understanding of the mechanism of neoplasm induction by DNA viruses may clarify the mechanism of neoplasia in a general way.

References and Notes

1. G. J. Todaro and H. Green, *J. Cell Biol.* **17**, 299 (1963).
2. G. J. Todaro, G. K. Lazar, H. Green, *J. Cell. Comp. Physiol.* **66**, 325 (1965).
3. R. W. Holley and J. A. Kiernan, *Proc. Nat. Acad. Sci. U.S.* **60**, 300 (1968).
4. S. Hakomori and W. T. Murakami, *ibid.* **59**, 254 (1968); S. Hakomori, C. Teather, H. Andrews, *Biochem. Biophys. Res. Commun.* **33**, 563 (1968).
5. I. Macpherson and L. Montagnier, *Virology* **23**, 291 (1964).
6. I. Macpherson and M. G. P. Stoker, *ibid.* **16**, 147 (1962).
7. H. E. Hopps, B. C. Bernheim, A. Nisalak, J. H. Tjio, J. E. Smadel, *J. Immunol.* **91**, 416 (1963).
8. M. Stoker, *Nature* **218**, 234 (1968).
9. H. Westphal and R. Dulbecco, *Proc. Nat. Acad. Sci. U.S.* **59**, 1158 (1968).
10. D. Gillespie and S. Spiegelman, *J. Mol. Biol.* **12**, 829 (1965).
11. M. R. Michel, B. Hirt, R. Weil, *Proc. Nat. Acad. Sci. U.S.* **58**, 1384 (1967).
12. J. Sambrook, H. Westphal, P. R. Srinivasan, R. Dulbecco, *ibid.* **60**, 1288 (1968).
13. S. Kit, T. Kurimura, M. L. Salvi, D. R. Dubbs, *ibid.*, p. 1239.
14. M. C. Weiss, B. Ephrussi, L. J. Scaletta, *ibid.* **59**, 1132 (1968).
15. G. Marin and J. W. Littlefield, *J. Virol.* **2**, 69 (1968).
16. M. Stoker, *Nature* **200**, 756 (1963); G. J. Todaro, *ibid.* **219**, 520 (1968).
17. E. J. Pollock and G. J. Todaro, *ibid.*, p. 521.
18. D. Freifelder, *J. Mol. Biol.* **35**, 303 (1968).
19. P. Gerber, *Virology* **28**, 501 (1966); H. Koprowski, F. C. Jensen, Z. Steplewski, *Proc. Nat. Acad. Sci. U.S.* **58**, 127 (1967); J. F. Watkins and R. Dulbecco, *ibid.*, p. 1396; P. Tournier, R. Cassingena, R. Wicker, J. Coppey, H. Suarez, *Int. J. Cancer* **2**, 117 (1967).
20. H. Harris and J. F. Watkins, *Nature* **205**, 640 (1965).
21. M. Vogt, *J. Mol. Biol.*, in press.
22. M. Fried, *Proc. Nat. Acad. Sci. U.S.* **53**, 486 (1965).
23. F. Cuzin, M. Vogt, M. Dieckmann, P. Berg, *J. Mol. Biol.*, in press.
24. C. Mulder and M. Vogt, personal communication.
25. D. A. Clayton and J. Vinograd, *Nature* **216**, 647 (1967).
26. Y. Aloni, E. Winocour, L. Sachs, *J. Mol. Biol.* **31**, 415 (1968); K. Oda and R. Dulbecco, *Proc. Nat. Acad. Sci. U.S.* **60**, 525 (1968).
27. G. Sauer and J. R. Kidwai, *ibid.* **61**, 1256 (1968).
28. S. Uchida, K. Yoshiike, S. Watanabe, A. Buruno, *Virology* **34**, 1 (1968); K. Yoshiike, *ibid.*, p. 391.
29. S. Uchida and S. Watanabe, *ibid.* **35**, 166 (1968).
30. R. Cassingena and P. Tournier, *C. R. Hebd. Seances Acad. Sci. Paris Ser. D* **267**, 2251 (1968).
31. K. B. Fraser, A. Smith, M. G. P. Stoker, *Virology* **28**, 494 (1966).
32. W. Eckhart, *ibid.* **38**, 120 (1969).
33. G. di Mayorca, J. Callender, G. Marin, R. Giordano, *ibid.*, p. 126
34. M. Stoker and R. Dulbecco, *Nature* **223**, 397 (1969).
35. J. H. Pope and W. P. Rowe, *J. Exp. Med.* **120**, 121 (1964); A. B. Sabin and M. A. Koch, *Proc. Nat. Acad. Sci. U.S.* **52**, 1131 (1964); K. Habel, *Virology* **25**, 55 (1965).
36. K. Habel, *Proc. Soc. Exp. Biol. Med.* **106**, 722 (1961); H. O. Sjögren, I. Hellström, G. Klein, *Cancer Res.* **21**, 329 (1961).
37. M. Vogt, personal communication.
38. R. Dulbecco, L. H. Hartwell, M. Vogt, *Proc. Nat. Acad. Sci. U.S.* **53**, 403 (1965); R. Weil, M. R. Michel, G. K. Rushman, *ibid.*, p. 1468; D. Gershon, P. Hausen, L. Sachs, E. Winocour, *ibid.* **54**, 1584 (1965); M. Hatanaka and R. Dulbecco, *ibid.* **56**, 736 (1966).
39. R. Dulbecco and T. Johnson, in preparation.
40. R. Dulbecco, unpublished data.
41. M. Hatanaka and R. Dulbecco, *Proc. Nat. Acad. Sci. U.S.* **58**, 1888 (1967).
42. C. Basilico, Y. Matsuya, H. Green, *J. Virology* **3**, 140 (1969).
43. The work discussed was carried out with the aid of research grant No. CA-07592 from the National Cancer Institute, Bethesda, Maryland.

