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Over about 35 years, labor requirements for harvesting processing tomatoes have dropped from 5.3 to 0.4 hours per ton with the introduction of mechanical harvesters and sorters.

# Harvest mechanization helps agriculture remain competitive

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***California farmers have remained competitive in the global marketplace by using technology to reduce their costs and to expand production. Case studies of rice and processing tomatoes show that harvest mechanization has reduced labor use by 92% to 97% and has also reduced labor costs, down from half to two-thirds of total costs to less than 20%. Mechanization is at least partly responsible for the steady increase in production of these two crops. Although mechanization has reduced the number of labor hours for harvesting, overall employment for rice and processing tomatoes has risen due to increased production, and so have harvester operator wages. Further advances in tomato harvest technology will continue to reduce labor needs, while the rice industry will experience moderate changes.***

Since the Depression, farmers have had increasing difficulty remaining profitable in competitive markets. The business strategies available to them are limited to raising profits by lowering costs per unit and increasing total units of output. Farmers' ability to increase total output has also been hampered by periods — such as World War II and the end of the *Bracero* farmworker program — when fewer workers were available. Harvesting is one area where technological advances have enabled California farmers to increase output while lowering labor costs per unit, thereby greatly improving their competitive position in global markets over the last half of the 20th century. Competition is one of several reasons for farmers to adopt new technology.

Harvest mechanization offers farmers at least three ways to maintain profitability. It has (1) reduced costs per unit; (2) contributed to the ability to expand total production volumes; and (3) provided a more reliable, cost-effective replacement for the diminishing labor pool.

To gain insight to the future of mechanization, we conducted two case studies that show how California agriculture has benefited from harvest mechanization.

## Seeking competitive advantages

For an increasing number of agricultural commodities, markets are becoming global in scope. This puts economic pressure on California (and other American) farmers because "commodity prices are global, but production costs are local" (Blank 1998). This means that California farmers receive the same price for their products as do the increasing number of foreign producers who also compete in international markets. However, farmers in California incur production costs determined by local supply and demand conditions for inputs such as land, water, labor and others. Costs in California (and in America) are usually much higher than those incurred by farmers

Combine harvesting requires only 3% of the labor needed to harvest rice with the bind-and-thresh method, but total labor needs have not dropped proportionally because farmers have increased rice production.

This threshing crew poses in front of its thresher built around 1900 by the Advance Thresher Company.

in less-developed nations, meaning that farmers here have smaller profit margins per unit than many of their foreign competitors. To remain competitive, American farmers have used improved technology and management strategies to increase their production efficiency. For example, they have increased yields to spread their total costs over more units per acre.

Harvest mechanization has helped California farmers reduce labor costs. However, other nations can quickly adopt these new technologies, so there is constant pressure to develop new methods and machines that give California growers a competitive advantage. We use increasing production levels as a measure of increasing competitiveness.

The use of mechanization to improve labor productivity was fostered by agriculture's adaptation of the internal combustion engine. Applications began around the turn of the 20th century. From the 1930s through the 1960s, mechanical harvesters were developed for grain crops, many field crops and some processed fruits and vegetables.

The following case studies describe the history of mechanical harvesting and illustrate the significant economic effects that have resulted from the technology.

## Tomato harvesting

In the late 1940s, the processing tomato industry was concerned that expected shortages of laborers would prevent harvest of its increasing tomato production. In 1950, Coby Lorenzen of the Agricultural Engineering Department and Jack Hanna of the Vegetable Crops Department, both at UC Davis, began work to develop 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 harvest. By 1960 the university was issued a patent for the new variety and, in conjunction with a local equipment manufacturer, developed a machine that could successfully remove the tomato from the plant. It cut the plant at soil level and lifted it to a shaking mechanism that separated the fruit from the vine. A dozen people sorted the fruit, removing green or blemished tomatoes and dirt clods. The tomatoes were loaded directly into pallet bins that were transported on a trailer pulled beside the harvester.

Commercial use of the new variety and the harvester began in 1962. With the Bracero program ending in 1964 and reducing the labor supply, 262 harvesters came into commercial use the following season, harvesting 25% of the crop. Four years later, 95% of the crop was harvested by machine.

The harvester had a labor requirement of 2.9 hours per ton, compared with 5.3 hours per ton for hand-harvest (fig.1). We calculated these values from labor-use data in a series of production cost studies published between 1962 and 1997 by UC farm advisors in Yolo County, a major tomato processing and production area.

