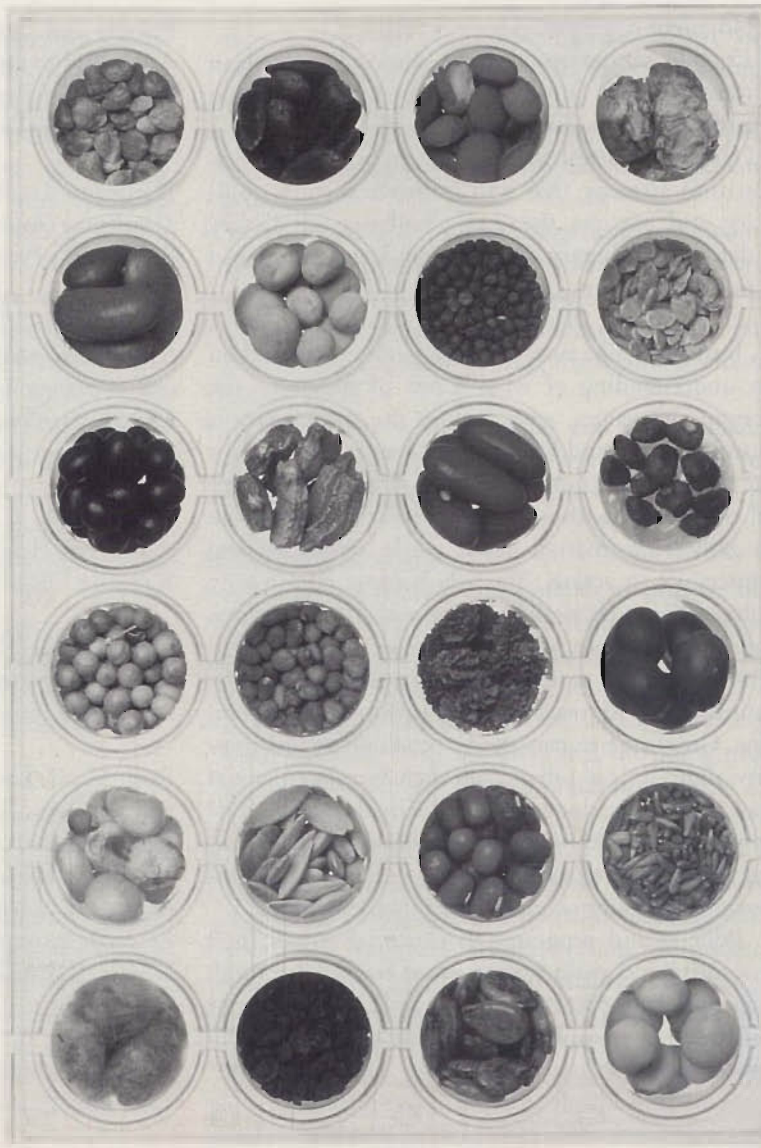

Seeds of Change

From Hybrids to Genetically Modified Crops

by Jorge Fernandez-Cornejo, Margriet Caswell, and Cassandra Klotz-Ingram

Nineteen ninety-eight marked the two hundredth anniversary of Malthus' essay on how geometric population growth and linear food production increases would jeopardize the future of humanity. Those predictions failed to materialize, to a large extent because research led to unprecedented growth in crop yields and total agricultural productivity over the past sixty years. Figure 1 shows the U.S. record.

Mechanical, chemical, and biological innovations undergirded this remarkable trend in agricultural productivity and the resulting abundance of food. The development of hybrid crops in the United States in the first part of this century marked the beginning of a series of biological innovations. Hybridization, a traditional breeding process, crosses two inbred lines to create seed varieties with greater yield potential than exhibited by either parent. Hybridization allowed breeders to enhance biological characteristics more predictably and quickly than did natural selection or chance mutations. The Green Revolution of the 1960s and 1970s was spurred by traditional breeding and adoption of high-yielding crop varieties in developing countries. The more recent development of modern biotechnology, especially genetic engineering, extends these processes of biological innovations.

