Recent developments in harvesting, storing, and processing sugar beets have greatly increased the efficiency of domestic production of sugar, our largest single item of imported food.

Mechanical harvesting is finally replacing hand methods, which have remained much the same ever since the industry was introduced into the United States about 80 years ago. Even the change from horses to tractors for harvesting and from the horse-drawn wagons to motor trucks for hauling did not greatly alter hand topping and loading methods. Before 1943 (when about 135 harvesters were built and used), not more than 15 or 20 machines were in commercial use, and they were experimental. The first machines for loading windrows of hand-topped sugar beets, many of them made by small manufacturers and local shops, elevated beets from a windrow into a truck driven alongside the loader. Their use for hand-topped beets may be a passing phase. To meet the need for more complete elimination of hand labor, sugar-beet harvesters are used. Some commercial harvesters leave the beets windrowed in the field, and for them windrow loaders will still be necessary. But equipment is favored that puts beets directly into trucks or trailers, rather than windrows.

From 1943 until 1948 the number of machines built each year was roughly double the number built the preceding year. The percentage of the crop mechanically harvested also was roughly twice that of the previous year until 1948, when about half the acreage was harvested mechanically. In 1949, when 54 percent was machine-harvested, the further increase was small, partly because of bad harvest conditions in some sections. In 1949 about 1,900 harvesters were sold and 9,100 were in use. Most of the larger growers now have harvesters.

Mechanization of the harvest has been more rapid in California than in other sections, because of the development of a harvester particularly suited to conditions there—large-scale operations, favorable weather during harvest, and a longer harvest season. In 1949, about 73 percent of the sugar-beet acreage in California was machine-harvested; more than 60 percent in Idaho, Washington, Oregon, and Utah; nearly 49 percent in the eastern slope of the Rocky Mountain area, including irrigated areas of Kansas, Texas, Nebraska, and the Dakotas; nearly 40 percent in the Minnesota-Iowa area; and about 35 percent in Michigan-Ohio.

Most of the harvesters in use today do a complete job. They dig the beets and put them, topped and ready for storage or processing, into trucks or trailers in one pass through the field. Some machines drop the beets in windrows, which are loaded with a separate machine. One type tops the beets in the ground, then digs them and separates out the soil. Another type digs the beets first and tops them in the machine. Some machines are tractor-mounted; others are pulled. Most are 1-row machines, but 2-row machines are more common on California's large fields. The harvesters travel 2¼ to 3½ miles an hour or more. The 1-row machines harvest 2½ to 3 or more acres
a day and usually average 50 to 75 acres a season. Some harvest more than 100 acres. The 2-row machines harvest about 5 acres a day and, with the long harvest season in California, average about 250 acres a season. Some harvest more than 500 acres.

A new development in mechanical harvesting came into use in 1947 in Idaho. It is the beater-topper, which beats off, chops up, and scatters the stems and leaves of the beets. It has one or two beater shafts, which carry rubber flails. The beater is mounted under a hood, crosswise to the beet rows, and is driven at 600 to 800 revolutions a minute, either by a power take-off from the tractor or by an auxiliary engine. It is necessary to cut a thin slice of crown from the beets to improve storing and processing properties. Equipment to do that has been developed. The beater-topped beets are usually dug by multiple-row diggers, which lift the beets and soil to a bed of kicker rolls. The rolls remove the loose soil before the beets are elevated to a truck or trailer. The machine is best suited for friable soils, where no clods or wet lumps of soil come up with the beets. A disadvantage is that the tops and crowns are lost for stock feed.

Mechanization of the beet harvest has brought large savings in labor requirements and costs. The savings over hand harvest depend on the yield, the previous methods of hand harvest, the machine, the depreciation period, seasonal use of the machine, and the size and efficiency of operations. The savings in both man labor and cost increase rapidly as yields increase. And, as with all machinery, more days of use during the season spread the overhead cost over more acres, reducing the cost of harvest per acre. Average harvest-labor requirements have been 30 to 35 man-hours an acre for hand harvest; they average 6 to 7 hours for machine harvest. The saving by mechanization usually ranges from 20 to 30 man-hours an acre. The cost saving by mechanizing the harvest, taking all costs into consideration, probably averages about 15 dollars an acre. As more than half of the 900,000-acre crop in the United States in 1950 was harvested by machine, the saving to beet growers was more than 7 million dollars.