Mechanical Harvesting of Food

Machine harvesting systems can be developed only as a result of scientific research.

Jordan H. Levin

Scientific research has made American agriculture the envy of the world. Last year less than 5 million U.S. farm workers produced food and fiber for over 200 million Americans and approximately 30 million people in other countries. This is a ratio of 1 to 46 and means that the remaining members of the working force could devote their time to creating the goods and performing the services that make up the high standard of living enjoyed in this country.

The high agricultural productivity is a result of research by many disciplines combined with the willingness of progressive growers to adopt these results. Yields per acre have been vastly increased by introduction of new plant varieties, by use of fertilizers, and by management of water. Losses from insects and disease have been decreased through proper use of chemicals and through methods of biological control. Agricultural engineers have contributed greatly by developing machines to do much of the hard work, so that one man can do the work formerly done by many. Many billions of dollars' worth of farm equipment is used in the United States. It is estimated that more than $2½ billion of farm equipment was sold in the United States last year; of this amount, harvesting machines accounted for approximately $550 million (*1*).

Harvesting requires more labor than any other operation in the production and marketing of most food and fiber crops. Fortunately, machines have been developed for harvesting almost all food crops, with the exception of most fruits and vegetables. For example, in the United States most grain (wheat, rice, oats, and so on) and beans are harvested with large machines called combines. A combine which harvests a swath 12 feet (3½ meters) wide costs approximately $8000. Such a machine enables one man to harvest a crop 100 times as fast as a worker using animal power and 1000 times as fast as a worker using hand tools. Animal and hand power are still used in many countries of the world.

In the last 5 or 6 years it has become difficult to find workers for harvesting fruit and vegetable crops. The only practical answer to the labor problems that are facing the fruit and vegetable industries is mechanization (*2*). The Agricultural Research Service of the United States Department of Agriculture and many state agricultural experiment stations are now conducting research on the problem of mechanizing the harvesting of fruits and vegetables.

This problem involves much more than making a machine to perform a

The author is on the staff of the Agricultural Engineering Research Division, Agricultural Research Service, U.S. Department of Agriculture, East Lansing, Michigan.

particular function. It is very complex and usually requires scientific research by many disciplines. A complete harvesting system must be developed before it can be adopted by the industry in question. Agricultural engineers and other scientists need to carry on research on such subjects as ways of selecting the fruit or vegetable to be harvested; detachment of the fruit or vegetable from the plant or tree; collection of the harvested product; separation of the trash or undesirable materials; handling and transportation; maintenance of quality; physical and rheological properties; plant or tree characteristics; preharvest practices; and feasibility of the proposed or new system.

Selection

Many crops do not ripen uniformly. Several pickings are required, and only the mature fruits or vegetables are harvested at each picking. If such a crop is harvested mechanically, the machine must distinguish between the individual fruits or vegetables which are ready for harvest and those which are not. Therefore, some property of the fruit or vegetable must be found which can be related to maturity.

For example, research by agricultural engineers in Arizona (*3*) and California (*4*) showed that firmness of lettuce heads is a good index of maturity. Harvesting machines which used firmness as a criterion for selecting mature heads were developed. The selective portion of the University of California machine tests the size and firmness of the lettuce heads by applying a force to the top of the plant. The machine locks into position on top of a head large enough to harvest and, with this as a zero point, slightly deflects the head vertically. The force required depends on the degree of maturity; soft and immature heads require less force than mature heads. The force is applied through a belt which is ground-driven and has zero velocity relative to the ground. This prevents scrubbing and rolling of the head, and keeps it from being injured. When the head offers sufficient resistance to the deflecting force, the selector gives an electrical signal which indicates that the head is ready for picking; the signal also locates the position of the plant in the row.

The selector unit, because of its size, is positioned ahead of the cutting and retrieving units. The signal that a head is acceptable is given by the selector when the cutter is still 30 inches (76 centimeters) behind the head. That signal must be stored until the cutter is in the proper position. Meanwhile, the selector may pass over two or three more heads. Since these heads may also be acceptable, the control system must include a memory unit capable of storing four signals simultaneously (*5*).

This selector system is a contact system. Electronic components are required, and these create problems when they are used in the fields, because of vibration, dirt, and moisture.

A noncontact method, based on the use of gamma rays to determine the density of the head, has been developed (*6*). A gamma-ray source is moved down the row past one side of the heads, and at the same time a device which measures radiation moves down the row on the opposite side of the heads. If the level of radiation passing through the heads is low enough, a signal activates the cutting mechanism. The use of ultrasonics for measuring the density and maturity of lettuce heads is also being investigated (*7*).

In New Jersey, agricultural engineers have developed a selector for asparagus (*8*). A light source and a photoelectric cell are moved through the field at a fixed height above the ground. If the spear of asparagus is high enough, it breaks the light beam and activates a knife which harvests the spear.

Engineers and scientists also have used other properties—such as differences in the force needed to detach the fruit, light reflectance, color, and fruit size—in developing selector equipment for other crops.

Detachment

Detaching the fruit or vegetable from the tree or plant may be accomplished by pulling, lifting, cutting, snapping, twisting, stripping, and so on. Shaking has proved to be a successful means of detaching some tree fruits (including oranges, cherries, apples, and plums) and some bush berries (including blueberries and raspberries). When a fruit is shaken, its motion is accelerated and a force is created which equals the mass times the acceleration ($F = ma$). If this force is greater than the detachment force needed to pull the fruit from the stem or limb, the fruit will be detached. Since this detachment force can be measured and the mass of the fruit can be determined, the required acceleration can be calculated. The optimum combination of stroke and frequency for obtaining the needed acceleration is then determined.