Despite the promise of benefits, environmental and consumer concerns currently temper acceptance of agricultural biotechnology in the United States and globally. The ultimate contributions of biotechnology will depend on our ability to recognize its potential benefits and its risks.

The adoption of plant innovations

Plant breeding takes time. Breeders may need many crop generations to successfully transfer a targeted trait to an elite strain. Superior hybrid corn varieties, for example, were introduced in the early 1930s

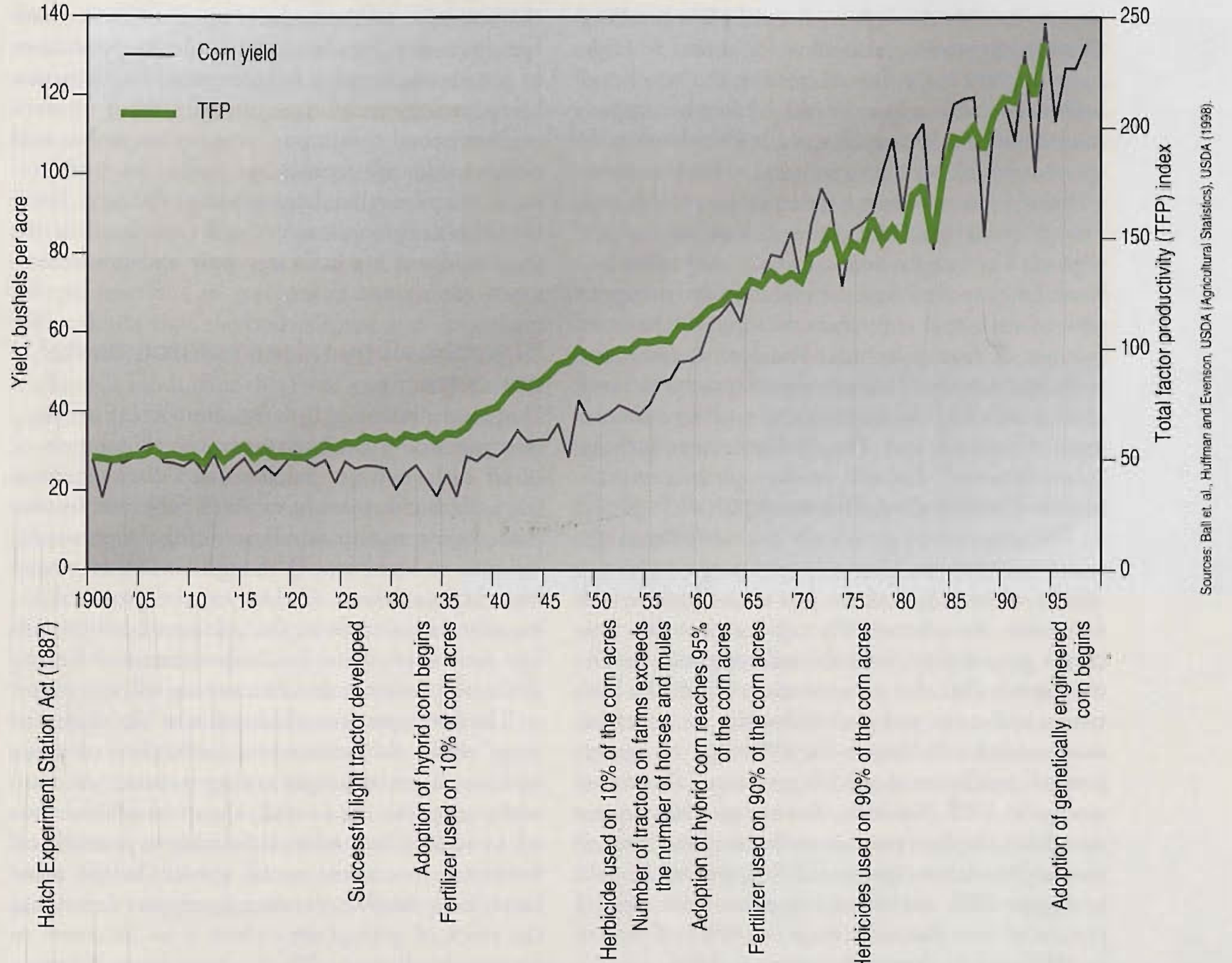

Figure 1. Corn yields and total factor productivity in U.S. agriculture

after more than twenty-five years of research. Adoption, too, took time. The percentage of corn acreage planted with hybrid corn in the U.S. grew from about 1 percent in 1933 to more than 95 percent by 1960. The speed of adoption of corn hybrids differed by region because plant breeders had to produce varieties compatible with local growing conditions. The adoption of hybrid corn in the U.S. led to a 15 to 20 percent increase in average corn yields between 1938 and 1945. Further yield gains were facilitated by the adoption of chemical fertilizer and pesticides (figure 1).

Prior to the development of hybrid technology, private firms had little incentive to conduct plant breeding because the seed of improved plants could be easily reproduced by farmers. Furthermore, according to the Patent Act of 1790, seeds were considered "products of nature," and could not be patented. Hybrid seed technology, however, required farmers to repurchase seed each year because the seed of hybrid crops did not carry the vigor of the original hybrid seed. Yields would fall 15 to 20 percent if farmers planted saved seed. This characteristic of hybrid crops encouraged the development of the seed industry. The first seed company to produce hybrid corn was organized in 1926 and an increasing number of private firms were established in the 1930s.

In a practical sense, only corn, sorghum, and sunflower can be hybridized. Thus, Congress enacted the Plant Patent Act of 1930 and later the 1970 Plant Variety Protection Act to strengthen patent protection and encourage innovation for other crop varieties. Moreover, in 1980 the U.S. Supreme Court ruled that "living material was patentable." Subsequent rulings by the Patent and Trademark Office's Board of Appeals and Interferences extended protection to all plants and nonhuman animals, expanding Intellectual Property Right (IPR) protection for biological innovations.