Sugar beets are grown principally in temperate climates, where the growing season may be from 5 to 8 months. The longer growing seasons generally produce higher yields. The harvest has to be finished before wet weather makes the work difficult or freezing weather damages the crop. The extractable sugar per acre sometimes increases more than 25 percent during the last month of a short growing season, but the late increase is usually less in areas with longer growing seasons. Economic crop production, therefore, requires that maximum advantage be taken of the growing season and that the beets be harvested when high yield and quality are attained.

The fixed costs of factories for processing sugar beets are necessarily high. Estimates based on 1948-49 costs are that a factory capable of processing 2,800 tons of beets a day will cost about 7 million dollars and will require approximately 150 thousand dollars a year for maintenance. Obviously, only a large yearly volume can insure profitable operation, and the operating period of a factory must be extended far beyond the ideal harvest season that would give maximum economy of crop production. Between the opposing economic factors of reduced yield and quality by prolonged harvest and high-cost of factory capacity for direct processing lies the possibility of storing the crop harvested at the best time until it can be processed by a factory that can operate long enough to make its expenses and some profit.

The breeding of improved varieties of biennial sugar beets has produced a superior type for storage. Roots have been stored from one season until the next in order to produce seed the second year. The roots that did not store well were eliminated.
from seed production. Losses of sugar do occur in beets that are stored, however. We therefore have three economic factors to consider—cost of crop production, factory capacity, and storage losses.

About 3 million tons of beets are stored each year from 3 weeks to 3 months. An equal amount is stored from 1 to 3 weeks before processing. Normal storage amounts to from 120 million to more than 200 million tons-days. Normal losses range from about 0.2 pound to more than 1 pound of sugar a ton a day of storage. Rapid spoilage frequently develops in storage piles. Sometimes losses amount to as much as 5 pounds a ton a day, or to complete loss in a few weeks if the beets are not quickly processed. Removal of the hazards of storage is the primary problem of commercial-storage improvement.

Storage losses result from two general causes: Through the normal process of respiration of the living tissues of the beet, whereby oxygen is absorbed, stored food, principally sugar, is used up, and carbon dioxide, water, and energy as heat are given off; by spoilage through the action of invading organisms, principally certain species of fungi.

Both factors must be considered in attempts to improve commercial storage, because some conditions may reduce loss from one cause and increase loss from the other. Many factors influence losses from respiration and spoilage. Several investigators have agreed that each increase of 15° to 18° F. doubles the rate of respiration, but they have failed to agree on the respiration rate at a given temperature, indicating that other factors also caused large differences.

Studies of some of the other factors showed that partly dried or wilted beets respired and also spoiled more rapidly than fresh, crisp beets. Beets that were topped high respired more rapidly, but were less subject to spoilage than low-topped beets. High-topped beets also yielded more sugar to the acre. Lowered oxygen concentration in the storage atmosphere reduced respiration, but increased spoilage, especially if the oxygen concentration was below 5 percent. Increased carbon dioxide concentration (up to 5 percent studied) reduced both respiration and spoilage.

Beets grown in a cool climate respired much more rapidly at a given temperature than those grown in a warmer climate. Broken beets and beets severed into top and bottom halves and stored together respired and spoiled more rapidly than whole beets. The top halves of severed beets, when stored separately, respired more rapidly, but the bottom halves were more subject to spoilage.

Healthy beets stand relatively rough treatment in harvesting, handling, and piling without an appreciable increase in respiration or spoilage. Treatment of beets with disinfectants or fungicides has had little effect on respiration and usually has increased spoilage. Treatment with methyl ester of naphthaleneacetic acid, which is used to prevent sprouting of potatoes, nearly doubled the respiration rate and increased the inversion of sucrose. The chemical apparently reduced top growth, but increased the development of small rootlets on the beets.

