Engineering and Biology

K. H. Norris and W. T. Pentzer

THE EFFECT of controlling the color of the light a plant gets is an example of the place of the biological sciences in modern agriculture and of the need for coordination among the engineers and biologists in their work.

Advances in engineering often create new problems for biologists, and potential engineering advances may not come because the effect on the biological reactions were not foreseen. Only through the combined efforts of the physical and biological scientists are we able to attain the maximum in technologic process.

Plant scientists have known for years that a vital pigment in plants reacts to light to control such functions as growth, flowering, coloration, and germination. Its presence has been demonstrated in seeds, plants, and trees, but only by the physiological response to the light stimulus. Little is known about the pigment, but its importance to agriculture is recognized, and the knowledge we have is used on a practical basis.

We know that the pigment exists in two forms, a red-light-absorbing form and a far-red-light-absorbing form. It can be converted from one form to the other in the plant. By irradiation with red light, the pigment becomes the far-red-absorbing form. By irradiation with far-red light, it becomes the red-light-absorbing form.

In the far-red-light-absorbing form, it acts as an enzyme that promotes germination of seeds, prevents flowering of many plants, prevents stem elongation of seedlings, promotes rooting of plant cuttings, and enhances the red coloring of tomato and apple skins.

In the red-light-absorbing form it causes the opposite reaction. It inhibits germination, rooting, and tissue coloring and promotes flowering and stem elongation. Controlling the color of the light given to a plant makes it possible therefore to control many of the biological responses of the plant.

Florists use the knowledge that plant responses can be controlled with light to provide us with chrysanthemum blooms at any time of the year and the poinsettia at Christmas. These are relatively minor examples of the possibilities that exist for control of plants through the action of this photoreversible pigment, but they illustrate how biological reactions in plants can be modified by physical techniques to produce a desired effect.

Engineering and biological techniques have been combined recently in a study of this pigment, which is so important in controlling plant development. Engineers of the Department of Agriculture have developed extremely sensitive spectrophotometers for study of pigments in biological tissues. The instruments were developed for measuring pigment changes related to maturity and ripeness of fruits and vegetables.

At the same time Department scientists were conducting a long series of experiments to demonstrate that the photoreversible pigment should be concentrated in certain plant tissues and were busily engaged in attempts to detect and isolate the pigment. They were not able to detect the pigment with commercially available spectrophotometers.

Then the two groups combined their efforts with the result that the pigment was detected in a number of plant tissues. With an instrument to detect the pigment, the chemists then proceeded with their isolation procedures, concentrating the pigment into a form suitable for further study. Engineering provided the instrumentation for an important development in biology. Further developments will follow and lead to new applications, which must be engineered.

Animals also respond to light. The egg production of chickens and the fertility of sheep, goats, and turkeys can be altered by controlling the length of day. The mechanism by which this control takes place is not known, but the technique is used to increase egg production during the short days of winter. Further exploitation of this control must wait for understanding of the biological reactions. Any engineering developments are likely to be of minor consequence until more of the biology is known. Once these reactions are known, however, methods will be developed to control the reactions as desired.

THE GREAT STRIDES in the mechanization of crop production have created some serious biological problems. For maximum yields, small grains should be harvested when their moisture content is 20 to 30 percent, but grain of that moisture level soon develops mold when it is stored and is more subject to insect contamination.

Engineers provided a solution to this problem, but in doing so they created new problems in biology. Heated-air driers were developed to dry the wet grain.

If the drying is too rapid, however, the grain cracks, and the yield of final product is less. If the temperature of the grain exceeds a safe limit, the viability is destroyed so that the grain cannot be used for seed. Barley for use in the malting industry is particularly subject to damage from artificial drying. Corn that is dried at a high temperature is much harder to mill. Peanuts develop a bitter flavor under poor drying conditions.

Again, the biological reactions limit the engineering techniques. As a result, close controls are required on the engineering techniques to insure the maintenance of the quality of the product.

Biologists have come to the aid of engineers in the mechanization of grain harvesting. They developed chemicals that cause plant leaves to dry and fall to the ground so that the grain loses moisture faster. They developed grains that are less subject to shattering, so that combine harvesting can be done when the grain has a lower moisture content without excessive losses.

They also have started to develop ways to control the biological reactions in moist grain to permit extended storage of high-moisture grain for specific applications. Wet corn can be stored in gas-tight storage for animal feeding. In such storage not all the biological reactions are stopped—only those that cause mold and decay. The stored corn has a fermented odor, but animals produce as well on it as they do on dry corn. These research developments in biology may provide the answers needed for engineering advancements in grain production.

Harvesting fruit and vegetables requires a high labor cost. The substitution of machines for this human labor has not been practical in many instances because of characteristics of the crop. It may be possible to overcome some of these limitations by engineering techniques, but a better solution is possible if the crop can be modified to facilitate the mechanization.

We can modify characteristics of plants. Radical changes in their shape, size, and other physical aspects are possible by breeding, applying chemicals to regulate growth, and pruning and physically forcing a plant to grow in a specified manner. These modifications are not easy, and they may take years of intensive breeding and plant shaping to obtain the desired change. This should not prevent us from considering at least the possibility of designing the plant to fit a machine operation, rather than always trying to design a machine to fit the plant.

Designing a machine to harvest the crop and modifying the plant to permit the use of the machine demands coordination. Many compromises are required because some problems are solved more readily by changing the machine; others, by changing the plants. The goal is to provide the best product with the lowest cost of production. All decisions must be in line with this goal.