As the new millennium begins, U.S. farmers are rapidly adopting genetically engineered crops. Genetic engineering modifies organisms by recombinant DNA techniques. These techniques allow a more precise and time-saving alteration of a plant's traits, facilitating the development of characteristics not feasible through traditional plant breeding. Genetic engineering also allows scientists to target a single plant trait, thus decreasing the number of unintended characteristics which often accompany traditional breeding techniques, and increasing the speed at which breeders can develop new varieties.

Some industry observers classify genetically engineered crops into three generations or "waves" (Panos). The first generation includes crops with "enhanced input traits," for example, crops carrying genes selected for insect control, herbicide resistance, and drought or frost tolerance. The second generation includes crops with "added value output traits," such as corn with high oil content and nutrient enhancement of livestock feed. The third generation includes "plant factories" that will produce pharmaceuticals, biobased fuels, and other materials.

The adoption of genetically engineered crops for insect resistance and herbicide tolerance is growing rapidly in the U.S. with the promise of higher yields and lower costs. Genetically engineered cotton contains a gene derived from the soil bacterium *Bacillus thuringensis* (Bt) that protects cotton from the budworm, bollworm, and pink bollworm. Bt cotton became available to farmers in 1995 and its use expanded rapidly to about 17 percent of the cotton acreage in 1998. Similarly, Bt corn provides protection from the European corn borer. The Environmental Protection Agency (EPA) approved Bt corn in August 1995 and its use has grown from about 1 percent of corn planted acreage in 1996 to 8 percent in 1997, and to almost 20 percent in 1998.

Adoption rates for herbicide-tolerant crops have been particularly rapid. Herbicide-tolerant soybeans became available to farmers in limited quantities in 1996, but its usage expanded to about 17 percent of the U.S. soybean acreage in 1997 and to more than 40 percent of the soybean acreage in 1998.

The use of genetically engineered crops with pest resistance and chemical tolerance traits may reduce chemical pesticide use. Bt cotton is reported to reduce the need for conventional chemical insecticides to control insect pests (Marra, Carlson, and Hubell). Similarly, herbicide-tolerant soybeans may reduce overall herbicide use because farmers can control weeds by switching to an efficient postemergent herbicide that previously would have destroyed the crop (Fernandez-Cornejo, Klotz-Ingram, and Jans).