One variety of beets respired and also spoiled more rapidly than another variety grown and tested under the same conditions. Breeding improved varieties for storage, therefore, appears promising. Beets that were deficient in phosphorus spoiled more rapidly than those given enough. Boron-deficient beets developed heart rot in the growing crop even before storage and continued to spoil during storage. Unbalanced nutrition, therefore, may be expected to affect storage adversely.

Research has indicated that any treatment that seriously interferes with the normal functioning of the living tissues of the beets adversely affects storage and that healthy beets have a strong resistance to invasion by most fungi.

Losses are the lowest when healthy, freshly harvested, clean beets are im-
DEVELOPMENTS IN HANDLING SUGAR BEETS

mediately stored at the lowest temperature possible without freezing, in a storage environment that produces little drying and no persistent moisture on their surfaces and is ventilated only enough to control temperature, eliminate respiratory moisture, and maintain adequate amounts of oxygen in the atmosphere. Low temperature seems to be the most important single factor in keeping losses down.

ECONOMICAL METHODS of storing and recovering the beets for processing have largely determined commercial storage methods. Beets must be washed before processing. Soaking for a few minutes during transportation to the factory greatly reduces the task of washing and removing small stones and trash. Many beets stored at the factory yard, therefore, are stored over concrete flumes. When the flume covers are removed, the beets drop into water and are carried to the washers. Such storage has sometimes resulted in heavy spoilage losses, usually caused by water in the flumes, especially warm water, which evaporates, rises through the pile, and condenses on the beets. If kept dry, the flumes provide a means of introducing cool air for ventilating the piled beets.

The development of efficient heavy machinery for receiving truckloads of beets, cleaning and piling them, and recovering them from the piles has helped relieve the problem of rapid delivery and recovery for processing. One large piler can handle truckloads at the rate of one a minute. The beets are dumped from either side into a hopper, from which they are conveyed up into a large piler and tumbled over kicker-type rolls or screens to remove dirt and trash. The dirt and trash are returned to the truck that delivered the beets. The beets are then borne over an oscillating-boom conveyor to the top of the pile. All the beets are delivered along the top edge, from which they tumble down to form the slopes of the growing pile. Piles are usually 16 to 22 feet high and 110 to 130 feet wide at the base. As the pile grows, the piling machinery is moved back to extend the pile to 1,000 feet or sometimes more. A pile 20 feet high, 130 feet wide at the base, and 1,000 feet long contains about 45,000 tons. It is not unusual to see 75,000 tons of beets piled at one receiving station.

Storage difficulties usually develop just below the top edges or shoulders of the piles. Dirt or trash that is not eliminated by the cleaning equipment concentrates a few feet from the top of the pile, where, because more beets are delivered on the shoulders, the concentration of dirt and trash is greatest.

A PILE OF BEETS contains 60 percent beets and 40 percent air spaces. If the spaces are filled with dirt or trash, natural ventilation is restricted, and the respiratory heat and moisture do not escape. A 50,000-ton pile of beets at 41°F gives off as much heat every 24 hours as is produced by burning nearly 2 tons of coal. At 77°F, the heat evolved is equivalent to that produced by burning 10 tons of coal. The heat is produced by converting sugar into carbon dioxide and water. It is important that ventilation is not restricted so that the heat can escape without further increasing the temperature of the beets. Otherwise, a cycle of increased respiration that further increases temperature and again increases respiration results. Partly spoiled beets are difficult and expensive to process.

There is little resistance to air movement in a pile of clean beets. In a series of tests, beets caused an increase of only 1/8-inch static water pressure when 150 cubic feet per minute of air was forced through an experimental column of beets 24 feet high and 3 feet wide at an average velocity of 58 feet a minute. The heat and moisture transfer to the air stream was rapid. Relative humidity of the air increased nearly to the saturation point after passing through 8 feet of beets at an average velocity of 22 feet a minute.