Since mechanical shakers are attached to the tree trunk or main scaffold limbs, such factors as the frequency of the limb's natural vibration, its efficiency in transmitting vibration, the damping effect of the leaves, the damping effect of the fruit, the mass of the limb, and the direction of vibration must be considered.

A new type of shaker, called the inertia shaker, has been developed by agricultural engineers and has proved very effective in harvesting fruit crops (*9*). Since this type of shaker attaches to, and becomes part of, the vibrating limb, the mass of the shaker parts, as well as the total mass of the shaker and boom, must be included in calculating the optimum stroke and frequencies. The problem is further complicated by other factors: the leaves and fruit may be wet; the limbs are tapered, and vary in size; the trees differ in age; and the amount of fruit on the tree varies while the crop is being harvested. The mathematics become quite complicated. Figure 1 shows the force relations in an inertia shaker (*10*).

In order to determine the constants and to check theoretical calculations, instruments such as accelerometers and units which automatically integrate twice to obtain strokes are used. Using such instruments on tree limbs and shaker parts, under conditions that exist in an orchard, is not a simple task (*9*).

United States Department of Agriculture agricultural engineers, in cooperation with personnel from state agricultural experiment stations in Florida, California, Hawaii, and Michigan, have determined the optimum stroke and frequencies for harvesting oranges, grapefruit, coffee, apples, prunes, cherries, and blueberries. The requirements differ for the various crops. For example, a stroke of 1½ inches and a frequency of 1200 cycles per minute is best for harvesting tart cherries, while a stroke of 3½ inches and a frequency of 400 cycles per minute is best for harvesting apples. The design of most commercial shakers is based on the research findings, and in the last few years over $10 million of tree shakers have been sold.

Collection

Each crop presents its own problems when scientists attempt to develop methods of collecting the harvested fruits or vegetables into some type of container for handling and transportation. The collecting may be done by the same machine that detaches the fruit or vegetable, as in the case of potato harvesters and tree-fruit shakers.

A two-row potato harvester traveling at 2 miles (3.2 kilometers) per hour lifts 8 to 10 tons (7 to 9 metric tons) of soil and between 300 and 350 pounds (135 and 157 kilograms) of potatoes *each minute* of operation (*11*) (600 tons of soil and 10 tons of potatoes each hour). Conveyors must be rugged enough to handle these huge amounts, must be resistant to abrasion, and must be able to separate the potatoes from the soil and still not bruise them.

Self-propelled collecting equipment used in conjunction with tree-fruit shakers must cover the total area under the tree (which for apples is a circle with a radius of 16 feet), yet be designed for easy maneuverability through the orchard and for turning at the end of the rows.

Collecting equipment may be separate from the harvesting machine. For example, mechanical shakers or knockers are used to detach almonds and walnuts from the tree and allow them to fall onto the ground; self-propelled machines are then used to pick up the nuts from the ground and transfer them into bulk containers. Experiments on harvesting oranges by means of this same technique, which requires preparation of a level orchard floor, are being made. Timing is another factor which must be considered for each crop, because of varying rates of deterioration as the detached fruit lies on the ground.

Separation, Cleaning, and Sorting

Harvesting machines collect leaves, twigs, dirt, and stones along with the desired fruits or vegetables. They also collect fruits or vegetables that are immature, overmature, too small, decayed, or scarred. The foreign material and unsalable produce should be sorted out on the harvester, or as soon as possible after being removed from it. Transporting this material to the packing house or processing plant costs money, may cause damage to the usable fruits and vegetables, and results in an increased waste-disposal problem at the plant or packinghouse.

Many of the major potato-growing areas, such as Maine, have very stony soils, and this adds to the difficulty of the harvesting process. Since many of the stones and potatoes have the same shape and look alike, it is difficult to separate them. Many techniques have been tried. In England, researchers found that the difference in x-ray absorption is sufficient to permit separation (*12*). A mixture of potatoes, stones, and soil clods in a single layer is allowed to fall through a series of beams of ionizing radiation falling on scintillators. Differences in the absorption of radiation by potatoes, stones, and clods are then used for discriminating between them and for activating a bank of fingers which deflect stones and clods in one direction and potatoes in the other. A potato harvester which utilizes this principle is now being manufactured in England.

In the mechanical harvesting of cultivated blueberries, the ripe berries are removed and the pink and green ones are left on the bush for later harvesting. However, some leaves and pink and green berries are also shaken off. These must be separated from the good berries before the latter are packed for market. Researchers found that the foreign material and immature fruit could be separated by means of a constant air blast, on the basis of specific gravity and surface texture (*13*). By controlling the flow of air, a final product consisting entirely of blue mature berries or a combination of blue berries and pink berries can be obtained.

Tomato harvesters have been developed which remove the plants from the ground and transfer them to the machine, where the tomatoes are shaken off and collected, then deposit the vines back on the ground (*14*) (Fig. 2). The tomatoes do not all ripen at one time, and the percentage of green tomatoes may vary from 10 to 45 percent. Green tomatoes have no commercial value and must be sorted out, by hand. This problem is being worked on by scientists at Pennsylvania State University; they have developed an experimental unit on the harvester which will separate ripe from green tomatoes on the basis of light reflectance (*15*). Essential concurrent work has been carried on by plant breeders, who have developed varieties much more suitable for mechanical harvesting. The plant scientists also have conducted research relating to the application of chemicals which cause the fruit to ripen more evenly and thereby reduce the percentage of green fruit which must be sorted out and which is lost to the market.