Manual harvesting had been done mainly by men because of the hot, dusty environment and the strength required to carry 50-pound field boxes. Much of the labor associated with machine harvest was for sorting fruit on the machine, a job that attracted women workers. The machine could also operate well at night, allowing two shifts per day.

In succeeding years, labor use per ton gradually declined as the machinery was further developed and tomato growing was adapted to machine harvest. Growers learned improved weed control, field preparation and irrigation techniques, and breeders continued to develop tomato varieties that were better suited to mechanization. In the mid-1960s, typical yield was 20 tons per acre. By 1977, typical yield had increased to 26 tons per acre. Equipment companies improved the reliability of the equipment and reduced time lost to in-field repairs (Johnson, personal communication, 1999). Some growers began a night harvest shift. By the mid-1970s, a machine could harvest 220 acres in a season, with an average labor need of 1.6 hours per ton. However, the harvesters still used a considerable total amount of labor, with as many as 20 sorters in addition to the driver.

The next major advancement was an electronic sorter that could automatically remove green fruit. In 1976, 25% of the harvesters were equipped with the new sorter, and the hand-sorting crew was reduced to about six people to pick out dirt and moldy fruit. Labor requirements dropped to 1.0 hour per ton. Since then, improvements in harvester reliability (particularly because of the brush shaker developed by Henry Studer at UC Davis) and yield increases to 33 tons per acre have reduced labor requirements by another 60%, to 0.4 hour per ton. One machine can now harvest about 800 acres in a season.

Over 35 years, harvest labor requirements per ton for processing tomatoes dropped by 92%. This efficiency was at least partially responsible for the expansion of processing tomato production in California. It increased from about 2.5 million tons per year in the early 1960s to over 10 million tons per year in the mid–1990s (fig. 1). California now produces 94% of the U.S. processed tomato crop and 37% of total world production. In 1997, exports of California processed tomato products were valued at $226 million and were the state's seventh largest export commodity. Total labor use for the crop dropped from 13.5 million hours in the hand-harvest years to about 3.8 million hours per year in 1997, while production increased 4-fold.

Hand-harvest was costly, accounting for almost 50% of total production

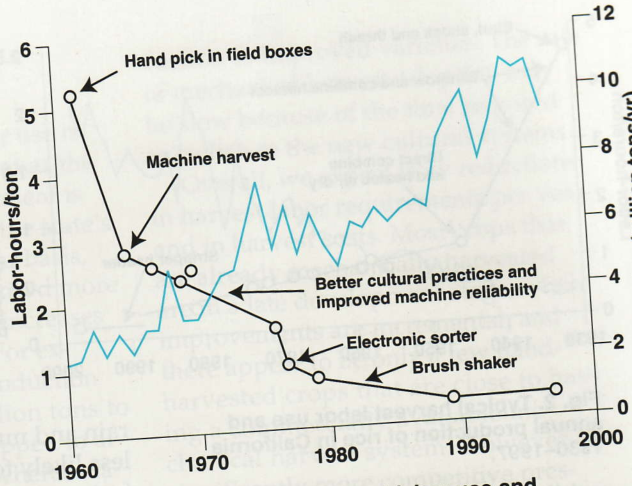


**Fig. 1. Typical harvest labor use and annual production of processing tomatoes in California, 1960–1997.**

costs. The first harvester reduced harvest costs to 33% of total costs. After the electronic sorter was introduced, harvest costs dropped to 16% of total costs by 1979. Harvest costs have slowly declined since then. In 1997, when a new harvester cost nearly $300,000, harvest costs were 12% of the total costs incurred by a typical farmer.

The improved productivity of machine harvest allowed farmers to hire fewer workers at higher wages. Trained harvester operators command higher pay than field laborers. In 1998, tomato machinery operators earned 22% more than field laborers, $7 versus $5.75 per hour respectively.

## Rice harvesting

Before 1930, harvesting California rice was a labor-intensive operation compared with current technology. The plant was cut and tied by a machine called a binder into 10-inch-diameter bundles. A 2- or 3-man crew operated the binder. The bundles were stacked in the field in small piles, called shocks, where the grain was allowed to dry, if the weather was suitable. A 20-man crew then transported the bundles to a central location and separated the grain from the straw with an engine-driven thresher. The harvested grain was placed in bags for transport, drying and storage. This harvest method required 4.5 labor-hours per ton of dry rice. We calculated labor and production from a series of production cost studies

