. 1967. Mechanical harvesting of strawberries. *Proc. Amer. Soc. Hort. Sci.* 91:267-273.

Di Ciolo, S. and M. Zoli. 1975. Strawberry mechanical harvest with a prototype experimental harvester. *Riv. Ing. Agrar.* 6:3-8.

Fiedler, W. 1987. Entwicklung eines verfahrens der maschinellen erdbeernte und erste einsatzerfahrungen. *Arch. Gartenbau.* 35:379-391.

Gould, I.V. and J.R. Whiting. 1987. Mechanization of raisin production with the Irymple trellis system. *Trans. Amer. Soc. Agr. Eng.* 1987. p. 56-60.

Hansen, C.M., R.L. Ledebuhr, R.L. Van Ee, and O. Friesen. 1983. Systems approach to strawberry harvest mechanization. *Fruit, Nut Veg. Harvest Mech. (Amer. Soc. Agr. Eng.)* 5-84:325-331.

Hecht, C. 1980. 1979—The proving year of the SKH&S harvester of strawberries in Oregon. *Oregon State Univ. (Corvallis) Agr. Expt. St. Bul.* 645. p. 239-240.

Johnson, S.S. 1977. Mechanical harvesting wine grapes. *USDA Econ. Res. Serv. Agr. Econ. Rpt.* 385.

Kemp, I. 1976. Mechanical harvesting of strawberries. *N.Z. J. Agr.* 132:54, 57-58.

