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PROSPECTS AND CONSEQUENCES OF EMERGING CHEMICAL & BIOLOGICAL INNOVATIONS ON AGRICULTURAL PRODUCTIVITY OF CROP PLANTS

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Good afternoon. It's a pleasure to participate in this symposium on the "Private Sector Role in Increased Agricultural productivity". Dr. Benson has asked me to specifically address the "Prospects and Consequences of Emerging Chemical and Biological Innovations on Agricultural Productivity in Crop Plants." In this talk I will try to address the goals of the agricultural chemical industry and to illustrate its evolution from simple pest control to more subtle approaches to improved productivity including plant growth regulation (PGR's) and genetic engineering of crops.

Agriculture is a major United States industry. We have been blessed with ample high quality arable land and favorable climatic conditions, which when coupled with American ingenuity, has allowed us to fulfill U.S. food needs now and for many years to come. In addition, agriculture provides a significant economic advantage for the U.S. The 1981 U.S. corn grain crop alone was worth $30 billion dollars and agricultural exports accounted for $44 billion dollars, obviously impacting our balance of payments quite favorably.

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The rest of the world has not been so furtunate. In fact, it is estimated that 1/3 of the world population is living on a marginal diet and that some 12 million people starve to death each year. To make matters worse, U.N. experts expect that the world population will double in the next 35 years. During that time we must produce as much food as we already produced since the dawn of recorded history! This will be no simple task and it is complicated by the fact that there is very little high quality agricultural land to bring into production. We have all the good land that we are going to get, and in our opinion, the only way to increase the total world food supply is to increase the productivity per unit acre of farm land.

Hence, total food production and productivity are linked by necessity and in the final analysis become one and the same problem. But there is yet a darker side to the productivity issue. Not only are current land resources limited, they are shrinking! And other resources necessary to agriculture are also becoming scarcer. These include water - consider the impact on U.S. food prices when the Ogalala Aquifer dries up - energy and of course mineral resources. And that brings us to the very timely theme of our conference: Improved Agricultural Productivity.

What are the limits to productivity? I think they can be broken into two broad classes: environmental and genetic limitations. Energy may also be considered a limitation, but I will not attempt to cover this complex issue today. Environmental limitation can be broadly broken into three classes: weather related limitations such as heat stress, cold stress, and drought; soil related limitations such as soil quality, pH, and nutrients; and finally competitor related limitations such as weeds, diseases, insects and herbivores. Genetic limitations include inherent crop ability to withstand environmental limitations such as cold stress and disease pressures, as well as desirable agronomic characters such as maturity, standability and overall yield potential.

What are the roles of industry in addressing these limitations and what are the goals of the agricultural industry? The goals of the agricultural industry are threefold: (1) to increase total production to meeting rising worldwide food needs, (2) to increase productivity in order to conserve resources for the future, and (3) to return a profit to the shareholders of the corporation. Historically, industry, especially the agrichemical business, has focused on competitor related problems, namely pest control. There are a number of reasons for this but the foremost is that pest control is easy to assess financially, both in terms of pest related losses in the absence of control and yield gains in the presence of control. This points to a major limitation in private sector contributions to agricultural productivity: such contributions must have financial value since not only do the stockholders of a company require a return on investment on a product but <u>so</u> <u>do</u> <u>farmers</u>! Farmers will not buy a product to break even. Pest control then was recognized early as an area of immense importance both financially and in a productivity sense.

Pest control is composed of a number of subsets including weeds, insects, diseases, nematodes, and herbivores (mice, rats, rabbits). Perhaps the major contribution to pest control is that of weed control or herbicides. In any given field there are limited resources: water, light, carbon dioxide for photosynthesis, and fertilizer. Weeds compete for these resources and depending upon their degree of success, they will limit crop productivity per acre. Herbicides selectively eliminate weeds either before or after emergence. For instance, soybeans and corn both suffer from severe infestation from grass weeds, which if not controlled will completely inundate the crop and contaminate the grain and thereby lower the yield and quality of the crop by as much as 80%. Lasso® herbicide selectively eliminates many grassy weed problems resulting in considerable gains in productivity.

Herbicides which are selective and therefore safe on all crops have not been developed. Subsequently, these crops are not realizing their full productivity potential. For instance, Lasso® generally controls weeds which infest grain sorghum fields but unfortunately, also damages the sorghum plants extensively. Recently, an alternate to the development of new herbicides has been discovered. That alternative is a herbicide safener. These chemicals "safen" known herbicides so they may be applied to crops which are normally susceptible to and damaged by these herbicides. Hence, treatment of sorghum seeds with the safener Screen® stimulates the sorghum plant to be resistant to Lasso® and allows this weed control technology to be utilized with a resultant increase in sorghum productivity.