It is doubtful that such a light-reflectance separation system will prove practical on a harvesting machine, because of the following problems: (i) the required capacity is high (the system would have to sort approximately 180,000 tomatoes an hour); (ii) reflected or direct light results in false determinations; (iii) light of the proper wavelength must be maintained; and (iv) vibration and dirt affect electronic equipment. Separation by floating the tomatoes in alcohol or other fluids looks promising. However, this method could not be used on the machine; the equipment would have to be located in a field sorting station.

Handling and Transportation

Fruits and vegetables harvested by hand usually are handled in small containers holding 20 to 100 pounds each (*16*). Because the rate of harvest is high when machines are used, small containers cannot be used and it is necessary to use bulk or semibulk methods of handling. In many machine harvesting operations, speed of harvest depends, not on the capacity of the harvester, but on that of the handling system.

Containers called pallet boxes which hold from 800 to 2000 pounds of fruits or vegetables have come into widespread use (*17*). Researchers have spent considerable time on designing these containers and on developing methods for handling them. It is important to know to what depth a container can be filled without damaging the fruit or vegetable. Agricultural engineers in England have made plastic fruits and have instrumented them so that stresses and internal pressures can be determined at any container depth. A container can be filled with grapes to a depth of 14 inches, with sweet cherries to a depth of 18 inches, and with apples to a depth of 24 inches without the fruit's being bruised from pressure.

Since these containers cannot be handled manually, power equipment is necessary in the field, at the loading areas, at receiving stations, in the storage areas, and at the packinghouses and processing plants. In the past 15 years, equipment which was not needed or available before the introduction of pallet boxes has been developed—machines such as tractor forklifts, straddle carriers for pallet boxes, and rotary dumpers (*18*).

Sampling of fruits and vegetables is standard practice for determining the grade and size, on which price is determined in the purchasing by processors and packers. A slight error in the assigned grade may result in a difference of $20 to $40 per ton, and on a crop of 100 tons or more the amount of money involved is significant. When deliveries are made in small boxes, one box, or more, customarily is selected at random for sampling and inspection. Mechanical harvesting and the necessary bulk handling of fruits, nuts, and vegetables introduced the need for an effective method of obtaining representative samples from large containers. Research is needed on the problems of (i) grade variance in the container, (ii) determining the size of sample that statistically represents the complete load, and (iii) determining how to obtain this random sample (*19*). Methods and equipment acceptable to both the grower and the buyer have been, and are being, studied and developed.

Fruits and vegetables are transferred by truck to processing plants and packing houses and are subjected to the risk of in-transit vibration damage. This can be serious and must be kept to a minimum. Researchers in California (*20*) found the factors affecting the amount of damage to be as follows: (i) the type of suspension on the truck; (ii) conditions on the road; (iii) the depth at which the fruit rests in the containers; (iv) the natural vibration frequency of the fruit; (v) the fruit's resistance to bruising; (vi) its maturity; and (vii) the tightness of the pack. Research was conducted on actual and simulated in-transit vibration damage on peaches, pears, and tomatoes. Measurements show that the acceleration could vary from 1.4*g* at the top third of the pallet box, to 0.58*g* in the middle third, to 0.36*g* in the bottom third. The top layer of fruit, and not the fruit in the bottom of the box, receives the greatest damage. This is due to the large number of impacts and is sometimes called roller damage. Trucks with air-ride-suspension construction cause less damage than trucks with leaf-spring suspension.

Handling is an important part of a harvesting system. It affects capacity, costs, and quality, and considerable research is needed on what seems to be a simple and easy task—moving produce from one place to another.

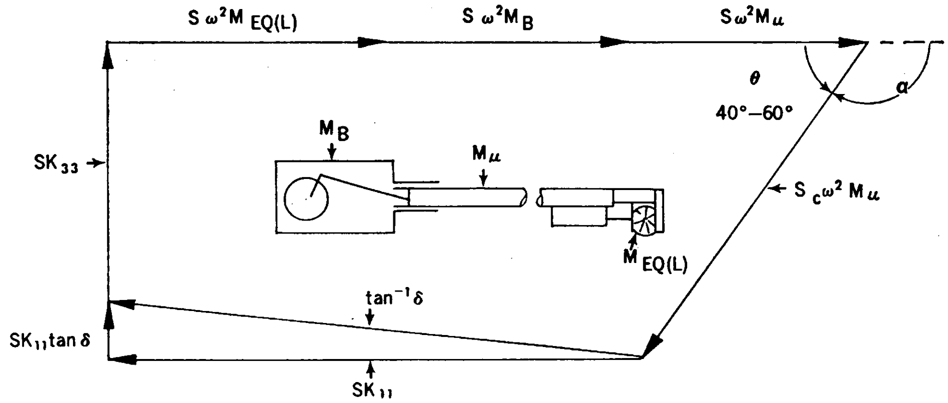

Fig. 1. Force relations in an inertia shaker. (ω) Frequency, in radians per second; (M_B) mass of boom; (M_u) unbalance mass of shaker; [$M_{EQ(L)}$] equivalent mass of limb; (K_{33}) external damping of limb; (K_{11} tan δ) internal damping of limb; (S) absolute displacement of limb; (S_c) absolute displacement of crank stroke.

Maintenance of Quality

Use of a particular machine may make it possible to harvest fruits and vegetables at a low cost with very little labor. However, if the crops are badly damaged during the harvest and handling, use of the machines is not practical. Machines can cut, bruise, and lower quality in many ways.

Mechanical damage to fruits and vegetables can be reduced by minimizing impact and pressure forces. Cushioning materials which absorb impact energies is one solution. Data on materials to cushion the fall of free-falling objects have not been available. Agricultural engineers have developed test equipment consisting of an automatic dropping mechanism that releases an object or a fruit or vegetable from heights up to 22 feet. In one test arrangement the object fell freely through a drop chute past a series of phototubes onto a beam equipped with strain gages (*21*). Cushioning materials were placed on the beam. The strain gages were used in measuring the impact forces, and the time gap between interruptions of adjacent light beams was used in measuring velocity and rebound heights. Over 92 materials were evaluated.

