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The Potential of Plants

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Department Editor

Biologists in many fields have become fascinated by the potential of genetic engineering. The possibilities are wide ranging. Repair of defective genes in humans, insertion of human genes into bacteria, and alteration of the genetic makeup of plants and animals are just three examples. The field of botany has been particularly revitalized by the promise of genetic engineering. Creating new plants, or at least radically altering old ones, is an attractive idea in a world facing food shortages. Adding the genes responsible for nitrogen fixation to plants that don't now carry them may be a boon to agriculture, though the payoff seems to be well in the future (*Nature*, September 24, 1981). Fusion of plant cell protoplasts may also lead to improved plants; scientists have fused potato and tomato protoplasts in an effort to transfer disease resistance genes from one species to the other (*Science 82*, January/February 1982).

However, some plant scientists have refused to be seduced by these new techniques. They would rather explore the genetic potential available in Nature. They are dazzled by the tremendous variety of plants which already surround us. A large number of plant species have yet to be identified, and of those identified, only 15 or so are responsible for the bulk of agricultural output, so there's a wide field open to those who don't care to manipulate genes.

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While some scientists dream of corn or wheat that can fix nitrogen, others are busy investigating some of the 650 genera and 18,000 species of leguminous plants that already exist (*Nature*, December 10, 1981). The winged bean, virtually unknown a few years ago, is now being advertised as "the soybean of the tropics" (*The New York Times*, February 25, 1982). Except for the stalk, the whole plant is edible and has a high protein and vitamin A content. The leaves taste like spinach, the flowers can be cooked to resemble mushrooms, and the roots produce tubers like potatoes. In the immature state, the pods resemble green beans, and the seeds are like peas. When mature and dried, the seeds are similar to soybeans, though they have a better flavor. What makes the plant particularly attractive is that, since it is a legume, it can be grown without nitrogen fertilizer, and it thrives in poor sandy or clay soils.

The National Academy of Sciences report, *Tropical Legumes: Resources for the Future*, describes other promising legumes. The Bambara groundnut, native to Africa, grows well in poor soil and arid areas, and contains enough oil, protein, and carbohydrate to make a well-balanced food. The moth bean, indigenous to Southeast Asia, may be useful in extending agricultural production into marginal regions.

Several legumes produce fruit that could be more widely exploited in the future, such as the tamarind pod with a sour-sweet pulp and the honey locust pod with a sweet, succulent pulp. Among the legumes are also many fast-growing trees; *Leucaena leucocephala* grows 65 feet tall and 16 inches thick in five years and produces wood suitable for paper pulp, furniture, or building.

The hairy vetch, *Vicia villosa*, is a legume that's being exploited solely for its nitrogen-fixing ability (*The New York Times*, March 9, 1982). With the price of synthetic nitrogen fertilizer rising steeply, corn farmers are turning to this plant that resembles clover or alfalfa. The vetch is planted around the time of the corn harvest. It germinates in fall, lies dormant during the winter, and grows rapidly in spring. By corn planting time, the vetch may be 20 inches high. Herbicides are then used to kill the vetch which deteriorates rapidly. With this technique, more than one-half of the nitrogen the vetch has fixed is available to the corn.

Scientists are also looking more closely at non-leguminous nitrogen-fixing plants that harbor bacteria of the genus *Frankia* rather than the *Rhizobium* of the legumes (*ABT* 44(2):229). The alder, for example, can grow in marginal soils. It is being studied as a forage plant for sheep and is a good candidate for use in land reclamation projects in strip-mined areas.

One approach to the problem of growing plants under adverse conditions is to select unfamiliar species that naturally grow under such conditions, rather than to try to adapt more familiar species. Humans are creatures of habit. They'd rather stick with what they know, but there are literally thousands of plant species living under all kinds of conditions that we would consider less than ideal. It's just a matter of becoming less prejudiced; in a world of shortages and pollution we can no longer afford old biases.

