SYMPOSIA

The following group of six articles are from the symposium "Impact of Biotechnology on the Future Training of Plant Breeders," which was sponsored by Division C-1 and Division C-7 of the Crop Science Society of America. The symposium was held 16 October 1989 in Las Vegas, NV, at the annual meeting of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. Special appreciation is given to Dr. David Knauft, former JAE Associate Editor, for overseeing the review process of the six papers.

Training Expected for Future Public Plant Breeders

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ABSTRACT

An important goal of graduate training programs is the professional preparation of students for meeting the diverse job requirements they may face in academia, industry, federal research positions, or international programs. Most future public plant breeders will be faculty members at land-grant universities where job responsibilities will include teaching, supervision of graduate students, breeding and genetic research, and, in many cases leadership of applied plant breeding programs. Field-nursery effort must be given high priority in breeding/genetic research and in applied breeding programs. Students must receive hands-on training in nursery layout and procedures, trait evaluation, choice of parents, experimental design, data analysis, project management, and the "art" of plant breeding. We have required our students to possess knowledge of computer and software utilization so they are able to communicate effectively with specialists in those fields. Now they also must possess knowledge about molecular genetics and the associated biotechnologies that may become useful tools in a plant breeder's repertoire. If cultivar development is a part of the position description, along with teaching, supervision of graduate students, and research, it is probably unrealistic to expect a major thrust in laboratory-oriented molecular technologies. Crop-oriented, multidisciplinary teams offer one option for achieving maximum progress from the integration of complementary professional interests and skills of team members while allowing realistic work-load assignments, job responsibilities, performance expectations, and recognition of achievements in the form of tenure, promotion, and salary adjustments.

AN IMPORTANT GOAL of our graduate training programs is the professional preparation of our students so they are qualified for and capable of meeting the diverse job requirements they may face in academic institutions, in industry, in federal research positions, or in international programs. This is a tall order, and we rely on (i) up-to-date curricula for generating historical perspectives and for developing a strong foundation in plant breeding and genetics, (ii) thesis research for the rigors involved in generating new knowledge, and (iii) experience within the major professor's program for expanding the student's research horizons, for the initial steps in developing the "art" of plant breeding, and for learning the mechanics of conducting an applied plant breeding program. Any evaluation of the training required for future public plant breeders must, however, be preceded by our best possible definition of job responsibilities associated with pertinent positions in public institutions.

Most future public plant breeders in the USA will be faculty members at land-grant universities. Job responsibilities will include the teaching of undergraduate and graduate courses, supervising the research and academic programs of graduate students, planning and conducting research in plant breeding and genetics, and, in many cases, supervising and participating in applied plant breeding programs. It is reasonable to expect that points of emphasis along the continuum from research to germplasm enhancement to cultivar development will vary from state to state as influenced by specific in-state needs, the role played by industry, and the thrust of USDA-ARS research programs in the state. The existence of private cultivar/hybrid development programs, e.g., for maize (*Zea mays* L.) and soybean (*Glycine max* L.), does not mean that we have license to abandon applied phases of breeding programs in public institutions. Three important reasons for maintaining the applied breeding component as an integral part of a total public program are (i) in-house verification and utilization of research dealing with genetic engineering or with breeding procedures, (ii) training of graduate students, and (iii) development of superior cultivars, inbred lines, or hybrids worthy of release. In many cases, marketable products resulting from applied public breeding programs (Step iii above) are the results of unique research using special germplasm, or they may be products evolving naturally from verification stages of research

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projects (Step i). In other cases, as for oat (*Avena sativa* L.), the agricultural community must rely solely on cultivars developed by public breeders, because in the U.S. there are no commercial oat breeding programs at this time. This focuses attention on a fourth important reason for maintaining applied breeding efforts within public institutions, i.e., the maintenance of a solid, permanent base of activity that allows public researchers not only to collaborate with and be a supportive force for industry, but also to protect the agricultural community from instabilities that can develop within industries due to changes in company ownership, in company policies, or in key personnel. It is important, however, that the need and justification for applied breeding programs be accompanied by financial support from such justifiable sources as state funds, commodity organizations and user groups, commodity check-offs, and research fees and royalties associatedwith plant variety protection.

A critical issue worthy of attention is the impact of biotechnology on the training of future public plant breeders who, as part of their job responsibilities, will be involved in applied plant breeding. Field-nursery effort must be given high priority in breeding/genetic research and in applied breeding programs, especially for key steps such as crossing, scoring for disease reaction, and selection. New biotechnologies will not diminish the need for these diversified breeding skills and efforts. The question is: Will any one faculty members have the time or, equally important, the personal interest, desire, and skills to conduct simultaneously molecularly oriented *and* conventional, whole-plant-oriented phases of a breeding program?