Deterioration in quality is caused by a high rate of respiration and oxidation. Cooling slows down the respiration rate. To take advantage of this effect of cooling, scientists developed a system of handling cherries in cold water in pallet tanks (*22*). Over 90 percent of the crop is now handled in this way. Research has been conducted

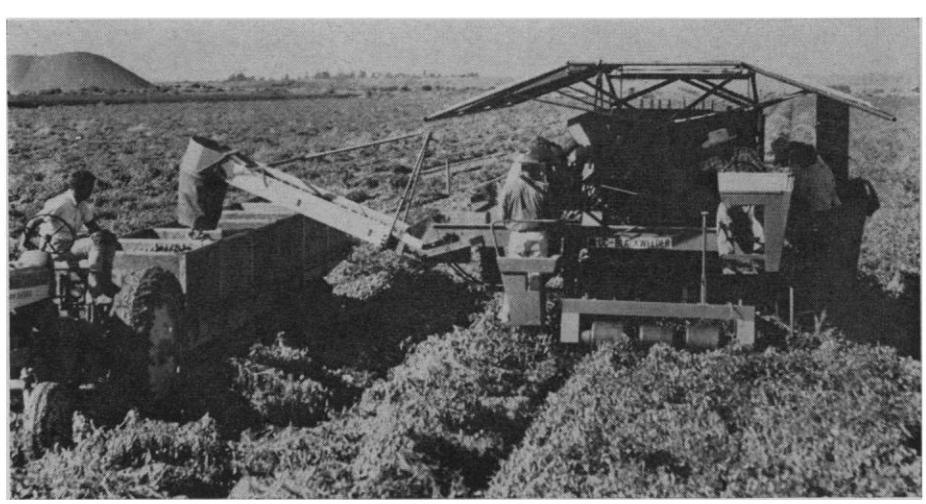

Fig. 2. Tomatoes being mechanically harvested and loaded into bulk bins on a tractor-drawn trailer. [Courtesy Blackwelder Manufacturing Company]

at Michigan State University and at other agricultural experiment stations on thermal properties of cherries (*23*) and other fruits, on hydrocooling systems, and on the control of oxidation by the use of carbon dioxide, waxes, and dips.

Quantitative measures are needed in research on quality. In tart cherries, for example, firmness is an excellent measure of quality. Simple instruments for measuring firmness have been developed (*24*). One of these, the "PL meter," has been used by researchers on coffee and other crops. It is a modified commercial micrometer dial gage which detects variations in firmness by measuring the deflection of cherries subjected to a constant load applied over a constant area. An instrument for automatically measuring the firmness of red cherries has also been developed. It is much more sophisticated and can be used only in the laboratory.

Developing harvesting machines that maintain acceptable quality is one of the most difficult problems, and considerable time and effort on all phases of this problem are being expended by plant physiologists, biochemists, and food technologists as well as by agricultural engineers.

Physical and Rheological Properties of Fruits and Vegetables

It is obvious that, in order to develop and evaluate selection, detachment, collection, handling, quality maintenance, equipment, and methods, knowledge of the various physical and rheological properties of fruits and vegetables is needed. Data on mechanical, thermal, electrical, optical, and even sonic properties are useful to researchers. Yet only a few of the many basic physical characteristics and properties of agricultural products have been determined. Shape, size, volume, surface area, density, color, and appearance are some of the important physical characteristics. Compression strength, impact and shear, stress-strain relationship, and creep are a few of the mechanical properties that need to be determined. Friction coefficient, hardness, and elasticity are others.

Agricultural engineers at Pennsylvania State University established the first facilities and equipment laboratory for determining physical and rheological properties of fruits and vegetables about 9 years ago. Today many universities, including Michigan State University, the University of California, Purdue, the University of Hawaii, and West Virginia University, have special laboratories for studying physical and rheological properties.

Fruits and vegetables are alive after being harvested as well as before. They use oxygen and give off carbon dioxide, heat, and moisture. Fruits and vegetables are different from man-made materials in that many of their properties are time-dependent and are viscoelastic in nature. Moreover, not only do fruits and vegetables of different varieties differ but individual fruits of the same variety can differ greatly. Therefore, statistical approaches are needed. The techniques and equipment used for determining properties of conventional materials are not satisfactory. Some testing equipment and techniques have been developed, and many more are needed. Terms and definitions must be standardized, so that results can be understood and compared.

Progress is being made. Many universities in the last 2 or 3 years have offered, for the first time, courses in physical and rheological properties of fruits, vegetables, and other agricultural products. The first textbook on the subject was published in 1968 (*25*).

Force-deformation stress-strain curves for fruits have been found to be similar to those in metallurgy (*25*). Figure 3 shows a force-deformation curve for apples. Point 0 is not found in most man-made material and has been given the name of "bio-yield point." It occurs when there is a drop in the force-deformation curve, as in apples or pears, or when a change in slope of the curve occurs, as in peaches and potatoes. It has been found that, until the bio-yield pressure is reached for fruits and vegetables, no browning or visible bruising can be detected. Slope of the curve and values for the bio-yield point and the rupture point depend not only on the particular fruit or vegetable but also on the rate of loading and on such factors as temperature and moisture.

