

Advances in Mechanization of the Tall Spindle Apple Orchard System: Part 2 - Harvest Mechanization Prospects

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This research was partially supported by the New York Apple Research and Development Program.

The adoption of the Tall Spindle apple planting systems with its simple and narrow canopy by the many NY apple growers has created an opportunity to adopt partial mechanized

“Harvest labor represents the largest annual cost of growing apples and accounts for about 1/3 of the labor hours in an apple orchard. We expect that over the next 5 years many growers will begin to use one of the various harvest assist machines. Gains in labor efficiency will likely be in the 20-50% range. With this level of modest gains in labor efficiency the benefit / cost ratio of harvest assist platforms will depend on price of the machine and the number of acres one machine can harvest in a season. If our prediction of the adoption of harvest aid machines is to be realized growers will need to rapidly convert orchards to narrow fruiting wall type canopies that are suitable for partial mechanization of harvest.”

solutions to several orchard tasks. Pruning, hand thinning and harvest are the major labor-intensive tasks performed annually in apple orchards. We have previously reported on our research and extension efforts to adopt motorized platforms to position human workers for greater canopy management efficiency in pruning and hand thinning, and mechanical pruning with hedging machines to reduce pruning

which detached the apples, which then fell onto a catching frame and were collected and transported to a bin with conveyor belts. This technology resulted in significant adoption of mechanical shake and catch harvesters in the largely processing growing regions of Western NY, Pennsylvania and Michigan. However, fruit bruising was substantial. Significant research in the late 1970's dealt with modifying the catching surfaces and the conveying systems to reduce bruising, but the velocities imparted to the fruits in the shaking process still resulted in significant damage.

A significant advance was made at Cornell University in the early 1980's, when engineers invented the impact trunk shaker, which applied a sharp impact force to the tree trunk. The impact trunk shaker imparted much less energy to the fruits than the centrifugal shakers. With this system the tree moved rapidly away from the fruit, snapping the stem and the fruit basically fell straight down. At the same time Dr. Alan Lakso at Geneva developed the Geneva Y-shaped apple canopy in an effort to design the tree for the machine. The Geneva Y-trellis growing system allowed most of the fruit to borne in a single plane so that there were few fruit to branch impacts as the fruit fell. Evaluation work done by Robinson et al. (1990) showed significant reductions in fruit bruising with the combination of the impact shaker and the Y-trellis. The best results showed only 10% fruit bruising with this system. However, this technology was never adopted by the apple industry due to an abundant labor supply. (More recently the impact shaker technology of Cornell made its way to USDA-Kearneysville and then to Washington State for use as a mass removal strategy for stem-less sweet cherries).

By the late 1980's the interest in mechanical harvest of apples in the US had waned as it appeared there would be an endless supply of migrant Hispanic workers who could harvest the crop relatively cheaply. In addition, apple processors became less willing to accept fruit from mechanical shaker harvesters and by the early 1990's all of the commercial harvesting machines in the eastern US had been de-commissioned.

In Europe a different approach was pursued to reduce harvest labor by developing harvest assist machines. As early as 1980, researchers in the Netherlands had built machines, which used humans to detach the fruit from the tree and then place it on conveyers to transport the fruit to a mechanical bin filler. These machines were built as either single row or multiple row machines (up to 7 rows at once) using over the row fruit conveyers. Evaluation research showed that these harvest assist machines could improve labor efficiency by only 15-20%. This relatively small improvement

costs. In this article we cover the recent advances for mechanized apple harvest in NY and the US.

Harvest labor represents the largest annual cost of growing apples and accounts for about 1/3 of the labor hours in an apple orchard. Goals to significantly reduce the costs of growing apples need to first focus on reducing the costs of harvest. This has been a goal of apple researchers and engineers for about 40 years.

History of Mechanical Harvesting of Apple

In the early 1970's there was concern over the availability of labor and there was a strong demand for mechanical harvest research on apples. The harvest of other crops had been mechanized but apple was still harvested by hand. The initial flurry of research resulted in mass-removal trunk shaking machines, which detached the apples by applying a centrifugal force to the trunk,



Figure 1. DBR harvest assist machine from Michigan, which uses suction tubes to transport fruit to the bin.



Figure 2. The Pluck-O-Trac harvest assist machine from the Netherlands which uses conveyor belts to transport fruit to the bin.

in labor efficiency was not sufficient to justify the purchase of the machines and few were sold. However, slowly over the years the machines were improved and more and more European growers have purchased these harvest assist machines but they have never been adopted in the US.

