The Status of Labor-saving Mechanization in U.S. Fruit and Vegetable Harvesting

By

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A. Introduction

Farmers advanced through oxen, horses and mules, steam tractors and then tractors with internal combustion engines to provide power on farms. Tractors started to be a competitive source of power in the early 20th century as progress moved from steam to internal combustion engines and steel to rubber tires. Early reapers and binders were forerunners of stationary threshing machines and mobile combines or mechanical harvesters for grain, beans and cotton, which became available over 1930-1960s. However, hand harvesting of fruits and vegetables continued into the early 1970s. The invention and later adoption of the self-propelled processed tomato harvester in the mid-60s was a major labor-saving factor in fruit and vegetable harvesting. However, as later related inventions occurred, further labor-saving and product quality improvements occurred. Mechanical harvesters have been developed for some of the other processing fruit. Although fresh fruit and vegetable harvesting continues largely by hand, mechanical aids have made the harvesting process faster and with less stress on workers’ backs.

U.S. agriculture competes with other sectors of the economy for inputs of labor, chemicals, building materials, and land. Since the 1980s, increasing international competition in fruits and vegetables has occurred with, for example, Mexico and Chile, as low cost supplier of fresh fruits and vegetables. However, U.S. growers have for an extended period drawn upon

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1 The author is C.F. Curtiss Distinguished Professor of Agriculture and Life Sciences and Professor of Economics, Iowa State University. All cost of production estimates for CA fruits and vegetable were taken from the most recent U. of CA, Davis, CostStudies.com. Earlier version of the paper was presented at “Immigration Reform: Implications for Farmers, Farm Workers and Communities,” Washington, DC, May 27-28, 2010.
illegal and legal workers from Mexico for planting and harvesting labor in these crops. In particular, mechanization, modification of production practices and improved management practices have been central to reducing labor requirements for growing and harvesting fruits and vegetables. This paper provides a description of important steps in the mechanization of U.S. fruit and vegetable harvesting, which can be very labor intensive. Several figures are included as an aide to visualizing these technologies.

B. Mechanization of Processing Fruits and Vegetables

Although the most storied success in mechanical fruit and vegetable harvesters is the self-propelled Johnson Tomato Harvester in California, mechanical harvesters are being used by growers to harvest fruits and vegetables for processing elsewhere.

CA Tomatoes

Research and invention to mechanize harvesting of processing tomatoes in California was spurred by the anticipated end of the Bracero Program in 1964. In the 1950s, 5.3 hours of harvesting labor was required per ton of processed tomatoes. In 1950, Hanna, Department of Vegetable Crops, and Lorenzen, of the Department of Agricultural Engineering, both at UC Davis, began development of a system for mechanically harvesting processing tomatoes. Hanna began breeding a tomato that could withstand the stress of mechanical handling, would ripen uniformly and would detach from the plant during machine harvesting. Lorenzen worked on a machine that cut the plant at soil level and lifted it to a shaking mechanism. In the late 1950s, another UC Davis agricultural engineer developed a fruit-vine separator for Lorenzen’s machine. By 1960, the University of California had obtained patent for the new tomato variety, and the Blackwelder Manufacturing Company, Rio Vista, CA, undertook manufacturing and selling the first mechanical tomato harvesters.
This early mechanical tomato harvester cut the tomato plants at soil level and lifted them up into a shaking mechanism or separator that separated the fruit from the vines. Twelve workers rode on the early machines to sort the fruit, remove green or blemished tomatoes and clods of dirt, requiring 2.9 hours of harvesting labor per ton of fruit, which a 60% reduction from hand harvesting. The tomatoes are conveyed directly into pallet bins that were transported on a trailer pulled beside the harvester (Thompson and Blank 2000).

In 1964, 75 harvesters sold in California and in 1965, 250 were sold, yielding a combined capacity to harvest roughly 25% of the tomato crop. In 5 years, 95 percent of the CA processing tomato crop were harvested by machine at major social gain (Schmitz and Seckler 1970). In the mid-1970, a further major technical advance occurred with the invention of high-speed electronic color sorters, which identified and use blasts of air to separate ripe fruit from green and rotten tomatoes and clumps of dirt. Combined with a new brush shaker innovation, labor requirements were reduced from 12 to 2-4 hand sorters per machine or to 0.4 hour per ton (figure 1). Over 35 years, harvest labor requirement per ton of CA processing tomatoes dropped 92%.

Current models of the Johnson self-propelled tomato harvester (figure 2 and Appendix A), sold by the CA Tomato Company, are equipped with two 32-channel high-speed color and dirt sorters and use 2-4 hand sorters. They have a maximum capacity of 70 tons per hours and regularly are operated in two 10-hours shifts. The new cost is over $450,000. Under this new technology for California processing tomatoes, yield per acre and total production have increased increased from 3 million tons (and 69% of total US tonnage) in 1965 to about 12 million tons in 2010 (and 96% of total US tonnage).²

² In the 1960’s U.S. production of processed tomatoes was divided among three areas: California, the Eastern states of New Jersey, Delaware, Maryland, Pennsylvania, Virginia and New York and the Midwestern states of Indiana, Illinois, Ohio and Minnesota. Now only 4% of production is outside of California.
Midwest and Eastern Tomatoes

The Pik Rite Company has been a leader for inventing and manufacturing tractor drawn harvesters for small scale fruit and vegetable harvesting in the U.S. Midwest and Eastern. The founder of the company built his first small capacity mechanical tomato harvester in 1983, and after three years of improving and testing, sales began in 1986.

The Model 190 is a low capacity, 30 to 40 ton per hour, harvesting machine with a lateral rotating single-brush-shaker system (figure 3).\(^3\) This machine has high-speed optical color sorters with blasts of air as an aid to the separation of ripe tomatoes from green ones and chunks of dirt. The cost of this machine is $150,000-$160,000 and has a work life of 12-15 years, but harvesting costs are substantially higher in this area than in CA. The Pik Rite tomato harvester is in use in Indiana, Michigan, Ohio and Pennsylvania.

Midwestern and Eastern Cucumber, Carrots and Peppers

Pik Rite also develops and markets tractor drawn mechanical harvesters for processing cucumbers, carrots and peppers. The cucumber harvester has a special dirt removal system that uses blasts of air along with a “scrubber” belt to remove trash (see figure 4). It also has non-pinch conveyor chains spaced so small and medium sized cucumbers are saved and elevated to a storage bin, but oversized fruit exit with the vines into the field for better harvesting efficiency. This separation process is aided by blasts of air blowing the vines and chaff upward and out of the rear of the machine. The 125 bushel (6,250 lb) hopper unloads in 20 seconds.

\(^3\) The model HC 290 is a high capacity, 70-80 tons per hour, harvesting machine with a dual lateral brush-shaker system.
Florida Oranges

In Florida, Valencia oranges are grown to be processed into orange juice. Historically these trees were hand-picked by workers on ladders with a bag and when the bags were filled, the fruit was transferred to a large metal box. This was hard, dangerous work.

Currently several companies, e.g., Coe-Collier, OXBO, and Koran, are companies that manufacture and sell tree fruit harvesters to Florida orange growers. These machines are basically of two types. One type is a shake-and-catch system consisting of a two-part self-propelled unit, with the main power unit grasping the trunk of the tree. The second part of the harvester moves along the opposite side of the tree, and it contains a system to collect the fallen fruit, store the fruit and convey the fruit into a truck to be transported to a semi-trailer at the edge of the grove. The two units lock together around the trunk (or limb) and both have a slopping to the middle catchment rail system, e.g., see the Coe-Collier trunk shaker and receiver in figure 5. The power unit shakes the trunk (or limb) of the tree, and this hopefully dislodges the fruit so that it falls on the catchment rails, rolls to the middle and is conveyed into a truck. However, the stems of citrus fruit is tightly attached to the tree limbs, and this type of citrus harvesting machine shake the trunk extremely hard in order generate enough force to dislodge fruit. However, the severity of this shaking can seriously damage the bark on the orange trees, and orange growers in Florida are not currently using the shake-and-catch harvester. A very similar harvested is, however, used for processing plum harvesting in California where the ripe fruit detach more easily.

The second type of mechanical processing oranges harvester is the canopy-shaker system. With this system, a tractor drawn machine containing rotating bats is pulled alongside of a row
of trees containing ripe fruit. The rotating bats then dislodge the fruit, and it falls to the ground (OXBO machine in figure 6). It is then picked up by hand labor or rakes and windrow machines gather and collect the fruit, and remove leaves and trash. OXBO also makes a tree canopy-shaker with a catching table (see figure 7).

The U FL has experimented with fruit loosening agents, called abscission. This chemical is used to easily dislodge ripe fruit from the orange trees and reduce the damage of mechanical harvesting. However, mechanical harvesting of Valencia oranges posses an additional problem in that they contain two seasons of fruit at one time. One is mature fruit that is ready for harvest and the second is the young crop of oranges intended for the next year’s harvest. A successful abscission chemical should selectively loosen only the mature fruit, leaving the young crop unaffected. Also, there is a small window when the rotating bats in a canopy-shaker do not dislodge a significant share of next year’s premature oranges.

A little experimentation has been done with robotic harvesters that use GPS to scout fruit location and then to pick fruit. However, electronic assessment of tree fruit is complicated by the fact that tree limbs and unripe fruit may block the view of the electronic eyes. Overall, because of tree damage, tightly clinging fruit and two-crops on tree at one time, mechanical processing orange harvesting is a technology with a low adoption rate (6-12%) in Florida (Roka 2010).

Other crops

Mechanical harvesters for processing tart cherries have been successful in Michigan. The machine is of a shake-and-catch type (see figure 8). This is a two-part self-propelled unit similar figure 5, except the catching table is continuous. Ripe tart cherries bruise some in this harvesting system, but since the cherries are going immediately for processing, the damage has not been
viewed as significant. A large share of Michigan sour cherries are now harvested with this type of mechanical harvester.

For middle- and low-end CA wine grapes, mechanical harvesters are used for more than one-half of the harvested acres. These machines are a relatively tall self-propelled unit that straddles the trellised grapevine row. The harvested has rotating arms that dislodge the fruit which is then caught on a table and conveyed into a wagon, see Korvan machine (figures 9).

Korvan also manufactures and sells a mechanical berry picker for processing berries (largely for raspberries and blue berries). This machine is also self-propelled and surrounds the row of berry bushes similar to the wine grape harvester (figure 10). This machine does some damage to the fruit, but since it is going immediately for processing this is not a serious problem.

C. Mechanization of Fresh Fruit and Vegetable Harvesting

Mechanical harvesters for fresh fruits and vegetables are largely experimental. Fresh market CA iceberg and organic lettuce, melons, strawberries and tomatoes have substantial harvesting costs and harvester-aids have reduced the workload. For example, with iceberg lettuce, the head is cut by hand, laid on a table that conveys it to the center and workers on the wagon field wrap it in plastic and place 32-heads per box, which are stacked on the wagon. This process has significantly reduced the cost of harvesting and packing iceberg lettuce. A similar process is applied to melons, except then a packed directly into boxes with plastic wrap. Although the hand harvesting cost of fresh market CA strawberries is very high, about $615 per ton, this high-value delicate crop, which grows close to the ground and does not ripen uniformly, is difficult to mechanical harvest.

Washington State University and USDA-ARS scientists have developed a mechanical harvester for fresh market sweet cherries and apples (Peterson 2005). A chemical fruit loosening
agent (abscission) is first applied to the fruit a few days before harvesting. The mechanical harvester is a two-part self-propelled machine with each part going on opposite sides of the trees. Cushioned catcher pans on each unit are used to seal around the trunk and connect the two units. The harvester has a high density rubber arm on each unit that bumps the tree branches and this energy dislodges the cherries from their stems (see figure 11). Both harvesting units have inclined catchment tables, but the mechanical conveyors are covered with a soft material that reduces impact and the conveyors move the fruit gently to the outer top side of each of the machines catching tables. As the fruit rolls over the table a fan blows away leaves and trash, and the fruit passes to two slowly rotating modest sized storage bins or boxes.

A problem with mechanical harvesting of cherries is that they are stemless, and consumers like the cherries with stems, which come with hand-harvested fruit. A benefit to growers and consumers is that mechanically harvested cherries have less bruising or damage than from hand harvested fruit and reduced exposure to bacterial laden human hands. The major stumbling block to the mechanical cherry harvester is that the groves of trees need a new type of architecture relative to existing groves of threes which contain trees that are 20-25 feet tall and bushy. To be able to mechanically harvested the cherries, trees need to be short and have a “Y” shape (see figure 11). The mechanical sweet cherry harvester has excellent long term potential for harvesting high quality sweet cherries for the fresh market at an 80-90% reduction in harvest labor costs (Whiting 2006).

A machine similar to that developed for fresh sweet cherries has been developed and tested for harvesting apples for the fresh market. However, apple trees need to have uniformly ripening fruit and be relatively short, and the architecture of the tree needs to be of a trained “Y”
shape growth habit (see figure 12). As with sweet cherries, the quality of mechanically harvested fruit meets or exceeds that of hand-picked fruit.

The new BEI Black Ice Harvester works with delicate bush berries—raspberries, blackberries and blueberries. The Black Ice Harvester uses jets of air to create a turbulent local environment within the machine and around the berries, which then gently dislodge those that are ripe. The machine has padded walls, the berries fall onto a bed or table (the Centipede Scale catching frame) and then are gently conveyed to a one pound container or smaller that is carried on the machine (figures 13). A major advantage of this machine is that berries and bushes are not being touched by a picking mechanism. This helps minimize the potential for damaging the ripe fruit and scarring the bushes, which could make the plant more susceptible to frost damage and diseases. The harvester can be used to re-harvest the same row multiple times as the berries ripen at different dates. Fruit quality meets or exceeds that of hand-harvested fruit, and since no human handing of the fruit is required in the harvesting and packing, there are reduced food safety concerns. The machine is experimental being tested by a small number of berry farmers. Its estimated cost is $150,000 for the smaller rear-loading model and $200,000 for a larger top-loading model.

D. A Perspective on the Future of Mechanization

The future mechanization of additional crops will be driven largely by benefit-cost considerations, including the likely future international competitiveness of the U.S. industry. Relatively good machines exist for mechanically harvesting fruits and some vegetables that are destined for processing. The most exciting finding is that there are new and effective harvesters that are in the final stages of testing for fresh market berries, apples and sweet cherries. These technologies would move forward rapidly if there is a sudden increase in the cost of harvesting
labor or uncertainly of availability of this type of labor. Further, these machines have real 
potential for adaptation to other crops so that they could be used to harvest other fresh market 
crops. However, a short-turn hurdle is that the tree and vine architectures are not compatible with 
the new harvesting systems. Over time these orchards can be replaced with shorter and trellised 
trees and vines. Uniform ripening of fruit and berries is critical to the success of these new 
harvesting systems, but one new type of harvester does not damage bushes being harvested and 
repeated trips at 3- or 7-day intervals are possible.
E. References


Figure 1. Typical harvest labor use and annual production of processing tomatoes California, 1960-1997 (Thompson and Blank 2000).
Figure 2. Self-propelled Johnson mechanical tomato harvesters
Figure 3. Pik Rite 190 tractor-drawn mechanical tomato harvester
Figure 4. Pik Rite tractor-drawn mechanical cucumber harvester
Figure 5. Coe-Collier self-propelled trunk shaker and receiver harvesting oranges in Florida
Figure 6. OXBO tractor-drawn tree canopy shaker harvesting oranges in Florida – fruit falls on ground to be gather up
Figure 7. OXBO self-propelled fruit-tree canopy shaker with catching table
Figure 8. Self-Propelled mechanical sour cherry tree harvester – shake, catch and covey method
Figure 9. Korvan self-propelled mechanical (wine) grape harvester
Figure 10. Korvan self-propelled mechanical berry picker – raspberries and blueberries.
Figure 11. Self-propelled mechanical fresh market sweet cherry harvester, WSU and USDA-ARS (late experimental stage)
Figure 12. Self-propelled mechanical fresh market apple harvester, WSU & USDA-ARS (late stage experimental)
Figure 13. BEI International, Black Ice Harvester for berries using air jets.
Appendix A. New Self-propelled Johnson Mechanical Tomato Harvester