

38 acres of ground consisting of 4 acres of apples, 8 of truck crops, 19 nursery stock and 6 of teaching areas. From this acreage, the 20 girl students propagate, grow, harvest, and sell through commercial markets, produce valued at 30,000 English pounds annually (approximately \$84,000). This amount takes care of most of the expenses of the institution. Institute students usually are required to grow a crop of their own selection and make a written report of this work. Most institutes provide instruction for day release students and special courses as needed by the community.

3. The university programs are of three year duration. The student must have taken the academic program in his secondary work. The University of London at Wye (Wye College) requires all horticulture students to have had one year of commercial work experience before entrance, and to spend their vacations working with a commercial firm that has been approved by the college.

It can be seen that European horticultural training is oriented to commercial work. Most research and graduate work also is of a practical nature. Three university research projects of particular interest observed at Wageningen, The Netherlands, were: development of a double red delphinium; development of a garden pea in which the stringiness had been removed so that pod and pea can be eaten; and the study and development of tomato plants with additional chlorophyll.

Regardless of the level of instruction, the dedication of the teaching staff and the interest and sincerity of the students was impressive. The fact that most of the institutions

were separate and apart from the conflicting and confusing problems of a giant campus made the atmosphere more conducive to concentrated horticultural study. The testing and qualifying of the horticulturist at a national level has had much to do with raising the prestige and image of the industry. (i.e., the Royal Horticultural Society's *National Degree of Horticulture* and the Netherlands' *Master Gardener's Diploma*.)

The number of individuals involved in various horticultural programs was also impressive. In the Netherlands, for example, Aalsmeer, a city of 10,942 population, had 590 students over the age 14 enrolled in special horticultural programs. Although no comparable figures were available for any city in the United States, the following statistics are interesting by way of comparison. The U.S. Department of Health, Education, and Welfare Report, OE 56006 *Enrollment and Degrees in Agricultural Institutions of Higher Education*¹ for the same period showed a total enrollment in horticultural programs in the United States of only 1,339 students out of our population of 180,000,000.

It is doubtful if any of the programs as carried on in Europe could be used unchanged in our educational system. The fact that enrollment in most horticultural departments in the United States is dangerously low, and industry is in need of trained men, might indicate that we in the United States are not stressing sufficiently the practical and applied phases of horticultural education.

¹ This figure included junior colleges, colleges, and universities.

Pomological Aspects of Mechanizing Tree Fruit Harvesting

L. L. Claypool, *University of California, Davis, California*

In no other single operation in fruit production is so much labor cost involved as in harvesting. The harvest cost of sweet cherries for brining may equal two-thirds of the value of the cherries delivered to the brining plant, whereas it may be only 10-15% of the harvested value of Bartlett pears for canning, but even this is a sizable item. For centuries some control of harvesting costs has been accomplished by manipulation of tree size and shape. In recent years this approach has received additional impetus by the use of dwarfing rootstocks and new systems of training.

Many tree fruit and nut crops have in the past, or are now, receiving attention in relation to machine harvesting. Walnuts, almonds, prunes, and sour cherries are being harvested commercially by machine. Cling peaches, apricots, sweet cherries, apples, pears, plums, citrus fruits, olives, and dates have received varying amounts of attention. Mechanical harvesting studies with bush berries have progressed rapidly to the point where commercial machines are available for certain species. Emphasis has been on mechanical shakers associated either with catching frames or pick-up machines. Grape species are also receiving attention.

Basic considerations of the horticulturist relate to: a) tree health and longevity, b) yield of salable fruit, and c) fruit quality.

If these three considerations are not adversely influenced by mechanization, and overhead costs are equal or less than those for hand harvest, then harvest mechanization is on the verge of reality. Minor changes in labor availability and cost can change abruptly the feasibility of harvest mechanization of certain fruits.

Now let us look in depth at each of the requirements for successful mechanization of the harvest operation, and attempt some evaluation of its influence on eventual economic feasibility.

Tree Health and Longevity

Vibrations from impact or shaking generally have not been harmful to the tree, except where the energy used was sufficient to remove leaves or break weak branches. However, areas where the bark is bruised, loosened, or removed by the knocker head or shaker clamp are sites for infection by pathogens or entry points for beetle larvae, in addition to restricting translocation. This problem is one of major concern in California prune and peach orchards, where commercial shakers have been used for several years.

Two fungi, *Ceratocystis fimbriata* and *Cytospora leucostoma* (syn. *Leucostoma persoonii*), the latter similar to *Valsa cincta* and *Valsa leucostoma* identified by pathologists in Michigan, have proven to be strong pathogens to stone fruit trees in California. *Ceratocystis* is capable of killing large primary branches in 2-4 years and entire trees where infection is on the trunk. Both organisms are widespread with *Ceratocystis* having a wide host range. Michigan workers have reported concern from *Cytospora* infections when shakers are used for thinning peaches.