Other pest problems under investigation by industry which reduce productivity are insect and disease infestations. Insect and disease pressure is estimated to reduce yield by as much as 30% in any given year. Classically these pests have been controlled by identifying chemicals toxic to the pest and spraying fields with these chemicals. While this strategy works, and in the absence of other strategies, it must be employed to successfully eliminate severe yield losses, it is not without shortcomings. Generally, insecticides and fungicides suffer from resistance problems in which the target pest is no longer controlled by the pesticide. These compounds are also not systemic, meaning that as the plant grows they do not move into new growth and multiple applications are required. Finally, many insecticides and fungicides are not sufficiently selective and beneficial organisms like insect predators or symbiotic fungi are eliminated simultaneously with the pests. These shortcomings have led to the search for new types of products which will improve pest control and eliminate negative side effects.

In the area of disease control, industry is attempting to exploit the concept of induced resistance. Conceptually this is analogous to small pox vaccination in humans. Specifically, chemicals are sought which can trigger defensive reactions in plants that will allow the plant itself to ward off the disease. There is much scientific literature to suggest this approach is feasible but it has not yet been reduced to practice. At Monsanto we have identified several compounds which potentially can induce disease resistance and field evaluation is underway now. Such an approach has clear cut advantages. First, since the protection is mediated through the plant, multiple defense mechanisms could be involved thereby slowing the rate at which pests develop resistance to control. Secondly, since control is affected by chemical action on the plant by molecules which are not directly fungitoxic, beneficial organisms should not be harmed. Finally, there is evidence from work at Monsanto and elsewhere that such induced resistance can last six weeks or longer and therefore greatly reduce the number of applications required for effective control. This would impact productivity not only in terms of grain yield but also with respect to lowered energy inputs required for treatment application.

Beyond the traditional areas of pest control, the agricultural industry is trying to exploit biotechnology to improve agricultural productivity. The contributions from biotechnology will probably come first in the area of plant growth regulation. Plants produce grain to insure species survival, but that goal is not necessarily identical to maximum grain yield. Can we regulate the biochemistry of plants to maximize the grain yield of crops? This is not a simple problem since it integrates research on chemically induced changes in plants, genotypic response to chemical treatment and environmental effects on chemical-genotypic interactions. To identify a chemical plant growth regulator, one must go beyond the traditional screening of chemicals. Biochemical and physiological events impacting yield at the <u>field</u> level must be identified and then strategies developed to impact these events must be developed. This has necessitated considerable basic research into yield limitations. While this research is not trivial, there have already been some successes attained in plant growth regulation; for instance, Pix® in cotton and Polaris® in sugarcane. Others should be forthcoming in the major grain crops; soybeans, corn and wheat, in the next 5-10 years.

Finally, there is the area of genetic improvement of crops. The seed industry has, of course, made major contributions to increased agricultural productivity by developing improved crop varieties. Improvements in the genetic base of crops, particularly corn, have been dramatic. In fact, the development of hybrid corn, in conjunction with the use of chemical fertilizers, have afforded yield increases greater than 300% since 1940. Nevertheless, due to flower morphology, many crops including soybeans, wheat, rice and cotton, remain difficult to improve. Novel approaches are needed.

Plant tissue culture and genetic engineering offer the potential to circumvent the natural limitations of flower morphology in these crops. Plant tissue culture is the growth of plant parts such as leaves, stems, roots, embryos, etc. on synthetic media. Under these conditions a plant obtains nutrients, minerals and sugars from the media instead of from the soil and photosynthesis. Under culture conditions, plant tissue generally becomes disorganized into callus. In the presence of appropriate plant hormones, callus from some plants can be induced to undergo morphogenesis or regeneration into whole plants. It is this remarkable property which makes plant tissue culture a potential tool for crop improvement. Literally millions of plant cells can be grown in culture in a small room. These cells can be selected for new properties such as protein quality, herbicide resistance and disease resistance. Variants may be selected, regenerated and evaluated at the whole plant level in the greenhouse or field. Hence, selections for new plant types which would require large areas of land and many years might be accomplished more rapidly in tissue culture.