In the early 2000's new concerns in the US over the cost of labor revived an interest in mechanical harvest and a new group of young growers and researcher who had not been through the mechanical harvest "war" of the 70's and 80's lobbied for significant resources to be used for a new round of mechanical harvester development efforts with the possible development of robotic harvesters. This has resulted in significant research investment in harvester research over the last 10 years.

Challenges for Mechanical Harvesting of Apples

As a veteran of the apple mechanical harvest "war" of the 1980's, I feel it is important to step back and review the issues involved in mechanical harvest of apple. There are 4 steps in harvesting an apple:

1. Detachment of the Fruit. The big advances in agricultural mechanization of harvest with grain crops have come from moving away from a hand detachment of each ear of corn and then kernels from the cob to mass removal of corn with combines. This resulted in huge gains in labor efficiency and justified the purchase of expensive machines for harvest. (The benefit/cost ratio was very high.) Likewise the early research on apple focused on mass removal of fruits from the tree by trunk shaking. However unlike grains, fruit bruising is a major problem with apple and has made it almost impossible to consider mass removal techniques for apple. (The best possibility is with a Y-trellis using impact shaking technology.)

The delicate nature of the apple fruit has required the individual detachment of the fruit from the tree. This detachment process is further complicated by the different detachment issues with each variety (short vs. long stems, detachment of spurs with the fruit, etc.) and with maturity of the fruit. The traditional harvest system using the human hand, eye and brain has resulted in a very fast individual fruit removal system without bruising.

To compete with human harvesters, a robotic harvester would need to first identify the location of the fruit using machine vision cameras and then use robotic arms with end effectors (hands) to detach the fruit. Although there has been good progress on machine vision to identify the location of each fruit with cameras and computers, the difficulty of detaching the fruit without bruising with the speed of a human is not an easily solvable problem and is probably the major problem with the idea of a robotic harvester.

Given the difficulty and cost of fruit identification and detachment by machines, I view the human hand, eye, and brain systems as the more practical and cost efficient method of detaching the fruit. It is my view that we should continue to focus our efforts on harvest systems, which use humans to detach the fruit.

2. Conveying of Fruit to the Bin. Once a fruit is detached from the tree it must be conveyed to the bin. The traditional human harvest system utilizes a picking bucket with an operable bottom to transport fruit to the bin. This system can have significant bruising if the picker is careless in putting the fruit in the bucket or when transporting it to the bin. Good orchard managers have learned how to train and then supervise workers to minimize bruising with this system. However, significant labor inefficiency develops when the worker must climb up and down ladder and then walk to and from the bin.

An alternative to human transport of fruit to the bin is machine transport coupled with a mechanical bin filler. The original Dutch built harvest aid machines from the early 1980's used small conveyor belts to move the fruit to the bin and into the bin. Although these machines have worked well, bunching of the fruit at the collection point can be a problem and some bruising of the fruits (5-8%) has been documented by the bin filler machines.

A second solution has been to continue the use of humans to transport the fruit to the bin but to move the bin close to the picker so that there is little lost time walking to the bin. The European built pruning platforms fitted with fork lifts on the front and back and bin rollers on the platform allow pickers on the platform to pick the tops of trees while on the deck of the platform and then deposit the fruit into bins which are raised up to the deck of the platform. When the bins on the platform deck are full they are lowered to the ground behind the machine. These platform harvest aid machines allow only the harvest of the top of the tree while the bottom must be harvested separately in the traditional manner.

A third solution has been developed by two companies in the US where the fruit are conveyed to the bin by suction thorough tubes. The DBR machine from Michigan and the Picker-tech machine from Washington utilize suction systems to move the fruit from the picker to the central bin filler. Both of these systems attempt to increase the labor efficiency by eliminating climbing up and down ladders by positioning workers on platforms and by eliminating walking to the bin by conveying the fruit in suction tubes. The suction systems work well and have been shown to have a low amount of bruising but on average slightly more than a well managed hand harvest system.

A fourth idea has been developed by Paul Wafler from NY State



Figure 3. Picker-tech harvest assist machine from Washington that uses suction to transport fruit to the bin.



Figure 4. The Wafler harvest assist machine from New York that positions the bins close to the pickers and uses humans to fill the bins.

who has developed a harvest assist machine that uses humans to convey the fruit to the bin. With the Wafler machine, workers are positioned on a multi-level platform to eliminate the loss in efficiency from climbing up and down ladders but the bins are moved close to the workers by placing 5 bins on an innovative slanted surface positioning a bin close to each picker level (ground, mid level and top level) to eliminate the loss in efficiency due to walking to and from the bin and in climbing ladders. In this system the human picker conveys the fruit from the tree to the bin in a picking bucket. The multi level machine allows a one pass harvest of both the top and bottom of the tree.