The integration of new biotechnology efforts, in terms of faculty positions, budget support, and facilities, within existing departmental and college programs has required all of the innovativeness that campus and college administrators and departmental faculties have been able to muster. The diversity among biotechnology programs established within and between our different institutions is actually a strength; we need not expect one particular plan for bringing the tools of molecular technology to bear on plant breeding goals, together with conventional efforts, to be superior to other plans, at least not in these formative stages of biotechnology endeavors.

The educational requirements of future public plant breeders is discussed in an accompanying symposium paper by Dr. Michael Lee, Iowa State University. Therefore, I wish to focus attention on the hands-on training we need to provide our graduate students to properly prepare them for the plant breeding responsibilities that will comprise a part of their total job assignment.

Nursery Layout and Mechanics. Plot size, within-field location of performance trials, and alley dimensions are influenced by soil type, land availability, and characteristics of planting, weed control, and harvesting equipment available to the project. The best training we can give our students in these areas is to explain our own modes of operation as they share in our nursery activities, as well as to acquaint them with equally satisfactory but diverse methods employed by our colleagues at neighboring institutions. Interstate field days and program visits provide extremely valuable training experiences for our graduate students.

Trait Evaluation. Although the details of trait evaluation will vary from crop to crop, nearly all plant breeders must evaluate their breeding materials for agronomic performance, for response to insects and diseases, for product yield, and for product quality. Our students need to know the techniques of creating disease epiphytotics and artificial infestations of insect pests, because many former breeding program collaborators in plant pathology and entomology departments upon retirement are being replaced by basic scientists with less interest in field-oriented, applied breeding programs. While proper experimental design, data accumulation, and data analysis are expected and practiced, constant monitoring of plots throughout the growing season is required to assure the validity of the data.

Choice of Parents. Designation of lines and populations for use as parental stock is the keystone operation for any breeding program. Knowledge of morphological, physiological, and biochemical characteristics as well as overall agronomic performance is essential if designation of parents is to have a strong genetic basis and the size of the program is to be kept within the bounds of available funding. Multiple-trait indices, now often in the form of computer prediction of progeny performance, are tools our students need to understand. These indices or models usually have a regression base, and this emphasizes the need for solid understanding of regression concepts.

Experimental Design and Data Analysis. It is important that our students understand the fundamentals of biometry and experimental design if they are to conduct successful field-oriented breeding research and cultivar development programs. Although our computer programs provide experimental error as a source of variation in an analysis of variance or provide adjusted treatment means based on a lattice design, it is essential that students can explain what experimental error really is and what the biological and statistical bases are for making adjustments to line or selection means based on an experimental design.

Computer-assisted design and data analysis phases may be conducted within individual projects or they may be performed by departmental, college, or campus service units. Thorough knowledge of basic biometrical and design concepts is essential, regardless of the methods of operation available and employed. Again, project participation is a necessary adjunct to academic course work.

Project Management. It is important that our students gain some idea of the factors that influence or control program size. These factors include sources of financial support, land and equipment availability, and critical program windows such as the limited time during which breeding materials must be evaluated for response to a disease or the limited time between maturity and plant (usually stem) degeneration during which genotypes must be scrutinized for plant and seed characteristics and then designated for selection. Learning how to organize project personnel to accomplish critical operations in an efficient and timely manner can only come from participation in the process.

The Art of Plant Breeding. Two of the most difficult plant breeding/genetic concepts to master as an art are (i) to understand the nature of genetic and environmental variation observed in field nurseries, and (ii) how to efficiently generate and select superior combinations of genes worthy of release as a new cultivar or line. Persons not working in applied plant breeding, and who frequently are concerned with only one or a few genes or traits, often do not appreciate or understand the difficulties involved or skills required. The "art" of plant breeding is a skill acquired over time as the breeder gains both a detailed knowledge of the species with which he/she works and the experience and skills that allow trait evaluations and selection decisions to be highly repeatable and unbiased. It is important to realize, however, that the diversity of breeding methodologies and the differences in phenotypic ideotypes preferred by individual breeders, all being subject to use and expression in different environments, constitute a national strength and serve to enhance genetic diversity.