Biotechnology may also be used to develop crop varieties that tolerate higher levels of environmental stress. Such crops could maintain productivity in drought-prone areas or may help farmers adapt to global climate change, such as increased mean temperatures or extreme weather events.

Genetic engineering also offers the opportunity to create "designer" foods with enhanced nutritional characteristics and better harvest, transport, and storage properties. But beyond the direct applications of genetic engineering to create new crop varieties, biotechnology techniques can be used to monitor environmental conditions, detect plant and animal diseases, identify food-borne pathogens, and produce microbes that biodegrade pollutants. These biotechnology applications will contribute to the production of a safe food supply and lower environmental degradation.

Biotechnology raises environmental concerns

Despite the potential benefits, some scientists worry that genetically engineered plants will compete or breed with native populations and disrupt ecosystems. Herbicide-tolerant varieties, for example, may pass their genes to weeds, creating "superweeds" resistant to herbicides. Although USDA developed biosafety guidelines to decrease the potential for negative impacts from the release of biotechnology-derived plants, some doubts remain about the ability to guarantee that outcrossing will not occur.

The development and adoption of bioengineered crops could also reduce the availability of many traditional varieties, narrowing genetic variation within a species. As a result, the more limited varieties could become more vulnerable to pest infestations and to environmental stress. On the other hand, biotechnology product developers depend on the stock of germplasm—there is an incentive to preserve biodiversity. We don't yet know if private incentive will offset other market forces leading to monocultures. Critics made similar warnings about the development and adoption of hybrids.

The development of cotton and corn varieties containing Bt genes has raised concerns by proponents of biological pest management methods. They argue that Bt genetically engineered into a plant will hasten pest immunity because Bt plant material will persist in the environment longer than Bt in foliar sprays, extending the time for targeted insect pests to build Bt resistance. Many agricultural producers, including organic growers, rely on Bt sprays for insect control, but they could lose this option if insects become resistant. To guard against this concern, the Environmental Protection Agency's approval of the new Bt varieties was conditional on producers developing resistance management plans. Plans include subjecting insects to high doses of Bt to ensure that few resistant biotypes survive to mate, and setting aside refuges to ensure that susceptible biotypes outnumber resistant ones.

Biotechnology raises food safety concerns

Genetic engineering can be used to develop healthier foods. Food nutrient content can be enhanced beyond levels provided by traditional breeding techniques. In addition, biotechnology can be used to improve food safety through better hazard detection and monitoring.

Still, food safety concerns persist, especially in Europe. Foods with transplanted genes may cause allergic reactions. A gene from a nut inserted into another type of food, for example, might trigger allergic reactions in susceptible consumers. Some critics doubt that the body digests and assimilates biotechnology-derived foods in the same way as traditional foods. But the Food and Drug Administration (FDA) ensures that genetically modified foods reaching the marketplace are "substantially equivalent" to current foods, and pose no additional risk. The FDA would require a label for genetically modified foods only if there were known risks, as with traditionally grown foods.

Other critics worry that the essential characteristics of food may be changed with the insertion of genes from another species. Dietary preferences and religious strictures would be harder to follow if the consumer did not know about gene transfers. For example, would the insertion of an "antifreeze" gene from an animal render a vegetable no longer vegetarian? Would the use of a single swine gene violate dietary restrictions for those of Jewish or Islamic faiths? All life forms share some identical genes. It is not yet clear to what extent gene transfer changes the essence of the receiving species. In addition, some believe genetic engineering interferes with "nature" and "creation." Scientists argue, however, that all plants are genetically modified (that is what evolution means) either by natural selection from random mutations and recombinations, by domestic breeding, or, more recently, by "engineered mutation or recombination" (Panos).

Unlike hybrid crops, which were accepted by consumers worldwide, some consumer and environmental groups demand that genetically engineered foods be labeled and separated from other foods in production processes. They want the characteristics of the process identified rather than product properties alone.