3. Filling the Bin. The traditional human harvest system utilizes a picking bucket with an operable bottom to deposit fruit in the bin. This system can have significant bruising if the picker is careless in emptying the bucket. Good orchard managers have learned how to train and then supervise workers to minimize bruising with this system. When I watch a good picker of McIntosh empty a picking bucket it is a work of art.

The original Dutch built harvest aid machines used a rotating bin filler to deposit the apples in the bin. Several evaluations in Europe showed these bin fillers imparted very little bruising to the fruit even with Golden Delicious but evaluations in the US indicated greater bruising from the bin filler system. This difference in results has been one of the reasons why these machines have not been more accepted in the US.

The recently developed harvest assist machines in the US (DBR and Picker-tech) utilize a central mechanical bin filler based on a rotating head that indexes up as the bin fills and also spreads the fruit to the different quadrants of the bin. The systems work well and have been shown to have a low amount of bruising but on average slightly more than a well managed hand harvest system.

The Wafler harvest aid machine utilizes the traditional picking bucket to fill the bin and depends on good worker training and supervision programs to eliminate bruising. The efficiencies are gained by the worker only having to turn around to empty his picking bucket. In addition the upper 3 bins of the 5 bin group are angled so that when the picker empties his bucket the floor and side wall of the bin form a V where the apples are deposited which reduces bruising.

4. Bin Handling. The traditional harvest system is based on pre-spreading the bins in the orchard so they are close to the picker and then moving the full bins out with a tractor and forklift. The

moving of full bins one at a time is a significant labor and equipment cost. In the last 20 years most growers have tried to gain some efficiency by utilizing self loading bin trailers to work with groups of 5 bins instead of singly.

The European and the new US harvest aid systems have little improvement over the single bins system and generally require more labor to handle the bins. These harvest aid machines generally require one worker to load and unload bins. In addition all the pickers on the platform (4-8) must stop picking while the full bin is unloaded and an empty bin is loaded wasting significant time for each bin. The single bin approach then requires a tractor with forks or a self loading bin trailer to move the full bins to the loading area in the orchard. With several of the European machines and the DBR machines, an empty bin trailer pulled behind the machine can be loaded at the end of the row with 5, 8 or 10 bins to allow the machine to work to the end of the row without running out of bins. This works well if the combination of yield X row length does not exceed the carrying capacity of the empty bin trailer.

The Picker-Tech machine improves on bin handling by picking up bins that are pre-spread down the row through the front of the machine and then deposits full bins in the row behind the machine.

The Wafler harvest aid system has a significant advance in bin handling. The machine handles 5 bins at a time and when the bins are full, the machine unloads 5 bins at a time. The machine is supplied by a supply trailer that hold 5 empty bins in reserve. After the supply trailer transfers its 5 empty bins to the harvest machine, the supply trailer is restocked on the fly by a tractor drawn bin trailer that regularly visits the machine to pre-load the supply trailer with 5 empty bins. The tractor drawn bin trailer also hauls the full bins (in 5 bins increments) back to the loading area. The Wafler machine can continue moving while unloading 5 full bins and re-loading 5 empty bins from the supply trailer.

Comparison of Harvest Aid Machines

There have been no direct comparisons of the different harvest aid machines under identical conditions, to help guide apple growers to the most practical and cost effective machine. We have made some preliminary comparisons based on limited observations and testing of some machines and published figures on other machines.

Some important differences among the machines are:

1. Picking the Whole Tree or Just the Top. The pruning platforms (Blosi and Orsi) converted to harvest aid machines only

allow picking of the top of the tree while the bottom of the tree is harvested in a separate operation in the traditional manner by pickers on the ground. Other European machines like the Pluck-O-Trac position pickers at multi levels to harvest both the top and the bottom of the tree. The 3 US harvest aid machines (DBR, Picker-tech and Wafler) position workers on the ground and on multi-level platforms to allow one pass harvesting.

2. Transporting of the Fruit and Filling of the Bins by Humans or Machines.

The DBR, Picker-tech and several European machines like the Pluck-O-Trac are built around fruit conveyors (suction or belts) and mechanical bin fillers (rotating bins or rotating heads). The Wafler machine and the pruning platform machines rely on humans to convey the fruit to the bin and have no mechanical fruit conveyors or bin filler. The Wafler machine tilts the bin while it is being filled for less bruising when filling the bottom of the bin.