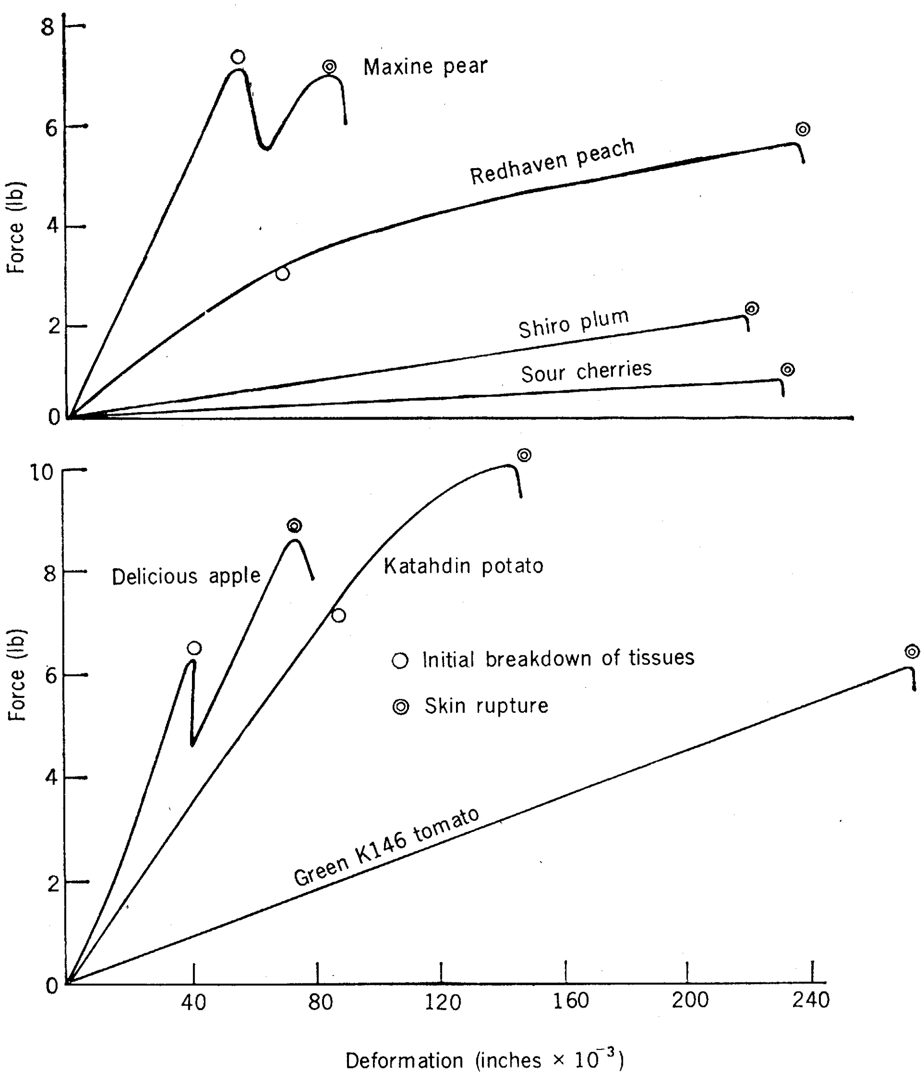

Fig. 3. Force-deformation curves for some fruits and vegetables.

Study of the Plant or Tree

Since fruit trees and vegetable plants have been in existence for thousands of years, it is surprising how little is known about their shape, their size, and the location of the fruit, and about such properties as vibration characteristics, bark strength, and resilience.

Shakers, which are being used extensively to harvest tree fruits and nuts, can damage the bark of the tree. Any break in the bark is an opening for disease microorganisms and insects. Crushed bark may affect transfer of nutrients within the tree. Studies (*26*) on the bark of peach, prune, cherry, and orange trees have been made. Trees in the orchard and carefully stripped pieces of bark that were immediately taken to the laboratory were subjected to tensile, shear, and compression forces. It was found that the tensile strength is about four times the shear strength. Very moist bark is much weaker than dry bark. The results of these studies are being used in the design of improved shaker clamps and in water management of the orchard.

An interesting study, not yet completed, is being made to determine the location of oranges on the tree (*27*). The field data consist of cylindrical-coordinates values for each fruit on orange trees of the navel and Valencia varieties in the main production areas of California. The longitudinal axis of the cylindrical-coordinates system was oriented vertically and in line with the trunk of the tree. To obtain the coordinate values, a plumb bob on a calibrated tape was lowered from each fruit (Fig. 4). The length of tape let out showed the height of the fruit. The point of intersection of the plumb bob with a polar coordinate board at ground level gave the angular and radial positions of the fruit.

In addition, approximations of stem length and extent of clustering were recorded for each fruit.

All the data have been put in a form such that they can be analyzed by a computer. By proper programming, many questions can be answered. For instance, approximately 90 percent of the fruits are located within 3 feet of the periphery of the tree. In one study it was found that about 90 percent of the fruit was located in the lower 13 percent of the tree (*27*). It was also interesting to note that more fruit was concentrated on the east side of the tree than on the west side. Such information is useful in the design of harvesting equipment. It helps engineers decide whether the machine should move straight down the row or circle each tree, and whether detachment units can be programmed in a random fashion or whether they have to have sensing devices.