We are not doing all we should be doing to solve cooperatively the problems of mechanical harvesting of fruit and vegetables. Work has started on some crops, but more is needed.

Cooperative work of engineers and plant scientists has brought advances in the automatic harvesting of grapes. Viticulturalists have developed methods of growing grapes on overhead horizontal supports. The clusters of grapes hang below the vines and leaves on long stems. It is relatively easy to design a machine to travel under the vines and harvest the fruit. It will be some time before this development can be used on a large scale, but it should reduce the cost of harvesting grapes.

Cooperative work on the automatic harvesting of tomatoes shows promise of success. Plant breeders are developing tomatoes that mature uniformly to provide an adequate production with a single harvesting. Engineers have been working on equipment to lift the tomato plants and shake the tomatoes into a container.

The equipment will be successful, however, only if a slight force is required to remove the tomatoes from the vine and the tomatoes are firm enough to withstand the treatment given by the machine. The machine must be designed to minimize damage to the tomatoes and to harvest a maximum yield of fruit. All of this plant modification and automatic harvesting must be done without a loss of quality in the final product.

THE STORAGE LIFE of agricultural products can be altered by the storage environment. The maximum storage life of a commodity depends on an exact control of several interacting variables. A fresh fruit or vegetable placed in storage is still a living biological system. It continually undergoes changes. Some of the changes we wish to retard. Others we wish to accelerate, depending on the use of the product.

Efforts to extend the storage life of fruit and vegetables by special treatments and control of environment have not always been successful. For example: Early work with gamma radiation indicated that sprouting of potatoes could be inhibited with a low level of radiation treatment. It appeared that thereby the storage life of potatoes could be extended several months. When an attempt was made to use the radiation treatment to extend the storage life, the potatoes did not sprout but developed rot. The radiation treatment that prevented the sprouting also killed the self-healing properties of the potato skin. Any slight bruise, which would normally heal without trouble, therefore became infected. It may be possible to develop a means of controlling this decay; if not, this promising engineering development cannot be utilized.

Proper control of the atmosphere surrounding a fruit or vegetable can be used to extend the storage life without deleterious effects on the quality of the product. Reducing the oxygen content slows the respiration rate of the plant tissue and reduces the rate of chemical reactions within the product, so that its useful life is extended. The amount of carbon dioxide in the storage atmosphere, however, must also be controlled to prevent deterioration from another source. A careful balance of the oxygen and carbon dioxide level must be maintained. The precise environmental conditions for optimum storage of each product must be determined, and techniques must be developed for creating and maintaining these conditions.

Marketing procedures are increasing the demand for the production of large volume, uniform, high-quality produce at minimum cost. To meet this demand, advancements must be made in the means for measuring and controlling the quality of the product.

Rapid and accurate instruments are required to measure moisture content, color, tenderness, maturity and other important quality factors. Some of them have been developed by cooperative effort of instrument makers and biological scientists. The biological scientists have determined the types of measurements required to express the quality of the product. Specialists in instrumentation have developed methods for making the measurements. So we have automatic machines for sorting lemons, beans, peas, and seeds by color, and for sorting eggs to reject those with defects.

The development of new instruments and procedures will open up larger fields for the application of engineering to biological problems in agriculture.

Costs of Farm Machinery

James Vermeer and Donald T. Black

THE LARGEST single item of expenditure on many farms in the United States is the cost of owning and operating farm machinery.

Of 30 typical farm situations in the United States, machinery costs in 1958 were more than 40 percent of total operating expenses on three-fifths of the farms. On some farms they made up nearly two-thirds of all operating expenses.

Expenditures for operating and replacing machinery among 30 types of the commercial family-operated farms ranged from about 400 dollars on small tobacco farms in the Coastal Plain of North Carolina to 6,700 dollars per farm on irrigated cotton farms in the High Plains of Texas. The average of the 30 types of farms was about 2,500 dollars.

The value of machinery by type of farm was 1,300 dollars to 18 thousand and averaged 6,600 dollars at the current value. The original purchase price probably was about twice as great. As prices of machines have risen since those investments were made, the cost of replacing 6,600 dollars' worth of equipment at 1960 prices probably would require an investment of 15 thousand to 17 thousand dollars.

Prices farmers paid for motor vehicles and farm machinery were about 2.5 times as high in 1960 as in 1940. For example, prices of 20–29-horsepower wheel tractors rose from 1,020 dollars in 1940 to 2,470 dollars in 1959. The 1940 and 1959 models were not identical, of course; the newer models have extras, such as generators, batteries, self-starters, lights, power takeoffs, power steering, hydraulic controls, and more comfortable seats. Thus the differences in cost of 1940 and 1959 tractors are not due solely to higher prices in 1959.

Many of the improvements in the machines perform more effectively the job for which the machines were designed or reduce the heavy physical labor required of farmworkers. In either case, costs of owning and frequently costs of operating machinery have risen. At the same time, improved machines have contributed to greater output, and machinery costs per unit of product have risen less than the total machinery costs.

THE COSTS of owning machinery often are referred to as fixed costs. All other costs are labeled variable costs.

Some costs are fixed, regardless of amount of use—the interest on investment, taxes, insurance, housing, and usually depreciation. Variable costs include fuel or power costs, repairs, lubrication, and service labor. Some variable costs are proportional to use. Others change with use but are not necessarily proportional to it.