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Fig. 1. Shake and catch harvester being used for apricots. Note padding and decelerator strips over the conveyor and areas of high density fruit fall. Arm of inertia limb shaker should also be padded. Limb clamp has been greatly improved over the one shown above.

Considerable progress is being made in the reduction of shaker damage. Clamp design has been greatly improved and operators are learning to exercise more skill and judgment, but the tree remains a problem. Since only branches that are nearly perpendicular to the shaker force at the point of attachment can be safely shaken without injury, considerable benefit may be realized by proper training of the tree. A reduction in the number of primary scaffold limbs reduces the number of shaker attachments where a limb shaker is to be used. The removal of low brush and a reduction of primary limbs also permits improved vision for better maneuverability of catching frames. Shakers mounted about 90 degrees apart are more easily oriented to give a perpendicular attachment than the more usual 180-degree mounting. Such modifications and precautions will reduce tree damage in addition to speeding the harvest operation.

Intensive studies by plant pathologists have developed much new information concerning modes of infection, control, and eradication of cankers resulting from fungal diseases. Results indicate the likelihood of satisfactory disease control when associated with suitable shakers and properly trained trees.

Yield of Salable Fruit

The percent of the crop removed by shakers is often somewhat less than with hand harvesting. Fruit mass, rigidity of the fruiting wood, and removal forces are key factors in the percent of fruits harvested. For example, removal of olives or some bush berries is very difficult because of small fruit size and willowy branches. Cherries on willowy branches may behave somewhat similarly, but near rigid wood, removal may not be difficult. Cling peaches near the ends of long hanger branches or close to wire braces do not remove easily even though their mass is relatively great. Where applicable, modification of pruning practices to reduce willowness of fruiting wood has been shown to increase percentage recovery of sour cherries, although an initial loss of total yield occurred. However, within 3 years yields of sour cherries in New York had returned to normal.

Trunk shakers have been less effective in removing fruits than have limb shakers or knockers. Further research may

narrow the difference. It appears that trees of many species can be trained in such a way that fruit removal by shakers may be within 5% of that of hand pickers.

In the past it has been customary to make two or more hand picks of many fruit species in order to obtain the greatest total yield of marketable fruit. With rising labor costs and less available labor, the trend is to fewer picks. Machines presently available for removing tree fruits are essentially non-selective between mature and immature fruit. Therefore, there may be no benefit from more than a single pick. On the contrary, many fruits not removed by the harvester are severely damaged and would be worthless if harvested later.

It is not always possible to harvest each tree mechanically when the greatest percentage of fruit is at an acceptable stage of maturity. Therefore, immature or overmature fruits may be excessive and lost to the grower. Different cultural regimes, particularly nitrogen nutrition, may greatly influence losses related to maturity where the stage of maturity is critical to marketing.

Where harvest maturity is critical to the processor the trends toward a single pick operation, whether by hand or machine, present difficult problems. A grading station evaluation may be satisfactory for those fruits suitable for processing immediately after harvest. But when ripening is required before processing, such as with pears or freestone peaches, additional procedures will be required to predict the condition and quality of fruits when they have attained a canning ripe stage.

A somewhat different situation exists with some of the bush berries, where there is a great difference between removal forces for mature and immature fruits. Here, the mechanical harvester may be somewhat more selective than the hand picker, but because the machine removes only the ripest fruit, pickings by machine must be at somewhat shorter intervals than those by hand.

Experiments with chemicals to aid in fruit removal to date have not been promising.

Condition of Harvested Fruit

Condition of the harvested fruit is a factor of concern to the processor or other market outlet. Information has been obtained in regard to padding and decelerator strips for catching frames, that permit the free drop of the highest fruits from the tree to the frame with little or no measurable damage. If conveyors and bin fillers are properly designed, the entire catching frame unit can be almost eliminated as a source of fruit bruising.

Unfortunately, falling fruit may be bruised or cut from impact with twigs, branches, and other fruit before reaching the catching frame. Since impact damage is more severe as the energy in falling fruit increases, large fruits are most susceptible to damage, and injury is more severe when impact follows a considerable fall.

Removal of low brush and stubs greatly reduces the amount of injury to cling peaches, but damage is not lowered to the low level attained by good hand pickers.