Biotechnology and the structure of agriculture

Biotechnology is also changing the industry structure of suppliers of agricultural inputs, particularly seed and chemical firms. Protection of intellectual property has promoted industry investment, but it also may have contributed to increased industry concentration. Private investment in seeds occurred earliest for hybrid corn because hybridization provided a biological form of protection for intellectual property embedded in the seed. Thus, the four-firm concentration for corn seed companies reached 57 percent by 1980, compared to only 14 percent for the seed industry as a whole. Following the

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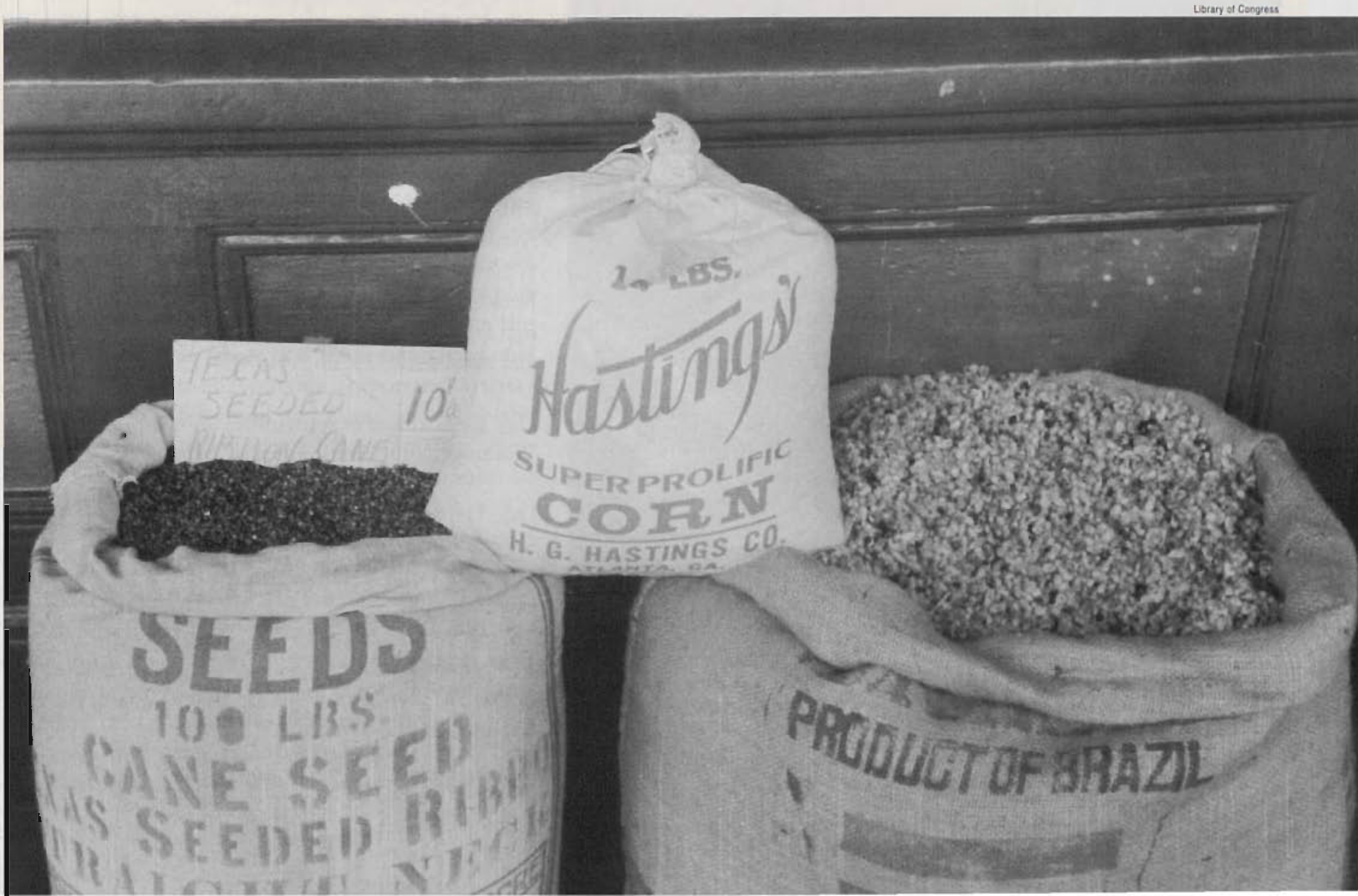

Plant Variety Protection Act of 1970 and strengthening amendments enacted around 1980, more than fifty seed companies were acquired by pharmaceutical, petrochemical, and food firms in the 1970s (Lesser). More recently, the government has further protected intellectual property for biological inventions, and higher levels of private investment in research, along with mergers and acquisitions, have followed.