The natural draft in a pile of clean beets is rapid. When the beets are
warmer than the outside air; the air movement is in through the sides and out the top of the pile. When the temperature difference is reversed, the direction of the air flow is reversed. This natural breathing, if it is not restricted, tends to keep the temperature of the pile near the mean air temperature. Enclosed storage would prevent the drainage of cold air from the pile and some drying and freezing, but would require other methods of piling and reclaiming the beets. It is possible that such complete control of storage conditions may be found economically sound, especially in climates where unprotected piles suffer excessive damage from freezing. The sides of one large commercial pile were covered with heavy waterproof paper almost up to the shoulder. Beets under the paper did not freeze, even when the outside temperatures dropped to 0°F. Some freezing damage was sustained, however, in the top of the pile.

Beets on the surface of a pile usually suffer greater losses than those inside unless hot spots develop inside. Surface beets are dried out, are warmer from exposure to the sun, and are more exposed to freezing damage in cold weather. To reduce pile surface in relation to volume, storage piles are built as large as practical. Whitewashing the surface of the pile with a mixture of lime and waste lime cake from the factory reduces drying, keeps the beets cooler, and reduces losses in storage. On a bright day the white-coated beets may be 15° to 20° cooler than uncoated beets.

A practical way to reduce the temperature of the pile is by forced ventilation at night when the air is cool. During the harvest season, night temperatures are 15° to 35° lower than daytime temperatures. The higher relative humidity at night also causes less drying. In an early demonstration of forced ventilation, air ducts were placed in the bottom of an enclosure, and about 65 tons of beets were piled over them. Air was blown through the pile for several nights to lower the temperature from 60° to about 35°. The beets were in excellent condition after 77 days of storage, and showed losses of only about 0.1 pound of sugar in a ton a day. One company, which operates several factories in the East, used forced ventilation at night on nearly all the beets it stored in the 1949–50 season. Tests have shown that savings are greatest when conditions for normal storage are unfavorable. Under normal or good storage conditions, tests to date have shown that losses are usually reduced at least one-third by using forced ventilation.

Portable units have proved effective for reducing the temperature of hot spots in piles of sugar beets. Fairly large perforated pipes were forced into the pile, and air was forced through them into the hot spot until the temperature was under control.

Another factor in storage is the condition of the beets as they are piled. Hand-harvesting methods invariably follow the practice of placing the lifted and topped beets in windrows in the field, then loading from the windrow into trucks by hand or machinery for delivery to the storage pile. Measurements have shown that on warm days the temperature of beets exposed to the sun may increase as much as 35° in less than 3 hours. That is enough to increase their respiration rate and heat output fourfold. The withering that occurs if they are left in the windrow very long makes them pack more tightly in the pile and increases their susceptibility to attack by fungi. The increased use of harvesting machinery, that delivers cool beets directly from soil to truck to pile, and improved piling equipment for the removal of soil and trash is doing much to reduce storage losses.

The improved methods that prevent temperature rise, freezing damage, or partial drying before storage also apply to beets transported by rail for several days before piling. Shortage of cars during harvest periods might delay delivery to the storage pile, but growers
frequently continue harvesting. The result often is that harvested beets are left unprotected in the field. Immediate delivery to a pile for storage and shipment later to the factory for direct processing would reduce car shortages, improve storage, and establish good will among growers, processors, and railroad companies.

Delivery of frozen beets to the storage pile is being greatly reduced by the use of mechanical harvesters, except when the crop is frozen in the ground. When beets are frozen, they normally are delivered directly to the factory for immediate processing, because they spoil very rapidly when they thaw.

Beets that freeze on the unprotected sides of piles lose considerable sugar, but beets that are frozen and then covered with undamaged beets cause much greater losses. Frozen beets inside the piles do not dry out as they thaw, but exude infected juice and contaminate surrounding beets so that spoilage spreads rapidly. Methods for protecting the freshly formed face of the pile during cold nights until piling is resumed the next morning are being studied. Radiant heaters offer a solution to the problem. Automatic operation of heaters during danger periods will reduce the hazards, heating costs, and need for constant supervision.

The increasing use of more efficient harvesting machinery is expected to cut the harvest to a few weeks in most areas. Equipment will then be needed for receiving and piling the increased daily volume of beets. Improved storage of the promptly harvested crop to allow a longer operating period for the factory is one way to improve the economy of production.