3. Self Propelled Machine or Pulled by a Tractor.

Almost all of the harvest aid machines are self propelled except the DBR machine from Michigan, which utilizes a tractor to pull the machine.

4. Labor Efficiency.

No comparable labor efficiency measurements have been made with the different machines. Estimates from Europe with conveyor belt and bin filler machines or pruning platform machines indicate only a 15-20% improvement in labor efficiency while recent estimates in the US for the DBR are closer to 30% improvement in labor efficiency. We estimate the Wafler machine will improve labor efficiency by 40%. We have no estimates for the Picker-tech machine.

5. Acres harvested by 1 machine.

We have made a number of assumptions to derive picking capacity of the various machines, which are summarized in Table 1. Our estimates of machine productivity indicate that in an 8-week harvest season with 6 working days per week (48 working days per year) and a yield of 50 bins per acre, the pruning platforms could harvest 31 acres/season, while the Pluck-O-Trac could harvest 46 acres/season, the DBR machine-38 acres/season, and the Wafler machine - 77 acres/season

6. Cost of the Machine.

Many of the European pruning platforms with no fruit conveyors or bin fillers cost between \$50,000-60,000. The more complex European machines with fruit conveyors and bin fillers like the Pluck-O-Trac have a labor cost ~\$80,000 while the cost of the DBR and the Picker-tech are likely to be ~\$100,000. We estimate the Wafler machine may cost ~\$40,000-50,000.

Table 1. Preliminary estimates of harvest aid machine performance and cost per bin.

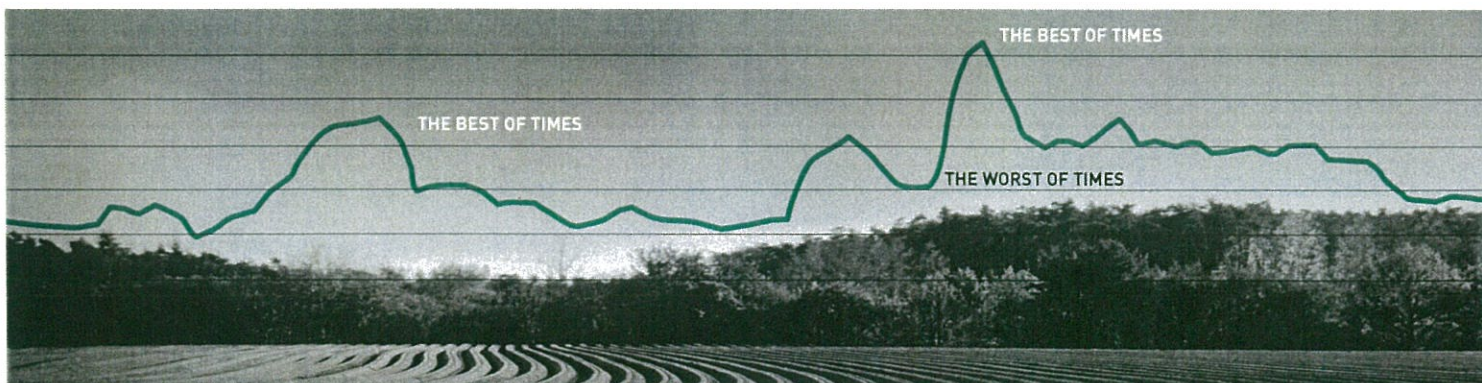
Machine	Number of Workers	Bins per Day	Acres/ Season	Cost of Machine	Cost/bin harvested	Labor Savings/ Bin
Platforms (Blosi, Orsi)	4	32	31 (tops only)	~\$60,000	\$3.90	\$6.25
DBR	5	40	38	~\$100,000	\$5.20	\$6.25
Pluck-O-Trac	6	48	46	~\$80,000	\$3.26	\$6.25
Wafler	8	80	77	~\$40,000	\$1.04	\$10.00

7. Cost per Bin.

We made a preliminary estimate of the cost per bin of several machines using our estimates of machine cost and our estimates of machine productivity. We used a 10-year depreciation assigning 10% of its purchase price as an annual cost divided over each bin harvested to develop a cost per bin. Assuming each acre of high density orchard has a yield of 50 bins then a rough estimate of the machine cost per bin of the DBR machine is \$5.30 while the Pluck-O-Trac cost is estimated to be \$4.30, the pruning platforms \$3.90 and the Wafler machine \$1.04. These numbers are a very preliminary estimate and need to be determined more rigorously with side by side infield time trials.

