by Donald N. Duvick

THE NEW BIOLOGY

A Union of Ecology and Molecular Biology

OVER the past six decades a chain of events in crop production culminated in an agriculture dependent on chemicals. Then, two events, concurrent but unconnected, started a chain of reactions with final consequence as yet unknown, but perhaps predictable.

➢ The new biology of the 1990s will integrate ecology and molecular biology in the service of agriculture. This new biology will surprise us. It will not present us with a cornucopia of genetically engineered chimeras. Nor will it present a plethora of chemically dependent cultivars, fragile in absence of expensive support systems. Instead, the new biology of the 1990s, grounded in ecological principles and deepened with new genetic insights, will make it possible to develop an agricultural production system that is more sustaining than it is today.

Environmental Concerns

First, biologist-led concern for the environment sparked public concern—at times even paranoia—about dangerous chemicals in food and water. Farm-applied chemicals topped the list of concerns: persistent pesticides entering the food chain, blanket insecticide applications upsetting the balance of predator-prey interactions, fertilizers (especially nitrogen fertilizers) and pesticides filtering down to groundwater supplies. Widespread public efforts to reduce, or eliminate, agriculture's dependence on chemicals was the result.

Admittedly, the public's fears are sometimes exaggerated, unfounded or out of proportion to actual risks. However, the fears are real and have real consequences in legislation and regulations that limit or proscribe farm chemica usage. It is clear to farmers, agri-chemica manufacturers and agronomists that w are in a new era. The 1970s trend of ever increasing, unrestricted plant-chemica interdependence is finished.

This is not to say that chemical aid will disappear, or that chemical use wil revert to kinds and levels of the 1930s. Bu rates of application certainly will b reduced, and the ways in which chemical are used in agricultural production will b more subtle and more biologically sound.

Molecular Biology

The second event with large conse quences was the application of molecula biology to agriculture. Its rapid develop ment started at about the same time a the rise in environmental concerns, bu from a very different base. Whereas ecologists led the environ mental movement, laboratory-based medical researchers led th way in molecular biology.

From the start, molecular biology was involved in genetics. new kind of genetics—molecular genetics—was soon created Genetic transformation—transferring genetic information fron one organism to another—forms the basis of molecular genetics The term "genetic engineering" was coined to refer to the abilit to isolate and move genes. Hitherto impossible genetic recombina tions now could be achieved.

Not only could genetic transformations be effected, but the could be accomplished in bacterial (or cellular) generation time

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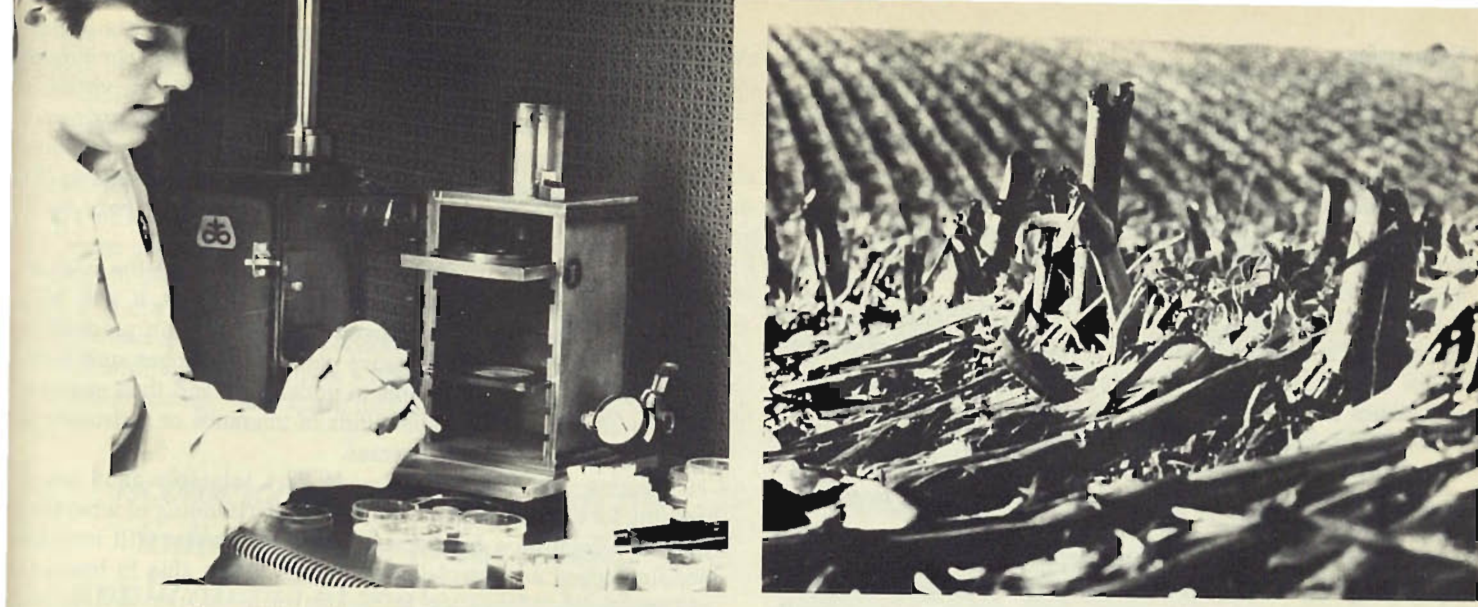