The U.S. Department of Agriculture recently tested the salt tolerance of trees commonly grown along roadsides in the northern United States where salting of icy roads is common (*The New York Times*, November 2, 1982). Of the seven species of conifers tested, the eastern white pine, one of the most abundant road trees, turned out to be the most susceptible to damage. Dogwoods and sycamores were the most easily damaged among the five kinds of deciduous trees studied. The Japanese black pine and the Swiss stone pine were the most salt-tolerant conifers, and the pagoda tree and honey locust (there's that legume again!) were the deciduous trees best adapted to a high-salt environment. The more tolerant species had lower concentrations of chloride in their stems. Researchers are using this clue to discover how these species achieve their tolerance, so that in the future this trait may be bred into other species. In the meantime, this information on salt tolerance is obviously vital for landscaping roadsides in northern areas. Dogwoods may look lovely in the spring, and eastern white pine may be comfortably familiar to us, but we'll have to develop new favorites that are better able to survive in the altered environments we have created.

Some plants don't merely tolerate adverse conditions, they thrive on them. For such species, the conditions don't seem adverse at all; this is just a human value judgment. *Agrostis tenuis*, a wind-pollinated grass, is one of a rich variety of species found in the pastures of Wales. But *Agrostis* also grows nearby on the tailings of abandoned mines. There it exists nearly alone. In this toxic environment, most of the other members of the pasture community not only fail to flourish, they cannot even survive. Yet *Agrostis* thrives (*Natural History*, March 1981). The plants of *Agrostis* growing on the tailings are genetically different from those in the pastures. The metal-tolerant plants sequester the toxic metals in the cell walls.

In the cases of the salt-tolerant trees and metal-tolerant *Agrostis*, scientists aren't simply identifying plants that can grow in what would be considered inhospitable environments, they are also investigating the mechanisms which allow plants to colonize these areas. Another example of this approach is the work of wetland ecologists studying how flood-tolerant plants survive the low oxygen tensions of their waterlogged environment (*Nature*, October 14, 1982). In the bogbean, *Menyanthes trifoliata*, the problem is solved by having oxygen diffuse from above-ground structures into the roots through anatomical air ducts. Some of the oxygen diffuses out of the root to form an oxygen-rich sheath. Other plants survive low oxygen tension by preventing the buildup of ethanol, the end product of glycolysis in anaerobic conditions. Flood-tolerant species such as *Glyceria maxima* and *Iris pseudecorus* divert the glycolytic pathway to oxaloacetate and nontoxic malate.

Some scientists are looking to plants not only to solve our food needs, but our energy needs as well. Some of these approaches are already familiar, such as the production of ethanol from sugar or grain. But since most rich farmland must be reserved for food production, the production of biomass must be relegated to marginal lands. Since these lands are called "marginal" because the conditions there aren't right for our favorite crops—wheat, corn, soybeans—we have to broaden our horizons and investigate those plants that find such marginal lands more than marginally acceptable.

In a program to identify the best plants for biomass farming on arid land in western Texas, 2,900 plants were screened and four selected: mesquite, saltbush, Johnson grass, and kochia (*Exxon USA*, First Quarter 1982). Mesquite can extract nitrogen from the air and is very efficient at capturing moisture in arid soils. Saltbush grows well in alkaline soil, and, as its name implies, it concentrates salt from the soil, so cropping it can remove as much as a ton of salt from an acre of land. Johnson grass is a perennial pasture grass that grows rapidly and produces a high yield. And finally, there is kochia, a fast-growing annual similar to tumbleweed.

Though all four plants are well adapted to the land researchers are trying to cultivate, there are problems to overcome. The fact that a plant grows well in its natural environment doesn't insure that it can be cultivated economically. For a plant to be considered successful, it must annually yield, on the average, three tons of biomass per acre. And it must do so with a minimum of fertilizer and irrigation—this crop is supposed to produce energy, not eat it up. Also, it has to be relatively easy to harvest and process, so it must be adapted not only to its environment, but must meet human needs as well.