7. Labor Savings per bin.

We made a preliminary estimate of the labor savings per bin of several machines using our estimates of machine productivity compared to picking with ladders on a Tall Spindle orchard. We assumed the hand harvest worker with a ladder could harvest 6 bins per day at a rate of \$25.00 per bin. Thus over the course of a 48-day harvest season he could accumulate \$7,200 in gross wages. We assigned that annual cost to each worker on the various platforms and divided the total seasonal labor cost of per platform by the number of bins harvested to develop a cost per bin with the machine. We then subtracted that cost from the standard \$25.00 per bin paid to workers with ladders. The savings per bin of the pruning platforms, the Pluck-O-Trac and the DBR machine was estimated to be \$6.25 per bin while the Wafler machine saved \$10.00 per bin. These numbers are a very preliminary estimate and need to be determined more rigorously with side by side infield time trials.



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Our Outlook for Harvest Mechanization

We see little possibility of harvest mechanization with robotic machines. Although considerable money has been spent in the last few years on this effort, it will require many more years of development to have a machine capable of competing with a platform assisted human harvester due to the extreme complexity of identifying the fruit location by the machine, detaching the fruit without bruising, and transporting the fruit to the bin and depositing the fruit in the bin without bruising. If such a machine is ever developed it will likely be too expensive and too slow with little or no gain in picking efficiency. We predict the benefit / cost ratio will be negative which would likely raise the cost to harvest a bushel of apples.

The picking aid machines like the Wafler, the DBR, the Blosi, the Orsi, the Pluck-O-Trac or the Picker-tech show much greater promise of being adopted. We expect that over the next 5 years many growers will begin to use one of the various harvest assist machines. Gains in labor efficiency will likely be in the 20-50% range. With this level of modest gains in labor efficiency the benefit / cost ratio of harvest assist platforms will depend on price of the machine and the number of acres one machine can harvest in a season. This will depend on the number of humans harvesting on each machine.

Matching Orchards with Harvest Assist Machines

If our prediction of the adoption of harvest aid machines is to be realized growers will need to rapidly convert orchards to narrow fruiting wall type canopies that are suitable for partial mechanization of harvest. The best canopies for harvesting with picking aid machines are narrow thin canopies that allow the picker to reach the center of the canopy without reaching out past the edge of the machine. To improve efficiency new orchards should be planted with many rows of the same variety and using crabapple pollinizers.

Acknowledgements

This research was partially supported by the New York Apple Research and Development Program and the NY Farm Viability Center.

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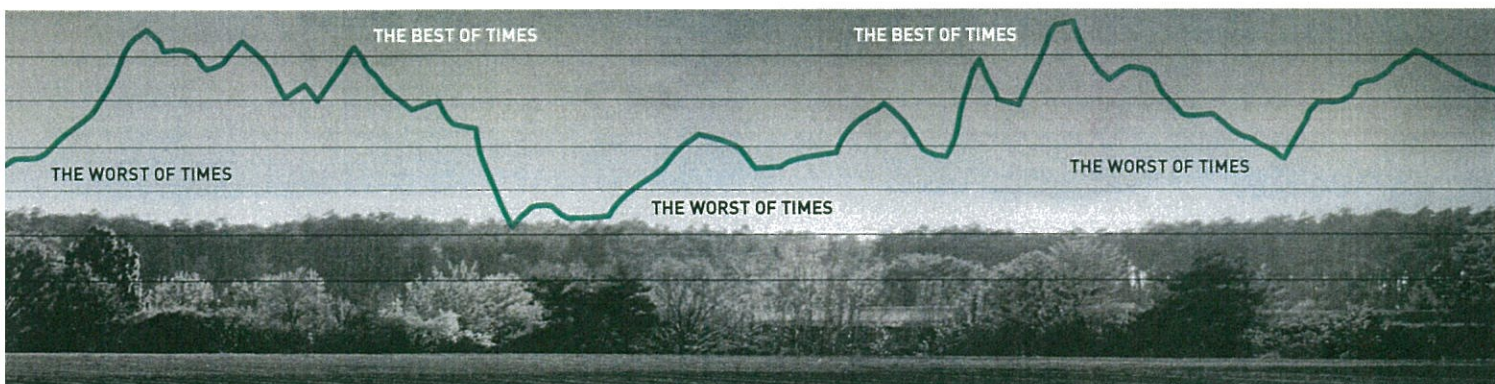
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