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not plant or animal generation time. Consequently, it seemed obvious that molecular genetics not only could produce powerful new genetic improvements; it also could make the improvements in incredibly short times.

Years have gone by since the early optimistic days. It is now clear that not all conceivable genetic transformations will work. Genes do not function in complete independence of their genetic background. And fully usable plant genetic transformations take longer than a few weeks. It requires whole plant generation time—seasons or years—to grow out the transformed plants, adjust their genetic background and, most importantly, test the new creations in field conditions.

Nevertheless, molecular genetics, and molecular biology in general, have progressed at breakneck speed, even faster than originally predicted. Almost weekly, announcements tell of successive, step-wise achievements in methods of plant gene identification, transfer and regulation. There is no question at all about the soundness of the science that supports molecular genetics. Therefore, it is bound to have utility for plant breeding, an art firmly grounded in genetics.

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Criticisms, Conflict

Despite the benefits wrought through molecular genetics, its application to plant breeding has been sharply criticized. There is strong concern on the part of some people that genetic engineering is dangerous, even immoral. And, agri-chemical interests and genetic engineers have been accused of conspiring to produce tailor-made cultivars that require chemical aids to production, thereby increasing the load of dangerous chemicals in an already overburdened environment. To these critics, engineering herbicide resistant cultivars, for example, is simply a way to increase total herbicide sales. To them, molecular genetics—particularly its use in genetic engineering—is essentially anti-environmental.

So, on the surface, environmentalists and molecular biologists appear to be in sharp, even irreconcilable, opposition. Pages of print, thousands of words, and scores of speeches attest to a widespread belief that, as environmentalists press for reduced use of chemicals, molecular biologists promote the use of more chemicals in agriculture.

I disagree with this belief. It is without foundation in fact. I say, instead, that the two outstanding biological events of the 1980s—environmentalism and molecular biology—complement each other. They need each other for successful application of biology to agriculture. Together they will make a new biology, at once ecologically sound, scientifically powerful and able to benefit agriculture, worldwide.

Potentials for Complementarity

Environmentalists are correct when they say that we cannot condone uncontrolled contamination of the environment with dangerous chemicals (whether of agricultural or any other origin). Proposed solutions are sometimes too drastic or even scientifically wrong, but time and experience will sort out the right from the wrong solutions.

The chief weakness of the environmental approach is that ecology is not a hard science. It may never be one, for it deals with innumerable biological entities interacting over long periods of time. Almost by definition it is a science where controlled experiments cannot easily by devised or conducted. Ecology needs a greater and more precise knowledge of the genetic and physiological interactions between organisms and the environment.

Molecular genetics now gives us the opportunity to gain such knowledge. It allows us to understand organisms and their genetics and physiology in ways never before available to us. It gives us knowledge that we didn't even know was missing, because we didn't know that its scientific base existed. For example, we now know the genetics of chloroplasts and mitochondria; previously we didn't even know that they had genetics, or if we suspected as much, we had no way of studying it.

Consequently, the power of molecular genetics, including genetic engineering, can be used to promote sound ecology in service of environmental health. It can be used to help ensure the safety and utility of new genetic creations, or of new uses of naturally occurring genotypes and organisms. It can be used as a tool to track organisms through the ecosystem in tests of ecological hypotheses, or to gather basic information about organism interactions.

Examples

The complementarity between ecology and molecular biology is well illustrated by possibilities for the two disciplines as regards plant herbicides and plant diseases.

Herbicides. People will continue to use herbicides in agriculture. But new herbicides will increasingly be of greater safety to non-target organisms, including humans, or, they will not be approved for release.

One way to promote the use of only the safest herbicides will be to engineer susceptible cultivars to tolerance of the safest herbicides. In so doing (or even when selecting with classic genetic techniques for tolerance to the environmentally safer herbicides), it will be important to know the molecular and biochemical basis for a cultivar's tolerance to each new herbicide, and conversely, it will be important to know the molecular basis for a target weed species' susceptibility to that herbicide.