The characteristics of apple and pear trees result in a particularly difficult bruise problem by the shake and catch method. Unless the skin is broken, bruises to pears may not show until the fruit is ripened and peeled. When commercially canned, such fruits must be trimmed to remove the discolored bruised area and are downgraded in quality. This problem, already troublesome in hand-picked fruit, could be intolerable under present mechanical harvesting methods.

Impact bruising associated with mechanical harvesting may require modification of present handling practices, particularly in relation to time lapse between harvest and processing. Cling peaches must be canned within 24 hours or less of harvest. Sweet cherries for brining must be placed

in solution within minutes after harvest, if bruises are not to show. However, when harvest mechanization reaches large proportions it will tax the ingenuity of the processor, who may find it necessary to considerably modify his preprocessing schedule.

Studies in Pennsylvania, New York, and California have been designed to reduce bruising by preventing fruit on high branches from falling through branches lower in the tree. The "plateau system" of training permits apples from upper level branches to be caught by an elevated catching frame, and fruits from lower level branches are caught by the conventional frame. A considerable reduction in bruising has been achieved in this way but no commercial models of such machines are available. A single-story tree has been attempted with pears but yield may be reduced to an uneconomic level. Such studies are important in determining what is horticulturally and economically feasible in modifying present harvest practices.

Economic Considerations

Only preliminary economic feasibility information relating to harvest mechanization can be projected for most fruits at this time. The ultimate machine for harvesting any particular commodity probably has not been developed. It may be that a grower will have a choice of machines depending on his operations, and that adjustments or accessories will make machines adaptable to several fruit species that vary in tree size and harvest problems. No reliable projection is possible relating orchard depreciation to mechanical harvesting, nor can one be sure of the ultimate effects of orchard cultural modifications to yield. Although the economic importance of canker diseases cannot be overlooked, neither can a reliable value be placed on it at this time.

Economic feasibility has already been established for mechanized harvest of several nut species and for segments of the dried prune and sour cherry industries. Preliminary information is promising for cling peaches, sweet cherries, and apricots for processing.

Overhead cost per harvested unit is the major consideration that affects economic feasibility of harvest mechanization in addition to those factors already discussed. Since this cost is determined by depreciation, obsolescence, and other fixed costs, it is greatly influenced by the number of units harvested. Therefore, harvest rate and length of harvest season are critical considerations that tend to minimize economic feasibility potential for the small grower or the short season crop. Offsetting factors may include: 1) less efficient but lower cost machines, 2) multiple crop use, 3) around-the-clock operation (which has already been proven to be practical), and 4) cooperative ownership or custom rental of machines.

Other factors that should receive consideration as they relate to specific crops are: tree supports other than props, soil preparation, and possible elimination of varieties not suited to harvest mechanization.

Mechanical Harvest Potential of Tree Fruits

Although predictions and generalizations based upon limited research are dangerous, perhaps they are justified in connection with a harvest mechanization discussion as a means of stimulating thought on the problems involved. Table 1 presents an estimate of the potential of a number of fruits for mechanical harvesting by shakers and catching frames. These estimates are judgments based upon tree characteristics, ease of fruit removal, selectivity in relation to maturity, cost of hand harvest, and fruit characteristics and utilization. They are not based on consideration of overhead costs of machine ownership or disease problems of the tree associated with shaker damage.

Table 1. Estimate of Mechanical Harvesting Potential* of Certain Tree Fruits.

Fruit	Utilization	
	Fresh	Processing
Apple	4	2-3
Apricot	4	1-2
Cherry, sour	—	1
Cherry, sweet	4	1
Grapefruit, Calif.	4	3
Grapefruit, Florida	3	2
Lemon	4	4
Orange, Calif., Arizona	4	3-4
Orange, Florida	3-4	2-3
Peach, cling	—	1
Peach, freestone	4	3-4
Pear	3-4	3-4
Plum	2-4	2-3
Prune	—	1

* 1 indicates greatest potential and 4 least potential; 2 and 3 are intermediate and may relate to specific varieties or conditions.

Assuming a degree of reliability of the ratings in Table 1, it appears that machines now under development may fill an important position in the harvesting of a number of tree fruits for processing, but that they offer little hope to other fruits or the fresh fruit industry. Changes in labor costs and availability could result in modification of the ratings given, but perhaps not in the relationships. Therefore, one must conclude that the present approach to mechanization of the harvesting operation, important as it is, is not a panacea to the harvest cost problem of tree fruits in general. This points to the need, not only for continued studies of harvest mechanization in its present form with minor modifications for improvement and adaptation, but for a broader approach covering various horticultural manipulations and their association with mechanical aids, and further considerations of other engineering concepts. Continued close cooperation between agencies and complementary groups within an agency, such as engineers, pomologists, food scientists, plant pathologists, and economists, as the situation may warrant, would seem to be essential for greatest progress.