The Tools of Biotechnology. In addition to the broad array of skills mentioned in preceding paragraphs, we now ask that our plant breeders possess varying degrees of knowledge about molecular genetics and associated biotechnologies. Most institutions have revised their curricula by integrating molecular concepts into existing courses and by developing completely new courses dealing only with molecular concepts and methodologies. Consequently, most recent Ph.D. graduates in plant breeding have at least some knowledge of the concepts of molecular genetics. Many universities and private companies, however, are seeking candidates with more than a cursory knowledge of molecular genetics. In fact, many departments are seeking individuals whom they expect to simultaneously conduct state-of-the-art cultivar development and molecular-genetic programs. A graduate student's predicament may be compounded when he or she seeks a postdoctoral position to gain skills and knowlege in molecular biology. Announcements of postdoctoral positions in genetics/molecular genetics often state that candidates should have a Ph.D. with a background in genetics and *molecular biology.* Thus, many students are required to have the knowledge and training they are actually seeking, an unfortunate situation.

In any event, the need for knowledge of genetic mechanisms at the molecular level must of necessity require either a longer graduate-training period or a decrease in time devoted to other subjects. The desired balance depends on future job requirements, realistic performance expectations as set forth by departmental faculties and college administrators, and especially the professional skills and professional goals of the individual investigator. Some molecularly oriented students and faculty members may not have any desire to be involved in field programs, and they should not be criticized for that, providing their job descriptions and performance expectations do not call for field-oriented activities. In like manner, a field-oriented researcher may not have the time, inclination, or training to also conduct laboratory research. Individuals operating in both arenas at the same time are faced with the professional responsibility of conducting meaningful programs and research in both arenas. This may be difficult but not necessarily impossible so long as the job description, professional interests and skills, and performance expectations are all in accord. Our search-and-screen exercises need to be centered around job descriptions and job requirements in which the investigator will not be faced with conflicts of time, the need for concurrent laboratory vs. field operations, or with expectations not aligned with professional skills or interests. If cultivar development is a part of the position description—along with teaching, supervision of graduate students, and a research component—it is probably unrealistic to expect a major thrust in laboratory-oriented molecular technologies.

For many years now, college administrators nationwide have sought the advice and counsel of departmental review teams regarding the integration of biotechnology research, budgets, and facilities into exiting departmental and college programs. At this particular stage of molecular capability, one particularly attractive and reasonable option has been the formation of crop-oriented teams that might include a field-oriented, whole-plant breeder geneticist, a plant physiologist, a molecular geneticist, and an extension-production specialist. This type of interdisciplinary approach takes maximum advantage of the complementary professional interests and skills of team members. At the same time, the approach allows for realistic work-load assignments, job responsibilities, performance expectations, and recognition of achievements in the form of tenure, promotion, and salary adjustments. Just as many plant breeders are able to communicate effectively with computer programmers and operators, wherein both parties are operating at state-of-the-art levels in their respective disciplines, we can expect this type of shared breeding/biotechnology expertise to result in maximum amounts of new knowledge and germplasm improvement in integrated crop improvement programs.

Training Expected for Future Private Breeders

John C. Thorne*

ABSTRACT

Sixteen major U.S. companies with plant breeding programs were surveyed regarding their current activity in biotechnology and their needs for training for future plant breeders. Thirteen of the companies have in-house biotechnology programs. All 16 have arrangements with outside companies for contract research. Fifteen expect their biotechnology program to increase in the next 5 yr. None of the sixteen companies surveyed expected a decrease in the number of traditional plant breeders in the next 5 yr. Only one expected a decrease in biotechnology staff. Twelve companies indicated expected increases in their plant breeding staffs; a similar number expected to increase numbers of scientists trained in biotechnology. When asked about training expected in prospective breeders, 13 companies said they would consider candidates' ability in traditional plant breeding first, but would give some consideration to skills in biotechnology. Two said they would give the two areas equal emphasis; one said they would not consider skills in biotechnology when hiring plant breeders. Although considerable variance of opinions regarding priorities existed, generally the highest-ranked areas of expertise for new plant breeders were traditional breeding, statistics/experimental design, and plant pathology.

PLANT BREEDING has always been an eclectic science. In fact, 30 or 40 yr ago, plant breeders deliberated whether they were practicing science or art (Smith, 1966; Johnson, 1981). Students trained for advanced degrees in plant breeding traditionally have taken courses in classical, population, and cellular genetics; agronomy and crop production; statistics and experimental design, including in recent years, computer science; cytology; plant physiology; plant morphology; plant pathology; entomology; and perhaps others, depending on individual interests. In addition, most new plant breeders quickly discover that at least a rudimentary knowledge and understanding of finance management and human resources are necessary to effectively conduct a program (Troyer and Laub, 1981). Thus, there has always been considerable pressure on graduate schools to provide the broad educational background required by plant breeding students (Rasmusson, 1981).