This kind of knowledge will be useful in predicting the reliability of a cultivar's herbicide tolerance, and the probable stability of the susceptibility of the targeted weeds over time. And finally with this knowledge it will be possible to predict the effect of the herbicide in question on non-target organisms, such as humans.

One should note the choices as well. Matching of cultivars and herbicide will not increase herbicide use on U.S. crops. Practically all cultivated land surface is already covered by herbicides. Cultivar-herbicide matching will, instead, shift use from least safe to most safe herbicides. Additionally, the shift likely will reduce total pounds of application since newer herbicides in general are applied at very low rates.

Plant Diseases. Another complementary relationship is perhaps even more important. It relates to plant diseases. The fundamental causes of pathogenicity of fungi or bacteria are virtually unknown today. Thus, in most cases, we do not know if toxins are an important cause of fungal leaf-diseases. Neither do we have broad understanding of pathogen-host recognition systems or the physical or chemical ways in which gene-for-gene virulence-resistance systems interact.

Molecular biology provides new tools to examine the interaction between microbial pathogens and host plants. It will help identify the timing of and biochemical steps in toxin production and compare virulence-resistance genes in pathogen and host. Biologists will some day be able to understand and then engineer or select effective and durable kinds of tolerance or resistance to pathogens that cause plant diseases.

Of course, plant breeders already do a tolerably good job of breeding for disease resistance. But an understanding of what they really are doing in a fundamental biological sense will increase breeding speed and precision manyfold. To be able to breed in (via genetic transformation or with other molecular techniques) kinds of resistance that can't be now developed with today's breeding methods will be an essential addition to the breeder's tool kit.

A Two Way Street

The complementarity between molecular biology and ecology is not going to flow universally from molecular biology to ecology and thus to environmental protection. The flow will go in the

Six Decades of Change

Starting in about 1930, grain yields of major U.S. crops began to trend upward. Area yields increased at average rates (not compounded) of 1 to 2 percent per year. Since about 1955, yields have increased at even faster rates—up to 3 percent per year. Among the major crops, maize has shown the highest rates of increase in area yields, soybeans the least, and the rates of increase for wheat and sorghum are between the two extremes.

Numerous analyses have shown that about half of the yield gains were due to changes in agronomic practices: better machinery for planting, cultivating, and harvesting; better weed and insect control via pesticides, and (especially since the mid-1950s) increased amounts of commercial nitrogen fertilizers. The remaining 50 percent of the gain is due to genetic improvements in hybrids and cultivars. The plant breeding improvements of the 1930s (when the results of scientific breeding were first released on a large scale) in many ways started the whole chain of events. For example, farmers who grew the new cultivars were willing to spend more for other inputs—machinery, fertilizers, etc.—because of increased assurance that the new cultivars would respond reliably, with higher yields.

Chemical Aids

Through the years, remarkable advances in formulation and specificity of chemical aids increased their utility and use manyfold.

By the 1970s, biology in service of agriculture had become virtually subservient to chemical aids. Entomology in agronomy was largely a science of insecticides and their interactions with crop growth and weather patterns. Weed science was a science of herbicides. Although plant pathology in the major farm crops was less affected by chemical aids, it was only because economical rates and methods of application had not yet been devised for most U.S. crops.

In Europe, in contrast, plant pathology was strongly affected by chemical aids. For example, fungicide control of wheat diseases became a necessity for high-yield production, so much so that rules for some of the official varietal yield trials specified that fungicidal disease controls must be used.

Plant breeding and genetics seemingly were not concerned with or affected by chemical aids. Plant breeders' success in breeding successively greater degrees of pest and stress tolerance is well documented, as is also their success in raising genetic yield potentials. But breeders may have been selecting cultivars adapted to chemical aids more than they realized. For example, selection for upright-leaved wheat and maize cultivars adapted to high density planting implied a faith that luxury amounts of nitrogen fertilizer would ensure full feeding of the multitudinous plants and ears throughout the season. And the knowledge that chemically protected sorghum seed could substitute for genetic resistance to downy mildew of sorghum, leaving breeders free to select for yield and other traits, doubtless affected directions of at least some sorghum breeding programs.

U.S. crop agriculture of the 1970s (and indeed, crop agriculture of all advanced economies, worldwide) was intimately associated with and dependent on chemical aids. The future of this productive union of crops and chemicals seemed assured.

other direction, as well. Ecological knowledge which describes and interprets interactions of biological organisms with the environment will be indispensable to successful applications of molecular biology.

For example, knowledge about the ecology of microorganisms is limited today, but such knowledge is critical in gauging the margin of safety for releasing engineered bacteria. At the least, any person contemplating the release of any engineered organism will need to be highly knowledgeable about the ecology of that organism. If the needed data don't exist, they will need to be gathered, via observation and/or experimentation.