An example of this type of technology which has recently been completed at Monsanto is the development of Roundup® tolerant alfalfa plants. Alfalfa tissue was placed into culture first on solid media and later into liquid culture. In liquid culture, the cells were exposed to a lethal dose of the herbicide Roundup® and the survivors were plated out for regeneration into whole plants. These new plants (or variants) were transplanted into the field and treated with Roundup® the way a farmer would use the herbicide. Several variants were found to have field tolerance to the herbicide. In addition, the other agronomic characters of the plant - standability, morphology, and disease resistance - appeared to be unchanged by the selection and regeneration process. The evaluation process is by no means complete and several more years of field work will be necessary before this experiment can be declared a complete success. Nonetheless, this illustrates the potential utility of this technology for crop improvement.

There still remain a number of problems with the use of tissue culture. First and foremost, not all crops can be regenerated from tissue culture, most notably soybeans and cotton, while wheat is regenerable only under special circumstances. Certain crops which are regenerable undergo dramatic changes during culture and may lose many desirable agronomic traits during the process. Potatoes are such a crop. Most crops cannot be regenerated from single cells and selections from clumps of cells may produce highly heterogeneous regenerates which will be difficult to use in a breeding program. Furthermore, selection in culture for e.g. herbicide resistance may result in variants with many changes besides the ones sought. Finally genetic transmission of tissue culture induced traits through the seed does not always occur. Considerable applied and basic research will be required to fully exploit the potential of tissue culture for crop improvement.

Genetic engineering offers an extremely selective method for modifying plants in culture. Instead of selecting for desirable traits by screening sheer numbers of cells for mutants (or variants), the gene coding for the desired trait is placed into the cell. The resulting transformed cell will now code directly for the desired trait. For example, genes coding for antibiotic resistance have been inserted into antibiotic susceptible bacteria, transforming these bacteria to antibiotic resistance organisms.

Similarly, if a gene coding for herbicide resistance were available, it could theoretically be inserted into a plant cell. This transformed plant cell could be regenerated into a whole plant which would putatively be resistant to herbicides. The potential advantage of genetic engineering is that a single gene change can be made in a plant cell as opposed to the unpredictable number of changes which may occur while selecting variants in culture. Unfortunately, plant cells have yet to be transformed and until this breakthrough occurs, genetic engineering of plants cannot be accomplished. While simple transformation of plant cells will probably occur in the next one to three years, useful transformation will require considerable research into gene organization, regulation and expression in plant cells. Until this research has been completed, it will be very difficult to place a gene into a plant cell and obtain meaningful expression at the right time and place. For example, if the gene coding for lysine were simply inserted into a corn cell and this cell regenerated into a whole plant, this plant might produce high quantities of lysine in all tissues (e.g. leaves, roots, stem). Since high lysine is only desirable in the grain, it is obvious that considerable energy would be wasted by the plant in producing lysine in all tissues.

Despite all the technical problems of tissue culture and genetic engineering, these technologies hold the key to revolutionizing plant breeding and crop productivity.

In conclusion, the agricultural chemical industry has effected great increases in crop productivity through development of pest control strategies while the seed industry has dramatically improved productivity with the introduction of hybrid varieties as well as improved pure lines. In the future, biotechnology will permeate both the chemical and seed industry and lead to further productivity gains through plant growth regulators, improved pest control strategies, tissue culture and genetic engineering. Plant growth regulation should impact productivity in the next 5-10 years, while tissue culture and recombinant DNA will probably not impact crop improvement for 10-15 years, barring unforeseen breakthroughs.

While we are very enthusiastic about the potential of biotechnology, let me summarize some of the important reasons for the time delay:

- o the lack of fundamental biochemical knowledge in plant sciences;
- o plant transformation is not yet feasible;
- o the lack of evidence that tissue culture can produce competitive commercial plants;
- o the lack of evidence that new traits can be usefully incorporated into plants via tissue culture;
- o new variety introduction is a 8-12 year process now and probably will not change significantly, if at all, for 5-10 years.

The final word is research. Much is needed in plants. While the United States is a leader in basic and applied plant research, this area has been given too little emphasis in the past, undoubtedly due to our fortunate climatological and geographic circumstances. More research on plant biochemistry, physiology and molecular genetics must be undertaken in University, Industry and Government labs to speed up the realization of the potential biotechnology for improved crop productivity.

Food, or lack of it, will surely become one of the major destabilizing issues in the next 30 years. Furthermore, the present economic plight of the farmer emphasizes the need to make him cost efficient and resource efficient consistent with better national policies on water utilization and land utilization. The United States must meet this challenge of feeding the world in the future and increased agricultural productivity is the only mechanism by which to meet this challenge.

Thank you.