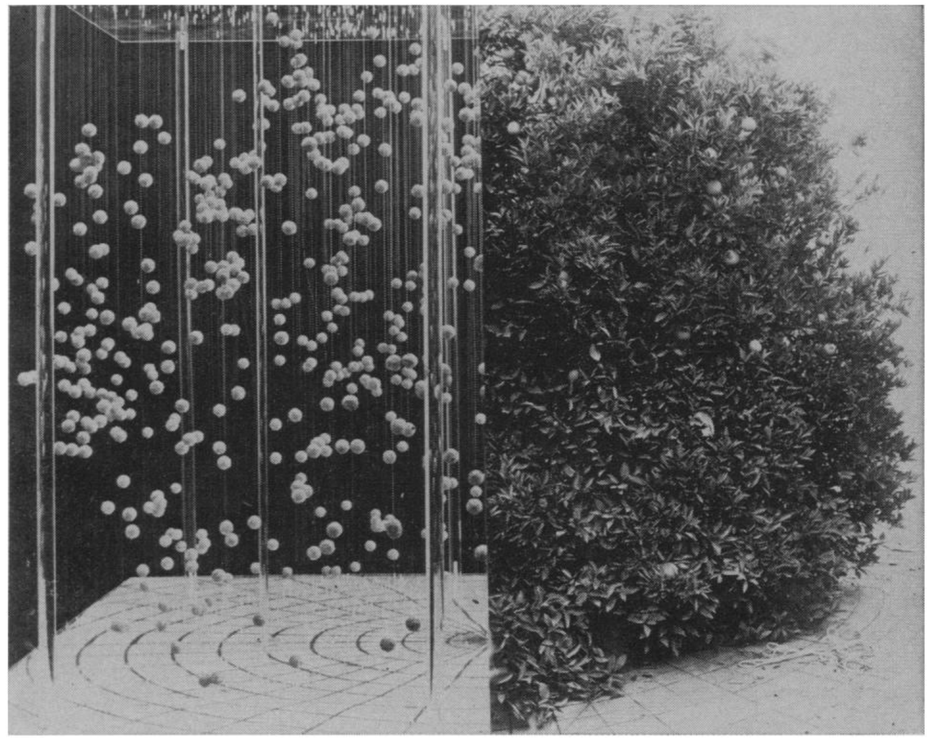

Fig 4. Composite photograph showing, at left, three-dimensional model of a method of determining the location of oranges on a tree, and, at right, photograph of half of the tree whose other half is represented by the model.

Studies are being made in which fruit trees are trained to grow in certain ways; the limbs are tied to the ground or back into the row so that hedgerows are formed. For these studies it is necessary to know the initial and long-term changes in forces needed to keep the limbs in position. Studies of changes in the elasticity and damping capacity of live apple limbs have been made. Limbs always tend to grow toward sunlight, and, therefore, more than engineering strength properties are involved.

Preharvest Practices and Operations

A harvesting machine is designed to satisfy a given set of stable conditions, such as between-row and in-the-row spacings, shape of the soil bed, shape of the tree, and size of the fruit. Although the machine can be constructed to operate satisfactorily with small variations, it cannot be expected to perform when conditions vary greatly. Therefore, preharvest practices which result in uniform field and growing conditions are of utmost importance.

Harvesting machines have increased the need for precision seeding and planting equipment which will result in uniformly spaced plants of the same degree of maturity growing in a straight line. The number of seeds per cubic inch can vary from a few to several hundred thousand, depending on the crop and the variety. The ability to pick up and place the seeds mechanically, one seed at a time, at precisely the proper depth and distance apart, and in a straight line, has been hard to achieve. Seeds have been coated with various substances for easy handling. Seeds have been placed on plastic tape, and the tapes planted. Electrical, vacuum, water, and other techniques have been tried. Although progress is being made, an ideal precision planter has not yet been developed.

In order for some selective harvesters to work, a minimum distance between plants is required. Thinners which remove the small plants at random intervals may leave two plants adjacent to each other. A thinner has been developed which senses a plant by means of electrical current. When contact is made with a plant, the plant conducts electricity and completes a circuit. A blade is activated and removes all the plants in front of it for a fixed distance. Such a method guarantees a minimum but not a maximum distance between plants.

Preharvest practices and operations greatly affect the efficiency of a harvester. The problem of separating stones and clods and potatoes is discussed above. Stone pickers have been developed, but there are indications that, if the stones are removed from the soil, erosion may result or yields per acre may be lowered. Much thought and research has been given to removing the stones from the fields, because harvesters operating in stony areas travel at a third to a half the speed of harvesters operating where stones are not a problem.

The shape of the soil bed can affect harvesting operations. If the bed is not flat, for example, tomato harvesters may not pick up all the tomatoes. New machines which shape soil beds are now being adopted.

Feasibility of Machine Systems

Any new machine or system, to be a success, must not only reduce labor requirements but allow the user to make a profit. The growing of food is a business just like any other business, and the objective is net profits. The complete system must be analyzed with respect to costs, labor requirements, and efficiency. Compromises between the various components of the harvesting system are necessary; one operation may cost more but may result in the overall system's being less expensive. Time, motion, production, and engineering cost studies must be made. Studies of these types are made both before and after a system is developed.

By studying the conventional system and projecting labor savings and production rates, the feasibility of a proposed machine can be determined. For instance, a study on the use of single-man and multi-man positioners for harvesting citrus (*28*) showed that the machine-cost per man should not be more than $970, on the basis of present labor rates. A man positioner is a machine on which the worker can move himself to any part of the tree by activating controls with his feet or hands. Such a machine eliminates the ladder and enables the worker to spend a greater percentage of work time in detaching the fruit. Engineers have had difficulty in designing a machine which can sell for under $2500 per worker.

Once a machine is developed, it must be evaluated from the standpoint of economic feasibility before a company will manufacture it or growers will buy it. A machine must be tested under commercial conditions, and time, production, and efficiency studies must be made. Fruit and vegetable machines are, for the most part, manufactured by small companies, since the total number of machines needed for harvesting any one crop is not large enough to interest the main-line implement companies. Therefore, the research group that develops the machine or machine system must also do the research necessary to determine the feasibility.