The first moderately successful factory for beet sugar was put up in Prussia in 1802. Another was established in France in 1811. Attempts to manufacture beet sugar in the United States began in 1830, but none was reasonably successful until 1870. Now more than 80 high-capacity factories process more than 12 million tons of beets annually and supply 20 to 25 percent of the sugar we consume.

Beet sugar is made by extracting the sugar from the beet by water and purifying the juice thus obtained to a degree that insures a finished sugar nearly chemically pure and equal to sugar from other sources. The washed beets, freed from trash and spoiled beets, are sliced into thin, V-shaped shreds, called cossettes. From them the sugar is extracted with moderately hot water in batteries of 14 or more cylindrical tanks. Fresh hot water enters the tank in which the cossettes are most nearly freed of sugar. The water passes through the other tanks until it leaves the system at the one just freshly filled. One tank of the series is always being emptied of the essentially sugar-free cossettes, now called pulp, while another is being filled with the freshly shredded beets. The resulting juice, the diffusion juice, contains about 12 percent dissolved solids, of which from 75 to 90 percent is sugar.

Besides the sugar, the juice carries all the other soluble substances from the beet root, such as minerals, proteins, pectins, and organic acids. The problem is to separate the sugar from the nonsugars and produce a commercial granulated white sugar that is at least 99.97 percent pure sucrose. Sucrose is the chemical name for common sugar, of which we consume more than 7 million tons annually. Sucrose is also the principal sugar of sugarcane, sorghum, and the sap of the maple tree.

Purification of the diffusion juice starts with the addition of lime until the juice is very alkaline, after which carbon dioxide is pumped into it. Both the lime (calcium oxide) and the carbon dioxide are produced at the factory by burning limestone. The carbonation of the juice neutralizes the lime. The resulting calcium carbonate separates as a flocculent solid, which removes much of the coloring matter and some of the nonsugars when it is filtered off. The light-colored, clear juice is slightly sulfurized with sulfur dioxide and refiltered. Then it is con-
centrated to sirup in multiple evaporators. The sirup is filtered through a powdered mineral to remove the last trace of suspended impurities.

The filtered sirup is boiled under vacuum, to remove the remaining water, until microscopic sugar crystals form. Boiling is continued, with addition of fresh sirup, until the sugar crystals have grown to the desired size, and the entire mass is a thick mixture of solid sugar in the remaining sirup. The sugar is separated from the mixture by centrifuges, which have perforated outside walls that hold back the sugar but allow the liquids to pass off. In the centrifuge, the sugar is washed with hot water or steam until it is white and free from the impure sirup. The wet sugar is dried in huge rotary drums by filtered hot air. It is then ready for sacking and sale.

Because the sirup recovered from the centrifuge still contains some dissolved sugar, it is reboiled for another crop of crystalline sugar. The second batch, of poorer quality, is washed, redissolved in water, and returned to an earlier part of the process. Even after the second boiling, the sirup (which by now is very dark) contains crystallizable sugar; so a final boiling is made and the crystals are given a long time to grow in special equipment. The result is a low-grade sugar, which is dissolved in water and often is treated with vegetable carbon to lighten its color before it is returned to the juice that is just starting through the process.

The sirup from the final boiling is molasses. It contains sugar but it will not crystallize. Sometimes it is given a processing that removes the sugar as a chemical compound from which fairly pure sugar can be recovered and returned to an earlier part of the process. That is the so-called Steffen process. The waste from the process is nearly sugar-free, but it contains a complex mixture of nonsugar substances that have value, especially as a source of monosodium glutamate.

Two innovations in beet processing are outstanding.

The first is a continuous automatic process to replace the battery for diffusing the juice from the cossettes. It gets around one of the most laborious parts of the conventional process—filling and emptying the tanks of the battery. In the continuous battery, the shredded beets are fed onto a special carrier, which transports the cossettes through a series of 21 narrow tanks against the reverse flow of warm water. The tanks are enclosed and look like a single unit. About one-fifth of the factories had installed continuous diffusers by 1951. Besides saving work, the continuous diffuser gives a more complete extraction of sugar from the cossettes, the diffusion juice is more concentrated, and the pulp is better drained and ready for processing for stock feed.