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Maximum Yields of Processing Vegetables

By M. T. Vittum, *New York State Agricultural Experiment Station,
Geneva, New York*

Intense competition in the fruit and vegetable processing industry rapidly eliminates the inefficient operator. Thus, in a free economy, only the most efficient growers survive. These are the growers who have the ability to manage their soils and crops in such a way as to produce large yields of high quality at low cost per unit of production.

Since large yields are usually a key factor in efficient production, it would be interesting to know the maximum yields that have been, or can be, produced by good growers. Thus, in the fall of 1964, a questionnaire was distributed to various processors, seedsmen, commercial agronomists, and land grant college research and extension personnel throughout the United States. Information was requested on the best commercial or field yields, and on the highest yield ever obtained in small research or extension plots, for 10 different processing vegetables. Response to the questionnaire was quite heartening. Processors, however, were considerably more cooperative than professors in supplying information. Thus, the maximum yields from small research trials reported herein for several crops represent a much smaller "sample" of response than that for commercial fields.

Top yields reported for each crop are summarized in Table 1. In studying these data, keep in mind the obvious limitations in this type of information. Most processing vegetables, for example, do not have definite maturity dates. They are harvested according to the type of pack each processor is putting up. The questionnaire requested information on crops of "acceptable processing quality." This could vary considerably from one processor to another.

In most cases the actual pounds or tons which are removed from a field are measured quite accurately, using

scales which are checked by local inspectors. Acreage data, on the other hand, are much less accurate. Although most good growers know the approximate size of each individual field, they sometimes contract for either a larger or smaller acreage. Unpublished work in New York State indicates that the grower's and/or fieldmen's estimate of acreage can vary as much as 20 percent from the actual measured acreage of any given field.

Yields for small research plots are usually higher than for commercial fields because of better control of such factors as plant population, fertilizer, weeds, insects, and diseases. Thus it is interesting to compare maximum yields from small experimental plots with those from commercial fields (Table 1).

Results for the different crops are summarized in Table 1, and the survey data are compared with state average yields and with potential or theoretical yields in Table 2.

Bush Beans: Average yield of the top 7 commercial fields was 5.6 tons per acre. Five experimental plots averaged double this yield, or 11.2 tons per acre (Table 1). All results are for a once-over harvest with a mechanical bean picker for commercial fields, and for a single hand picking for small plots. The best commercial field was a 20-acre field in Oregon which averaged 9.4 tons per acre. Rows were 30 inches apart with 7.5 plants per foot of row, or 131,000 plants per acre. Moisture was adequate throughout the season, and success of this crop was attributed to "total absence of stress—water, nutrients, temperature, wind, insects, diseases, etc."

It is interesting to calculate the potential yield that could be obtained if certain assumptions are made. If there are 174,000 plants per acre (1" apart in 36" rows, 1.5" apart in 24" rows,

3" apart in 12" rows, or 6" apart in 6" rows), and if each plant produces 10 sieve-size 4 pods and these pods average 7 grams each (or 65 pods per pound), the potential yield is 13.4 tons per acre (Table 2). Think of the potential yield if each plant produced 12, 15, or even 20 pods! Individual bush bean plants under ideal conditions can produce as many as 50 pods.

Pole Beans: Average yield of the top 6 commercial fields was 13.7 tons per acre; for 3 research plots 20.2 tons (Table 1). All of these yields were from the West Coast, where each field is irrigated and is picked 5 to 8 times by hand.

With 43,560 plants per acre (5 plants per foot in rows 5' apart, or 4 plants per foot in rows 4' apart), and with 1 pound of pods per plant, a yield of 21.8 tons should not be unreasonable (Table 2).

Green Lima Beans: Because of much smaller acreage, data on lima beans are not nearly so voluminous as for snap beans. Average yield of the 6 top commercial fields was 2.6 tons per acre, as compared with 3.5 tons for the top 5 experimental plots (Table 1). With a population of 87,100 plants per acre (2" apart in 36" rows), each plant would have to produce only 0.10 pounds of beans to obtain a theoretical yield of 4.4 tons (Table 2).

Beets: Only a small acreage of table beets is grown for processing in the United States, but this is an important crop in parts of New York, Wisconsin, Oregon, and Texas. Average yield of the 4 top commercial fields was 34.0 tons per acre, considerably higher than the 21.5 tons averaged in the top 4 research trials (Table 1). This crop is difficult to evaluate in this type of a survey. Small beets 1 to 1½" in diameter are worth 30 to 35 dollars per ton, whereas large beets, greater than 3 or