Team Research

The solution to the many problems of machine harvesting requires the knowledge and ability of many disciplines (*29*). For example, when cucumbers are grown for mechanical harvesting they are planted at a density of 125,000 per acre instead of the conventional 20,000 to 25,000, and scientists of several disciplines will have to help develop the new knowledge that is needed for best weed control, fertilization, irrigation, and other practices when plants are grown at this high density. Reducing the bonding force between the fruit and the tree would result in less costly tree shakers and more efficient operation. Little is known about abscission and what causes it. This is a problem for plant physiologists. It may be possible to use chemicals to cause abscission and loosen the fruit. Scientists have been interested in abscission for a number of years, but research had been limited up until about the last 5 years.

Agricultural research can be performed only by competent researchers. Engineers, chemists, biological scientists, and food technologists are all needed. The research is as challenging as any, and the opportunities are great. Harvesting machines for all food crops in all areas of the world must and will be developed.

References and Notes

1. *Agricultural Statistics 1968* (Government Printing Office, Washington, D.C., 1968).
2. J. H. Levin, "Harvest Mechanization Is Vital," *Amer. Soc. Agr. Engr. Pap. No. NA 66-201* (1966).
3. B. L. Harriott, K. K. Barnes, E. O. Finch, P. M. Bessey, "Mechanical Harvest of Crisphead Lettuce," *Amer. Soc. Agr. Engr. Pap. No. 64-123* (1964); B. L. Harriott, N. F. Oebker, L. C. Wolf, H. A. Hughes, R. O. Kuehl, "Physical Characteristics and Damage of Crisphead Lettuce during Harvest," *Amer. Soc. Agr. Engr. Pap. No. 67-144* (1967).
4. R. E. Garrett, M. Zachara, F. Zink, "Firmness, Density, and Volume of Crisphead Lettuce," *Amer. Soc. Agr. Engr. Pap. No. 68-118* (1968).
5. R. E. Garrett, "Development of a Control System for a Selective Lettuce Harvester," *Amer. Soc. Agr. Engr. Pap. No. 66-311* (1966).
6. Unpublished data, Agricultural Engineering Department, University of California, Davis.
7. Unpublished data, Agricultural Engineering Research Division, U.S. Department of Agriculture, Salinas, California.
8. NE-44 Annual Reports, Agricultural Engineering Department, Rutgers University, New Brunswick, N.J. (1963–68).
9. R. B. Fridley and P. A. Adrian, "Mechanical Harvesting Equipment for Deciduous Tree Fruits," *Univ. Calif. Bull. 825* (1960).
10. R. G. Diener, J. H. Levin, R. T. Whittenberger, "Relationship of Frequency and Length of Shaker Stroke to the Mechanical Harvesting of Apples," *U.S. Dep. Agr. Publ. ARS 42-148* (1969).
11. A. H. Glaves and G. W. French, "Increasing Potato-Harvester Efficiency," *U.S. Dep. Agr. Agr. Handb. No. 171* (1959).
12. W. H. Cushmore, *Farm Mechanization* **16**, 55 (Oct. 1964).
13. S. L. Hedden, H. P. Gaston, J. H. Levin, "Harvesting Blueberries Mechanically," *Mich. State Univ. Quart. Bull.* **42**, No. 1, 24 (1959).
14. R. E. Webb and W. M. Bruce, "Redesigning the Tomato for Mechanized Production," in *Science for Better Living, Yearbook of Agriculture* (U.S. Department of Agriculture, Washington, D.C., 1968), pp. 103–107.
15. K. Q. Stephenson, "Selective Fruit Separation for Mechanical Tomato Harvesters," *Agr. Eng. J.* (Mar. 1964).
16. J. H. Levin, *Agr. Eng.* **39**, 566 (1958).
17. H. P. Gaston and J. H. Levin, "Handling Apples in Bulk Boxes," *Mich. State Univ. Spec. Bull. 409* (1959).
18. J. H. Levin and H. P. Gaston, "Equipment Used by Deciduous Fruit Growers in Handling Bulk Boxes," *U.S. Dep. Agr. Publ. ARS 42-20* (1958).
19. M. O'Brien, *Trans. Amer. Soc. Agr. Engr.* **9**, No. 1 (1966).
20. M. O'Brien, J. P. Gentry, R. C. Gibson, *ibid.* **8**, No. 2 (1965).
21. E. D. Schmidt and J. H. Levin, "Cushioning Materials for Harvesting and Handling Fruits and Vegetables," *42-20 U.S. Dep. Agr. Publ. ARS 42-96* (1964).
22. J. H. Levin and H. P. Gaston, "Grower Handling of Red Cherries," *U.S. Dep. Agr. Circ. 981* (1956).
23. R. E. Parker and B. A. Stout, *Trans. Amer. Soc. Agr. Engr.* **10**, No. 4 (1967).
24. R. E. Parker, J. H. Levin, R. T. Whittenberger, "An Instrument for Measuring Firmness of Red Tart Cherries," *Mich. State Univ. Quart. Bull.* **48**, No. 3, 471 (1966).
25. N. N. Mohsenin, *Physical Properties of Plant and Animal Materials* (Pennsylvania State Univ., University Park, 1968), vols. 1 and 2.
26. P. A. Adrian, R. B. Fridley, D. H. Chang, O. K. Uriu, *Calif. Agr.* **19**, 8 (Aug. 1965).
27. G. K. Brown and C. E. Schertz, unpublished reports, Agricultural Engineering Department, University of California, Davis (1966, 1968, 1969).
28. P. F. Burkner, G. K. Brown, E. G. Vis, R. C. Ruck, *Calif. Citrograph* **54**, No. 1 (Nov. 1968); *ibid.*, No. 2 (Dec. 1968); *ibid.*, No. 3 (Jan. 1969).
29. J. H. Levin, "Adapting machines to plants for harvesting," in *Proc. Int. Hort. Congr. 17th* (1967), vol. 4.