The second innovation is the ion-exchange process, which removes practically all of the salts and many of the organic impurities from the juice before it is boiled and concentrated to a saturated sugar solution. The juice is merely percolated or forced through beds of the exchangers, which are of two types and are used in sequence. The granular ion-exchange resins soon became saturated with the materials being removed, however, and have to be chemically revivified. The process produces a lower-ash sugar, but its great advantage is that the sugar can be more completely crystallized. The impurities in sirups made by the usual process actually keep some sugar from crystallizing. That is why molasses contains sugar and why molasses is produced in quantity. In the juices that have received ion-exchange treatment, nearly all the sugar can be crystallized and the yields of molasses are low. Several factories were using the process in 1951.

Other improvements are being made constantly. The liming and carbonation of juices is more than just a haphazard mixing of the ingredients. It requires attentive control of alkalinity through chemical testing, as well as equipment that gives almost instan-
DEVELOPMENTS IN HANDLING SUGAR BEETS

taneous and uniform mixing. For many decades that was done on a batch basis, a tank of juice at a time. In most factories it is now performed continuously and is controlled all the time by instruments that maintain the best conditions for removing impurities and color. The process notably reduces variations in processing conditions.

Multiple-effect evaporators have also been improved. Many are now equipped with control instruments so that the flow of juice and sirup from one evaporator to the next is regulated and stabilized. Sometimes an electric eye is used to give warning of excessive foaming in the evaporator.

The centrifugal and washing operations (which separate the sugar from the molasses or sirup) largely determine the quality of the sugar. The operations have been improved by the use of higher-speed centrifuges and a higher-temperature wash, both of which are now automatically controlled. Often water under pressure at 220° F. or higher is used for the washing, which gives effective cleaning of the sugar with less loss of sugar crystals.

Among other advances are improved rock catchers, trash removers, and washers for the beets, thickeners for settling the juice after carbonation, rotary vacuum filters to filter the sediments from carbonation, automatic controls on the sugar boiling, more efficient sugar driers, and up-to-date packaging and storage of sugar in bulk. The list could be longer, but it serves to show that the industry is keeping pace with modern engineering and scientific developments in order to reduce operating costs and losses and to improve the quality of sugar.

Several byproducts come from the sugar beet; in fact, it is a two-crop industry. The harvested tops from an acre of beets plus the pulp that remains after extraction of sugar from the roots equals the stock-feeding value of the entire product from an average acre of corn. The tops are fed directly or after curing or ensiling. When properly cured, the total digestible nutrients of the tops are equivalent to alfalfa hay, pound for pound.

The pulp is fed wet in much of the western sugar-beet area. After temporary storage in huge open silos, it is used locally for fattening beef and lambs. In the East and far West the pulp is usually dried, with or without the addition of molasses. In this form it can be readily stored and shipped interstate. Because dried pulp is roughly 5 percent of the weight of the beets, the total potential domestic production of it would be over half a million tons annually. Beet pulp is known to be high in pectin, and a pilot plant in Wisconsin has started operations to recover the pectin for use in competition with fruit pectin.

Besides its use with dried pulp, beet molasses is also added to many mixed stock feeds and even is fed direct. That use is only for surpluses, as the molasses has become industrially important. It is used for the production of food yeast and citric, lactic, and gluconic acids and as an accessory in the fermentation processes that yield alcohols and acetone. Beet molasses is rich in the food substances and stimulants that favor rapid growth of micro-organisms and also supply the sugars for conversion into chemical products.

Glutamic acid occurs naturally in the beets and is accumulated in the molasses. Its recovery from the waste after desugaring molasses by the Steffen process has attained notable commercial importance. In factories in Ohio and California millions of pounds of monosodium glutamate are recovered and purified for use in foods.

Myron Stout is a physiologist in the division of sugar plant investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering.

S. W. McBurney is an agricultural engineer in the division of farm machinery in the same Bureau.

Charles A. Fort is a chemist in the Bureau of Agricultural and Industrial Chemistry.