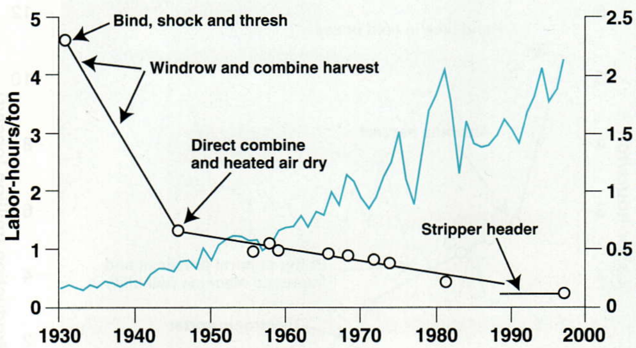


**Fig. 2. Typical harvest labor use and annual production of rice in California 1930–1997.**

published at irregular intervals between 1940 and 1998 by UC farm advisors in Butte and Sutter counties.

During the 1930s, growers began using combine harvesters for swathed rice (Olmstead and Rhode 1983). The plants were cut and laid in windrows. After 3 to 8 days, when the rice had dried, it was harvested with a self-propelled combine. A pick-up header collected the straw and attached grain and transferred it to a rotating cylinder that detached the grain from the straw. A series of moving grates and screens separated the grain from straw and chaff. Rice was handled in burlap sacks. Field drying reduced rice quality, and the system was used for a maximum of 60% of the crop in later years.

During this time a few growers experimented with a heated-air dryer that allowed the rice to be combined directly in the field without swathing. As World War II began, the labor supply became tight and burlap bags were in short supply. The industry switched to direct combining with bulk handling (Willson 1979). Grain was stored in a bin on the combine and periodically conveyed to a self-unloading wagon pulled by a tractor, which in turn hauled the rice to a highway truck for transport to a dryer. The first harvesters were pulled by a track-layer tractor and had a crew of two to four people. With this method, harvest labor requirements dropped to 1.2 hours per ton (fig. 2). By 1950, most rice was direct combined and dried with a heated-air dryer.

During the 1950s, most combines were self-propelled and operated by a single person. Yields increased steadily, from less than 2 tons per acre in the 1940s to 4 tons per acre in 1998, contributing to increased tons of rice harvested per hour. Breeders developed earlier maturing varieties, allowing more of the crop to be harvested earlier in the year, when rain and muddy field conditions were less likely to slow the harvest. Manufacturers steadily increased the capacity of machines. In the early 1980s, harvest labor requirements were reduced to 0.40 hours per ton.

In the early 1990s, the stripper header became commercially available. It removed the grain from the straw without cutting the straw. This allowed the separation equipment to operate with greatly increased capacity. In standing grain, this device allows a combine to travel two to three times faster than a conventional combine. (A conventional machine is still needed for lodged rice.) Average labor requirement for rice harvest is currently only 0.15 hours per ton.

A 1927 study (Stirniman 1927) indicated that rice harvest costs ranged from 63% to 67% of total costs. The early combine harvesters reduced harvest to 27% of total costs. By the mid-1960s, harvest costs dropped to 18% to 20% of total costs and have remained in that range since then. California rice production increased steadily from about 0.2 million tons per year in the 1930s to about 2 million tons in the mid-1990s (fig. 2).

As with tomatoes, rice harvester operators are paid more than field laborers. In 1998, rice equipment operators earned $8 per hour, 39% more than the minimum wage earned by field workers in many crops and by workers in many nonagricultural jobs.

## Effects of mechanization

Mechanization reduced harvest costs as a percentage of total production costs and is one of the factors that have allowed California farmers to remain competitive. Current harvest costs for processing tomatoes are 75% less than they were for hand-harvest, and rice harvest costs dropped by two-thirds. These cost savings are at least partially responsible for large production increases for both of these crops. In the 35 years since tomato harvesters were first used, production has increased 4-fold. In 70 years of mechanized rice harvest, California production increased 10-fold.

Although harvest mechanization greatly reduced labor-hours per ton of production — to 6% of hand-harvested processing tomatoes and to only 3% for rice — total labor needs have not dropped proportionally because of large increases in production. In fact tomato and rice processing operations have increased overall employment. Mechanization has expanded the worker pool because machine operator jobs are higher paying and less strenuous than hand-harvest jobs (Martin and Olmstead 1985).

The effect of mechanized harvest has been so significant on rice and tomatoes that hand-harvesting is no longer feasible. Based on current production and historical labor use, more than 45,000 additional workers would be needed to hand-harvest tomatoes, and more than 12,000 additional workers would be needed to hand-harvest rice. The additional workers needed outnumber the people currently employed in these crops statewide. The California Employment Development Department reported a total of 800 to 1,800 (varies by month) wage and salary workers in rice production firms for 1996 (CEDD 1996). CEDD reported 20,000 to 40,000 people working in all vegetable and melon production firms in the state in 1996. Even if farmers could find the additional workers, they could not afford the $332 million in additional wages (57.7 million hours multiplied by $5.75 per hour) and remain competitive in global markets.