- Lanier, M.R. and J.R. Morris. 1979. Evaluation of density separation for defining fruit maturities and maturation rates of once-over harvested muscadine grapes. *J. Amer. Soc. Hort. Sci.* 104:249-252.
- Lauro, E.M. and G.B. Hergert. 1987. Evaluating the technical and economic feasibility of machine harvesting strawberries. *Can. Soc. Agr. Eng. Paper* 87-206.
- Lucignani, M. 1979. Study and design of a new prototype of strawberry harvester working aside the row. *Riv. Ing. Agr.* 10:23-34
- Malcolm, D. (ed.). 1993. New drying and harvesting process developed for raisins: Sun-Maid develops dried-on-vine process. *Amer. Vineyard* 2(9):4-5, 20-21.
- Marshall, D.E., J.H. Levin, B.F. Cargill, and R.T. Whittenberger. 1972. Quality of bulk handled 'Concord' grapes. Presented at the 1972 Ann. Mtg. Amer. Soc. Enol., Univ. of Calif., Davis.
- May, P. and G.H. Kerridge. 1967. Harvest pruning of Sultana vines. *Vitis* 6:390-393.
- Moore, J.N. 1979. Small fruit breeding—A rich heritage, a challenging future. *HortScience* 14:333-341.
- Moore, J.N. 1984. Blackberry breeding. *HortScience* 19:183-185.
- Morris, J.R. 1994. Mechanical harvesting and vineyard mechanization. *Wine East's 1994 buyer's guide to winery and vineyard equipment and supplies.* p. 4-23.
- Morris, J.R. 1985. Approaches to more efficient vineyard management. *HortScience* 20(6):1008-1013.
- Morris, J.R. and D.L. Cawthon. 1979. Postharvest quality of machine-harvested strawberries. *J. Amer. Soc. Hort. Sci.* 104:138-141.
- Morris, J.R. and D.L. Cawthon. 1980a. Mechanical trimming and node adjustment of cord-on-trained 'Concord' grapevines. *J. Amer. Soc. Hort. Sci.* 105(3):310-313.
- Morris, J.R. and D.L. Cawthon. 1980b. Yield and quality response of 'Concord' grapes to training systems and pruning severity in Arkansas. *J. Amer. Soc. Hort. Sci.* 105(3):307-310.
- Morris, J.R. and D.L. Cawthon. 1981. Yield and quality response of 'Concord' grapes (*Vitis labrusca* L.) to mechanized vine pruning. *Amer. J. Enol. Viticult.* 32:280-282.
- Morris, J.R., J.W. Fleming, R.H. Benedict, and D.R. McCaskill. 1972. Maintaining juice quality of 'Concord' grapes harvested mechanically. *Ark. Farm Res.* 22(1):3.
- Morris, J.R., D.L. Cawthon, and J.W. Fleming. 1975. Effect of mechanical pruning on yield and quality of 'Concord' grapes. *Ark. Farm Res.* 24(3):12.
- Morris, J.R., D.L. Cawthon, G.S. Nelson, and P.E. Cooper. 1978a. Effect of daminozide and ethephon on yield and quality of erect blackberries. *J. Amer. Soc. Hort. Sci.* 103:804-806.
- Morris, J.R., G.S. Nelson, A.A. Kattan, and D.L. Cawthon. 1978b. Developing a mechanized harvesting and production system for erect blackberries. *HortScience* 13(3):228-235.
- Morris, J.R., A.A. Kattan, G.S. Nelson, and D.L. Cawthon. 1978c. Developing a mechanized system for production, harvesting and handling of strawberries. *HortScience* 13:413-422.
- Morris, J.R., D.L. Cawthon, and R.W. Buescher. 1979a. Effects of acetaldehyde on postharvest quality of mechanically harvested strawberries for processing. *J. Amer. Soc. Hort. Sci.* 104:262-264.
- Morris, J.R., D.L. Cawthon, and J.W. Fleming. 1979b. Effects of temperature and SO₂ addition on quality and postharvest behavior of mechanically harvested juice grapes in Arkansas. *J. Amer. Soc. Hort. Sci.* 104:166.
- Morris, J.R., G.S. Nelson, D.L. Cawthon, and R.W. Buescher. 1979c. Acetaldehyde effects on postharvest quality of machine-harvested strawberries. *Ark. Farm Res.* 28(3):10.
- Morris, J.R., S.E. Spayd, D.L. Cawthon, A.A. Kattan, and G.S. Nelson. 1980. Response of seven strawberry clones to hand picking prior to once-over machine harvest, p. 15-24. In: L. Martin and J.R. Morris (eds.) *Strawberry mechanization*. Oregon State Univ. Expt. Sta. Bul. 645.
- Morris, J.R., D.L. Cawthon, and C.A. Sims. 1984. Long-term effects of pruning severity, nodes per bearing unit, training system and shoot positioning on yield and quality of 'Concord' grapes. *J. Amer. Soc. Hort. Sci.* 109(5):676-683.
- Nelson G.S. and A.A. Kattan. 1967. A mechanical harvester for strawberries. *Ark. Farm Res.* 16(4):2.
- Nelson G.S., J.R. Morris, A.A. Kattan, and K.P. Shelby. 1978. Mechanical system for harvesting and handling strawberries for processing. *Trans. Amer. Soc. Agr. Eng.* 19:21-26.
- Nelson, G.S., J.R. Morris, and K.P. Shelby. 1979. In-plant equipment for handling machine-harvested strawberries. *Ark. Farm Res.* 25(6):8.
- O'Brien, M. and H.E. Studer. 1977. Closed and open transport and sampling of wine grapes. *Trans. Amer. Soc. Agr. Eng.* 20:631.
- Olmo, H.P. 1980. Mechanical harvest of grapes, p. 187. In: Univ. Calif. Davis Grape and Vine Centennial Symp. Proc.
- Petrucchi, V.E., N. Canata, H.R. Bolin, G. Fuller, and A.E. Stafford. 1974. Use of oleic acid derivatives to accelerate drying of Thompson Seedless grapes. *J. Amer. Oil Chem. Soc.* 51(3):77-80.
- Quick, G. R. and E.L. Denison. 1970. A strawberry harvest mechanization system. *HortScience* 5:110-151.
- Rosati, P. 1980. Mechanization of the Italian strawberry industry. Oregon State Univ. (Corvallis) Agr. Expt. Sta. Bul. 645. p. 66-69
- Shaw, I. 1986. Development of specialized trellis drying systems. Hanging cane, p. 93-94. In: I. Ballantyne and I. Macrae (eds.). *Trellis drying and mechanical harvesting of grapes*. Dept. of Agr. Rural Affairs, Conf. Proc. Ser. 7.
- Shepardson, E.S. and W.F. Miller. 1962. Progress report: Mechanical grape harvester research. N.Y. State Agr. Expt. Sta. (Geneva) Res. Rpt.
- Shepardson, E.S., N.J. Shaulis, and J.C. Moyers. 1969. Mechanical harvesting of grape varieties grown in New York State, p. 571. In: B. Cargill and A. Rossmiller (eds.). *Fruit and vegetable harvest mechanization*. Rural Manpower Center, Mich. State Univ., East Lansing.
- Shikaze, A. and D.R. Nyborg. 1973. Mechanical strawberry harvester trials. *Can. Soc. Agr. Eng. Paper* 73-320.
- Sims, C.A. and J.R. Morris. 1982. Effects of cultivar, irrigation, and ethephon on the yield, harvest distribution, and quality of machine-harvested blackberries. *J. Amer. Soc. Hort. Sci.* 107:542-547.
- Sistrunk, W.A. and J.R. Morris. 1978. Storage stability of strawberry products manufactured from mechanically harvested strawberries. *J. Amer. Soc. Hort. Sci.* 103:616-620.
- Spayd, S.E. and J.R. Morris. 1981. Physical and chemical characteristics of puree from once-over harvested strawberries. *J. Amer. Soc. Hort. Sci.* 106:105-109.
- Striegler, R.K., J.R. Morris, and G.T. Berg. 1996. Raisin production and processing, p. 235-265. In: L. Somogyi (ed.) *Processing fruits: Science and technology*. vol 2. Technomic Publ., Lancaster, Pa.
- Studer, H.E. and H.P. Olmo. 1969. Mechanical harvesting of grapes in California: Cultural practices and machines, p. 611-625. In B. Cargill and A. Rossmiller (eds.). *Fruit and vegetable mechanization*. Rural Manpower Center, Mich. State Univ., East Lansing.
- Studer, H.E. and H.P. Olmo. 1971. The severed cane technique and its application to mechanical harvesting of raisin grapes. *Trans. Amer. Soc. Agr. Eng.* 14:38.
- Studer, H.E. and H.P. Olmo. 1973. Vine-drying of Thompson Seedless grapes. *Calif. Raisin Adv. Board Raisin Res. Rpt.* 1973. p. 960-970.
- Studer, H.E. and H.P. Olmo. 1974. Parameters affecting the quality of machine-harvest raisins. *Trans. Amer. Soc. Agr. Eng.* 17:783.
- Swinkles, P.M. and R.A. Murray. 1991. Development of the Bragg strawberry harvester, p. 266 In: A. Dale and J.J. Luby (eds.). *The strawberry into the 21st century*. Timber Press, Portland, Ore.
- Thuesen, A. 1988. Maskinhost af industrijordbaer Gron Viden 141, Denmark
- Whittenberger, R.T. D.E. Marshall, J.H. Levin, and B.F. Cargill. 1971. Bulk handling of 'Concord' grapes for processing: Quality evaluation. Presented at Annu. Mtg. Amer. Soc. Agr. Eng., St. Joseph, Mich.