Genetically engineered products with quality enhanced traits, such as high-oil corn, enhanced-nutrient livestock feed, and "grown-to-order" foods, will also likely increase grower contracting and product labeling, diminishing standard commodity markets. Biotechnology firms increasingly work not only with farmers but also with end users and elevators to create market channels (Renkoski). More product differentiation, vertical and horizontal integration, and market segmentation may result, with the potential to significantly alter the structure of American agriculture.

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Biotechnology in the twenty-first century

The role that biotechnology will play in producing increased supplies of more nutritious foods will depend on how successfully the scientific community and government agencies handle the environmental and consumer concerns. Many environmentalists and consumers have expressed skepticism about the ability of the agricultural sector and government agencies to adequately consider negative effects. Consumer acceptance of biotechnology-derived products, however, will ultimately determine the investments in research and adoption of the technology by farmers.

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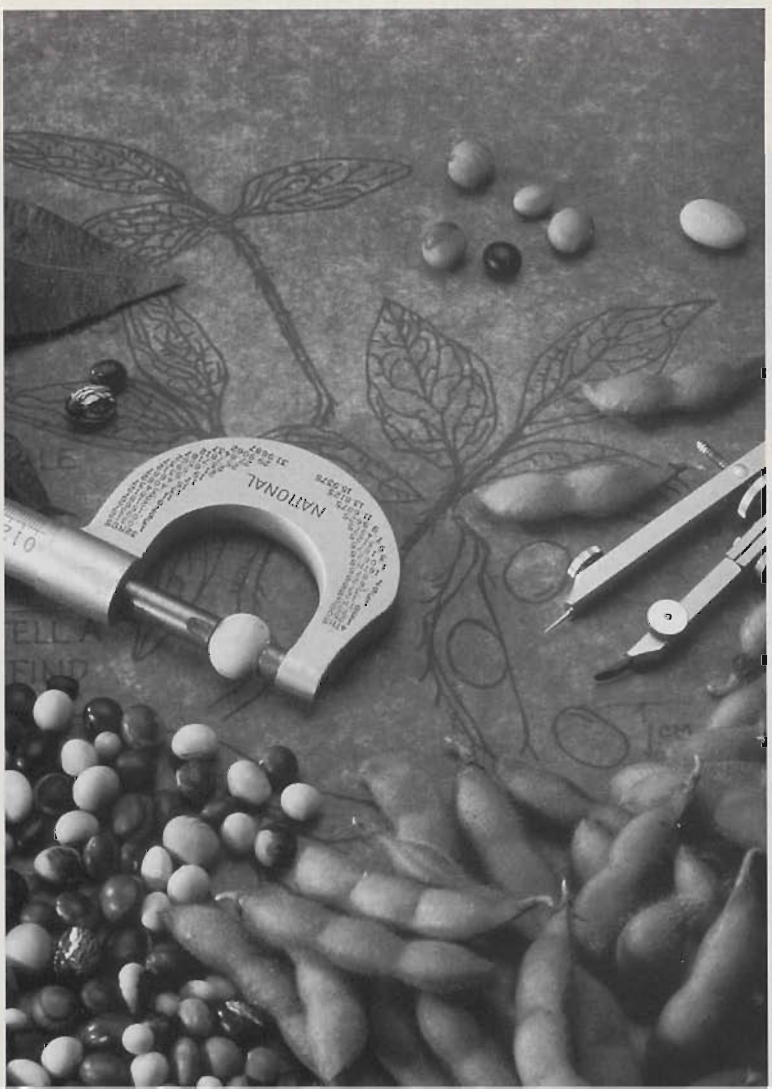

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