While some plant scientists are searching for new plants to fill human needs, others are trying to make plants we already exploit more productive. J.S. Boyer, a plant physiologist with the U.S. Department of Agriculture, points out that for eight major crops the record yields were three to seven times higher than the average yields (*Science*, October 29, 1982). His explanation for this large discrepancy is that "most plants grow in environments that are, to a considerable degree, unfavorable for plant growth." Boyer claims that disease and insect losses cause only a small drop in yield; the main problems are weedy competitors, inappropriate soils, and unfavorable climates. If plants were better adapted to deal with these environmental factors, crop yields would rise. The high record yields indicate that the genetic potential for high productivity is present in today's crops.

Boyer gives several examples of how crop yields increase when plants are selected for specific environments, so that there is a closer fit between genetic makeup and habitat. Since there are genetic differences in the ability of plants to accumulate nutrients from a particular soil, selection for efficient nutrient absorption might be one way to increase crop yields from marginal soils. In other cases, the problem may be the overabundance, rather than the lack, of something in the soil. Salinity is increasingly a problem in agriculture because of salt accumulation due to irrigation, and because of the increased cultivation of marginal lands with saline soils. Experiments with tomatoes show that salt-tolerant genotypes can grow in soils that kill domestic cultivars.

Besides the factors discussed by Boyer, there are also microorganisms in the soil that can retard or enhance growth. Though microbes that cause disease or fix nitrogen have been given a great deal of attention, there are also microbes that help to suppress plant diseases and thus promote growth (*Nature*, November 4, 1982). Since even if disease-causing organisms don't destroy a crop, they can seriously reduce the yields, it's important to discover how to encourage the growth of organisms that can keep the troublemakers under control. If the root systems of potato plants are colonized by beneficial rhizobacteria such as *Pseudomonas fluorescens* or *I. Putida*, their growth is enhanced, and the yield increased by up to 30%. The results were equally impressive when sugar beets were treated with *Pseudomonas*. The problem now is to find a practical way to introduce beneficial microflora into plants. Various highly concentrated inocula are being tested.

All plant productivity ultimately hinges on photosynthesis, but how the photosynthetic rate varies under the myriad of variables to which plants are exposed under field conditions is largely unknown (*Nature*, July 22, 1982). In fact, photosynthesis itself is still a subject of controversy (*Science*, August 28, 1981).

The catch-all term "photoinhibition" can be used to describe the types of stress that interact to limit photosynthetic processes. These stresses include the damaging effects of temperature extremes, limitations on carbon dioxide availability, and water stresses, combined with low and high light intensities. Photoinhibition is the damage done to photosynthetic capacity when a leaf absorbs more light than the normal photosynthetic reactions can use. Studies on higher plants grown under a variety of conditions indicate that photosystem II, the oxygen-evolving reaction, is most affected by photoinhibition under various forms of stress. If excess light energy can be dissipated in some way, the plant is able to survive. Changes in exposure to light can also vary the ratio of photosystem I to II, and balanced excitation of these systems seems to be important for photosynthetic efficiency.

Temperature has a large effect on photosynthesis. Low temperatures cause changes in chloroplasts. The thylakoid membrane lipids become less fluid, and this reduces the mobility of electron carriers between photosystems I and II. At the other end of the temperature scale, *Camissonia*, a desert plant found in Death Valley, has the highest photosynthetic capacity so far discovered. This seems to be related to the plant's high levels of the carbon dioxide-fixing enzyme, ribulose biphosphate carboxylase. It is too early to tell if this type of information can be used to breed plants that photosynthesize more efficiently under specific temperature conditions, but that possibility definitely exists.

Plant science is an exciting field at the moment. Many different plants and many different plant properties are being investigated in a host of different ways. This activity is a sign of renewed vigor in the field. The future is promising, not only in terms of increased crop yields and the development of new economically valuable plants, but also in terms of discovering more about the complex biochemical mechanisms that underlie useful plant properties.