In recent years the sciences generally categorized as *biotechnology* have advanced sufficiently that they are now an integral part of the science of plant breeding. Indeed, the possibility of creating a gene in a biochemistry lab and inserting it stably into the plant genome has evolved rapidly from concept to practical reality. Techniques involving molecular markers may drastically alter backcrossing procedures. Embryo rescue may allow wide crosses and new gene pools for selection. In fact, some might argue that as biotechnology evolves, traditional plant breeding will become obsolete. In any case, plant breeding students must now be knowledgable in new areas of science. Because commercial companies are heavily involved in plant breeding, an assessment of their needs for future training of plant breeders is appropriate.

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SURVEY OF COMMERCIAL PLANT BREEDING COMPANIES

To determine their expected needs for plant breeders and scientists trained in biotechnology, I surveyed 16 major U. S. companies with plant breeding programs (Table 1). Individual responses were not identified to maintain confidentiality.

The first three questions on the survey dealt with company involvement in biotechnology. In response to Question 1 (Table 1), 13 of 16 companies indicated they had an in-house biotechnology program. Ten indicated work with molecular markers and tissue culture, eight with recombinant DNA, four with interspecific crosses, and three with mutagenesis. One respondent commented that they were working with hybridization technology. One company indicated they had an in-house program, but didn't specify which areas.

The second question asked about arrangements for biotechnology research with outside companies. All 16 respondents have such arrangements.

In answer to the third question, 15 of 16 respondents said that their research efforts in biotechnology would increase in the next 5 yr, although one of these indicated they did not anticipate increasing their in-house program.

The results of the first section of the survey can be summarized very simply: the major U. S. plant breeding companies are heavily involved in biotechnology now and expect to become increasingly so in the next 5 yr.

The second part of the survey dealt with the company's needs for future plant breeders. In response to the fourth question, four companies indicated that the number of traditional breeders employed by their company would increase by more than 25%, three expected the number to increase by 10 to 25%, five by less than 10%, and four expected numbers to remain stable. No company indicated that the number of traditional plant breeders would decrease. Several respondents commented that biotechnology would not

Table 1. Results of a survey for future needs in plant breeding/biotechnology by 16 commercial companies.

Company involvement	Response: Yes	Response: No
1. Do you have an in house biotech program?	13	3
Which areas?		
a. Molecular markers	10	
b. Tissue culture	10	
c. Recombinant DNA	8	
d. Interspecific crosses	4	
e. Mutagenesis	3	
2. Do you have arrangements with outside companies for biotech work?	16	0
3. Do you anticipate that your efforts in biotech will increase in the next 5 years?	15†	1
Future plant breeders—needs		
4. Do you expect the number of traditional plant breeders employed by your company in the next 5 years to:	No. of responses	
a. Increase by more than 25%	4	
b. Increase by 10 to 25%	3	
c. Increase by less than 10%	5	
d. Remain stable	4	
e. Decrease by less than 10%	0	
f. Decrease by 10 to 25%	0	
g. Decrease by more than 25%	0	
5. Do you expect the number of scientists trained in biotechnology employed by your company in the next 5 years to:	No. of responses	
a. Increase by more than 25%	5‡	
b. Increase by 10 to 25%	4	
c. Increase by less than 10%	3	
d. Remain stable	3	
e. Decrease by less than 10%	0	
f. Decrease by 10 to 25%	0	
g. Decrease by more than 25%	1	
6. Which of the following best describes your company's philosophy for hiring new plant breeders?	No. of responses	
a. Will consider candidate's ability in traditional plant breeding with little or no emphasis on his/her ability in biotech.	1	
b. Will consider candidate's ability in traditional plant breeding first, but will give some consideration to skills in biotech.	13	
c. Will give equal emphasis to abilities in traditional plant breeding and biotech.	2	
d. Will place more emphasis on skills in biotechnology than on traditional plant breeding.	0	
e. Will not consider candidates who do not have at least some background in biotech.	0	
f. Will not hire traditional plant breeders. Will hire only scientists trained in biotechnology.	0	
7. Assuming that your company will continue to hire traditional plant breeders, rank the following in importance in consideration of candidates.	Total points§	
a. Traditional plant breeding	154	
b. Statistics/experimental design	121	
c. Quantitative/population genetics	76	
d. