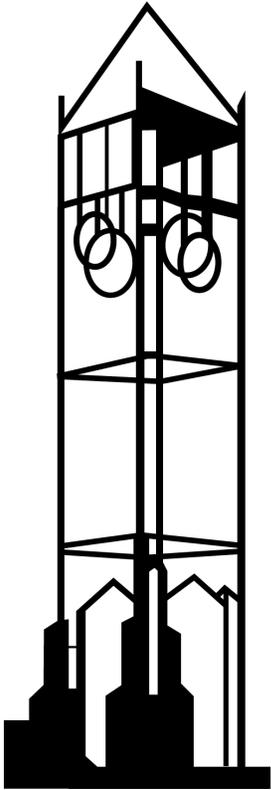


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Wallace E. Huffman



Working Paper No. 12009
July 2012

IOWA STATE UNIVERSITY
Department of Economics
Ames, Iowa, 50011-1070

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July 20, 2012

The Status of Labor-saving Mechanization in U.S. Fruit and Vegetable Harvesting: A Further Update

Wallace E. Huffman¹

Abstract: This paper provides a description of important steps in the mechanization of U.S. fruit and vegetable harvesting, which can be hard, backbreaking work, and in addition, the risk of falling is significant for hand-harvesting fruit trees from ladders. Switching to mechanical harvesting frequently requires the transformation of a farming operation, e.g., new crop varieties, new field configurations, and new packing processes. In addition, a significant capital outlay is frequently required. Progress in mechanization varies a great deal across fruit and vegetable crops.

Key Words: Mechanization, fruits, vegetables, mechanical harvesters, United States

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 conferences on immigration and agriculture in Washington, DC, May 27-28, 2010, and April 26, 2012.

A. Introduction

Farming 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, with later related inventions, further saving in labor and improvement in product quality were the result. Mechanical harvesters were developed for some other processing fruits. Although fresh fruit and vegetable harvesting continues largely by hand, mechanical aids have made harvesting 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, an increase in international competition in fruits and vegetables has occurred with, for example, Mexico and Chile, as low cost supplier of fresh fruits and vegetables (Calvin and Martin 2010). However, for an extended period U.S. growers have drawn upon illegal and legal workers from Mexico for the 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 the growing and harvesting of fruits and vegetables. Calvin and Marten (2010) report that 75 percent of vegetables and melons and 55 percent of fruit are mechanically harvested, but mechanically harvesting is most prevalent produce for harvesting. In 2009, the largest volume U.S. fruit and

vegetable crops (in millions of tons) are: tomatoes (15.6), oranges (9.2), grapes (7.3), apples (5.0), potatoes (4.1), melons and cantaloupes (3.2), head lettuce (2.5), sweet corn (1.5), strawberries (1.4) and carrots (1.1). (USDA, NASS 2010).

This paper provides a description of important steps in the mechanization of U.S. fruit and vegetable harvesting, which can be hard, backbreaking work, and in addition, the risk of falling from a ladder is significant for hand-harvesting of fruit trees. Consumers demand fresh market produce that has minimal blemishes, bruises or damage, which usually eliminates mechanical harvesting. However, a small amount of damage in harvesting is permitted for fruits and vegetables destined for processing, and mechanized harvesting can sometimes bring major cost savings. However, switching to mechanical harvesting frequently requires a transformation of a farming operation, e.g., new crop varieties, new field configurations, and new harvesting and packing processes. In addition, a significant capital outlay is frequently required. Several photographs are included as an aide to visualizing mechanical harvesting 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 a 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, or a 60 percent reduction from hand harvesting. The tomatoes are conveyed directly into pallet bins that are 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 percent 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-1970s, a further major technical advance occurred with the invention of high-speed electronic color sorters, which identified and used blasts of air to separate ripe fruit from green and rotten fruit and clumps of dirt. With improved leveling and ridging of tomato fields, new tomato varieties and 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, this dominant CA technology has reduced labor requirements per ton of CA processing tomatoes by 92 percent.

Current models of the Johnson self-propelled tomato harvester (figure 2 and Appendix A) sold by the CA Tomato Machinery Company are equipped with two 32-channel high-speed color and dirt sorters, use 2-4 hand sorters, and cost roughly \$450,000 with a life of 15-20 years under intensive post-harvest maintenance. They have a maximum capacity of 70 tons per hour and regularly are operated in two 10-hours shifts. Total harvesting costs are about \$28 per ton. Under this new technology for California processing tomatoes, yield per acre and total production have increased from 3 million tons (and 69% of total U.S. tonnage) in 1965, to about 12 million tons in 2010 (and 96% of total U.S. tonnage).²

Midwestern and Eastern Tomatoes

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

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, roughly \$48 per ton, in this area than in CA. The Pik Rite tomato harvester is in use in Indiana, Michigan, Ohio and Pennsylvania.

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 percent of production is outside of California.

³ The model HC 290 is a high capacity, 70-80 ton per hour, harvesting machine with a dual lateral brush-shaker system.

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 that 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. This machine can unload a 125 bushel in 20 seconds.

Florida Oranges

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

Currently several companies, e.g., Coe-Collier, OXBO, and Koran, 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 are tightly attached to the tree limbs, and this type of citrus

harvesting machine shakes the trunk extremely hard in order generate enough force to dislodges fruit. However, the severity of this shaking can seriously damage the bark on the orange trees, and orange growers in Florida have a low frequency of use of the shake-and-catch harvester. A very similar harvester is used for California processing plum, where the ripe fruit detach more easily.

The second type of mechanical harvester for processing oranges is the bat-shaker system. With this system, a tractor drawn machine containing rotating bats is pulled alongside a row of trees containing ripe fruit. The rotating bats then dislodge the fruit, and they fall to the ground. The fruit is then picked up by hand labor or rakes, and windrow machines gather and collect them. OXBO also makes a tree canopy-shaker with a catching table. Only the self-propelled shake-and-catch system is being used by Florida orange growers (Calvin and Martin 2010).

Oranges remain firmly attached to the tree when ripe, which hinders mechanical harvesting. The U FL has experimented with fruit loosening agents—abscission. When applied, this chemical loosens the stems so the ripe fruit is more easily dislodged, which reduces damage from mechanical harvesting. However, mechanical harvesting of Valencia oranges poses 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 is applied to selectively loosen only the mature fruit, leaving the young crop unaffected. Overall, because of potential tree damage, tightly clinging fruit, and two-crops on one tree at the same time, mechanical harvesting of FL oranges for processing has a low adoption rate (6-12%) (Roka 2010).

Other crops

Mechanical harvesters for processing tart cherries have been successfully adopted in Michigan. These machines are of a shake-and-catch type, similar to the Coe-Collier FL orange harvesting machine, except it is much lighter (see figure 6). This machine is a two-part self-propelled unit where the catching table is continuously moving harvested fruit to bins. 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 a large share of CA wine grapes, mechanical harvesters are now used. These machines are a relatively tall self-propelled units that straddle the trellised grapevine rows. The harvester has rotating arms that dislodge the fruit that is then caught on a table and conveyed into a wagon. See the Korvan machine (figures 9).

Korvan also manufactures and sells a mechanical berry picker for processing berries (largely for raspberries and blueberries). This machine is self-propelled, surrounds the row of berry bushes similar to the wine grape harvester, and small padded rotating arms knock loose the fruit (figure 8). This machine does some damage to the fruit, but since it is going immediately for processing, this is not a serious problem.

A little experimentation has been done with robotic harvesters that use GPS to scout fruit location and then to pick the 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.

C. Mechanization of Fresh Fruit and Vegetable Harvesting

The potato is a large volume crop where mechanical harvesters were first invented almost 100 years ago, and incremental innovations have transformed these machines into modern self-

propelled mechanical potato harvesters. Although simple mechanical potato diggers existed in the early 1900, the first complete harvester-separator machines did not exist until the 1950s. Today large scale harvesting is done by a self-propelled machine that scoops up the potato plant and the soil beneath it. This material is elevated up a rotating apron-chain consisting of steel links several feet wide, which allows loose dirt to fall away while retaining ripe potatoes. The chain deposits this mixture into an area where further separation occurs. The most complex designs use vine choppers and shakers, electronic sorters and a blower system to separate good potatoes from rotten potatoes, stones, dirt and vines (figure 9). These are used for harvesting potatoes for the fresh and processing markets. Potatoes are continuously elevated into a trailing wagon or truck.

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 and trimmed, then laid on a table that conveys it to the center, where workers on the wagon field wrap it in plastic and place 32-heads per box, which are then stacked on the wagon. This process has significantly reduced the cost of harvesting and packing iceberg lettuce. A similar process is applied to melons and cantelopes, except they are packed directly into boxes without 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 currently impossible to mechanically harvest.

Other mechanical harvesters for fresh fruits and vegetables are largely experimental. 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 trees 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 ripe fruit (see figure 10). Both harvesting units have inclined catchment tables, but the mechanical conveyors are covered with a soft spongy material that reduces impact, and the padded conveyers move the fruit gently to the outer top side of each of the machine 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 benefit to growers and consumers is that mechanically harvested cherries have less bruising or damage than hand-harvested fruit, and reduced exposure to bacterial laden human hands. However, sweet cherry consumers are accustomed to their cherries having stems, but the mechanical harvested cherries are stemless. For mechanically harvesting sweet cherries and apples, a special tree architecture is needed—short with a “Y” shape, as opposed to the 20-25 feet tall conventional trees (see figure 10). The mechanical sweet cherry harvester has excellent long-term potential for harvesting high quality sweet cherries for the fresh market, at an 80-90 percent reduction in harvest labor costs, with less damage than hand-harvested cherries (Whiting 2006).

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 one pound or smaller containers that are carried

on the machine (figure 11). A major advantage of this machine is that berries and bushes are not touched by a picking or rotating-arm mechanism. This helps minimize damage to ripe berries and scarring of the bushes. Given the minimal plant damage from the harvester, the machine can be used to make multiple passes over the same bushes as the berries ripen at different dates. With this machine, fruit quality meets or exceeds that of hand-harvested, and since no human handling of the fruit is required in the harvesting and packing, there are reduced food safety concerns. The machine is being farm tested. 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

Future mechanization of additional crops will be driven largely by benefit-cost considerations, including the likely future international competitiveness of the U.S. fruit and vegetable industry. Where growers are under intense foreign pressure, e.g., orange juice, raisins grapes, apples and/or facing serious pest problems, e.g., citrus greening, growers are not inclined to make large investments to mechanize harvesting. Relatively good machines exist for mechanically harvested vegetables and fruits 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 uncertainty of availability of this type of labor. Furthermore, these machines have potential for other crops. However, a short-term hurdle is that some crops are declining in acreage because of changing demand and international competition, and that old tree and vine architectures are not compatible with the new harvesting systems. When the future is good, 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.

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Figure 1. Typical harvest labor use and annual production of processing tomatoes California, 1960-1997 (Thompson and Blank 2000).

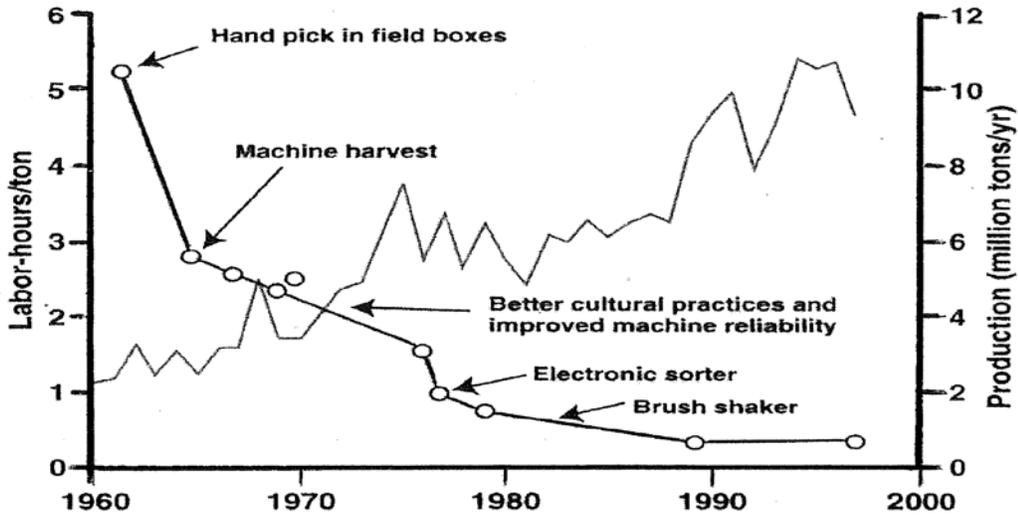


Figure 2. Self-propelled Johnson mechanical tomato harvesters



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. Self-Propelled mechanical sour cherry tree harvester – shake, catch and convey method



Figure 7. Korvan self-propelled mechanical (wine) grape harvester



Figure 8. Korvan self-propelled mechanical berry picker – raspberries, blackberries and blueberries.



Figure 9. Self-propelled straight-through mechanical potato harvester



Figure 10. Self-propelled mechanical fresh market apple (sweet cherry) harvester, WSU & USDA-ARS (late stage experimental)



Figure 11 . BEI International, Black Ice self-propelled harvester for berries using air jets and padded walls and catchment areas



Appendix A. A new self-propelled Johnson Mechanical Tomato Harvester