In addition, agronomists, with their detailed knowledge of agricultural ecology, have much to offer to the broader science of ecology. They should more often contribute to the basic ecological literature—to ecology's knowledge base. Such communication is essential for progress in ecology and in agronomy. Agronomists should get acquainted with and become a part of the broader science of ecology. Agronomists have much to contribute and much to learn from ecology—a fundamental and yet very practical science. And as "practicing ecologists," agronomists can give important assistance to those applying molecular biology to agriculture—and thus play a key role in integrating ecology and molecular biology. Agronomy can be the bridge between these two basic disciplines.

Ecological knowledge will be indispensable to successful applications of molecular biology.

Of course, integration of ecology and molecular biology will not be simple nor always successful. To integrate the most inductive biological science (molecular biology) with the most deductive one (ecology)—to reconcile determinedly reductionist and strongly holistic points of view—will be very difficult. To bring the two sciences together in any way at all will require strong inducements and at least a few exceptional, strong-willed culture-spanners. But in the end the two sciences must and will come together. Both sciences deal with agriculture and the environment, both are strong, growing and solidly based. Leading practitioners from both sides will find one another; indeed, a few have already done so.

The Future

The consequences of this union are many. Economically-based studies of crop culture will stimulate development of new, more environmentally sound yet profitable cropping systems. Indeed, full-partner participation by economists will be essential. Their analyses will guide the biologists of all persuasions as they strive to promote practices and provide products that are ecologically sound, agronomically productive, and also economically viable. Farmers, in the end, will only adopt those practices that improve their chances of economic success in farming. Deeper knowledge of the genetics and physiology of crop plants, their symbionts and pathogens, will allow more rational development of new ecologically-oriented ideas. For example, answers will be found to the questions about the physiological, pathological, or microbiological causes of increased yield of maize following soybeans. This will in turn lead to ideas on how to exploit that knowledge in confronting other constraints.

Plant breeding will be increasingly important for agronomic advance, as outright chemical assistance becomes less important. (My experience as a plant breeder may bias my conclusions on this subject, but I find confirmation from other quarters.) Genetic engineering and associated molecular technologies will move into the front line of plant breeding, side by side with time-tested older plant breeding technologies.

But the new cultivars, products at least in part of genetic engineering, will not (with rare exceptions) be recognizably engineered. Farmers will merely note with satisfaction that step-wise improvements appear at regular intervals, with new cultivars. Improvements will be in the plant traits that breeders have always focused upon: pest resistance, heat and drought tolerance, product quality, standability, and the sum of all the improvements—reliable yielding ability. Increasingly sturdy "dual-purpose" cultivars will produce maximum yields with full inputs and reliable yields under low-input and/or stressful conditions.

Someday, maybe even in the 1990s, certain obviously new traits may come into play, such as true resistance in maize to the corn rootworm, or soybean cultivars with a completely different spectrum of fatty acids. Such totally new traits will clearly be the result of genetic engineering, and their cultivars will probably be widely advertised as such. But even these cultivars will look like maize and soybeans; the basic "factory design" won't be changed.

It is just possible that startling, ecologically-based improvements may also be available before the turn of the century. Scientists may devise maize-legume associations that reduce soil erosion and lower requirements for synthetic nitrogen fertilizer, yet allow for profitable maize production. They may find associative bacteria or fungi that promote selective weed control, or better extraction of soil nutrients or better functioning of rhizobial bacteria. Most importantly, they may find ways to apply these improvements to field crops in a practical, economical manner. But I think the primary ecological benefit in the 1990s will come from use of already known ecological principles to promote environmentally sounder agriculture.

Integration of ecology and molecular biology will not be simple nor always successful.

Regardless, we can be sure of steady progress in agronomic production. This progress will be based on incremental inputs from the "new" biology: ecology and molecular biology linked in productive union with the best elements of the "old" biology.

We will use the powers of this new biology to promote efficiency in agricultural production, but only with a full awareness of our broad responsibility to promote and protect ecological balance, human health and economic well-being. The new biology will make it easier for us to do so.

Donations Solicited for Agricultural University in Romania

The Faculty of Agronomy in Timisoara, Romania, urgently requests professionals to donate books and technical equipment to its library and labs.

The faculty kindly asks you to share texts and other educational materials in agricultural economics, as well as other fields. Donations may be addressed to the attention of: Greg Kearns, Brother's Brother Foundation, 1025 Beaver Ave., Pittsburgh, PA 15233; (412) 431-1600. Please mark your packages in bold letters FOR DONATION TO INSTITUTUL AGRONOMIC TIMISOARA, Calea Aradului 119, 1900 Timisoara, Romania.