## Years of development

Developing a mechanical harvest system requires many years of research and development. The first commercial-scale tomato harvesters became available 12 years after research began. Further machine development over the next 35 years expanded machine-harvest capacity from 80 to 800 acres per season and reduced labor needs from 2.9 to 0.4 labor-hours per ton. Rice harvester and plant development similarly increased harvester capacity and reduced labor use over a 70-year period.

Mechanized harvest would not have been possible without improvements in plant breeding, growing techniques and other technology. Old tomato varieties were too delicate for mechanical harvest and did not ripen uniformly enough for a once-over harvest. Rice harvest mechanization was tied to the development of heated air dryers. New rice varieties allowed greater harvest capacity and fewer problems associated with harvesting in the rain-prone months later in the year.

Mechanization reduced harvester jobs and therefore jobs in particular crops as a whole, but adoption occurred over a number of years. Even the tomato industry, which experienced a fairly rapid transition to mechanical harvest spurred by a labor shortage, took 7 years to reach 95% usage. The adoption of the combine harvester for rice was similarly stimulated by the onset of World War II.

## More mechanization gains ahead

Tomato harvest holds the potential for even lower labor requirements. Current tomato harvesters need a driver and about four sorters. Manufacturers are developing automated equipment to accurately and economically detect dirt and moldy fruit. When these systems become commercially available and affordable, labor requirements will drop by 60% to 70% per individual harvester. This new technology will reduce total harvest labor use, even considering continued growth of tomato production.

Because current rice harvesters require only a single operator, there is little likelihood of a sudden large reduction in labor requirements. The steady trend in increased rice yields and the potential for wider headers and faster machine operation will increase hourly harvest capacity and slowly and steadily reduce labor requirement per ton of product harvested.

For rice harvest, total labor use is likely to remain fairly constant as the slow decline in labor requirement is balanced by the slow rise in the state's production. On a year-to-year basis, total labor use will be influenced more by total production than by increases in harvest labor efficiency. For example, around 1980, rice production rose from just under 1 million tons to 2 million tons and then dropped to almost 1 million tons again, whereas labor efficiency improvement averages about 1% to 2% per year.

## Mechanization for other crops

Other crops in California that are already harvested mechanically include most field crops, below ground vegetables, nuts and many vegetables and fruits grown for processing (Sarig et al. 1999). These crops will likely experience the same trends in reduced harvest costs and reduced labor needs as rice and tomatoes. Many of these crops have been mechanically harvested for a long time so harvest as a portion of total costs will remain fairly stable. Labor requirements per ton will drop slowly, perhaps by a few percent per year, as harvest machinery, cultural practices and plant yields steadily improve.

It is difficult to predict the trends for crops that are currently hand-harvested, mainly fresh-market fruits and vegetables. Much effort has been devoted to these crops, but in the last 20 years there have been only a few advancements in developing commercial harvesters (Sarig et al. 1999). In California, there is considerable privately and publicly funded work under way to mechanize the harvest of processing olives and raisin grapes. If these efforts are successful, there will eventually be significant reductions in harvest labor requirements per ton for these crops and potential cost savings. However, these harvest systems may require significant changes in crop culture, or even switching to new early-maturing varieties in the case of raisins. Total cost savings may not be as great as with tomatoes and rice, which are annual crops and allow easy conversion to improved varieties. The rate of mechanical harvest adoption may be slow because of the time required to switch to the new cultural systems.

Overall, we expect slow reductions in harvest labor requirements per year and in harvest costs. Most crops that are already mechanically harvested are in a late development stage, where improvements are incremental, and there appear to be only a few hand-harvested crops that are close to having a commercially available mechanical harvest system. However, significantly more competitive pressure from overseas suppliers or an acute labor shortage could accelerate mechanization in the few crops that have a feasible harvester near completion. For example, Florida processing orange growers are participating in a million-dollar crash program to develop a harvester because they have lost market share to Brazilian orange juice producers. For agriculture as a whole, however, harvest mechanization will not solve an acute labor shortage because of the time required to develop mechanical harvesting systems.

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▲ **Machine harvest of processing tomatoes has reduced harvesting from 63% to 20% of total production costs.**

**Before mechanization, *above and at right,* processing tomatoes were picked by hand and manually carried to the edge of the field.**



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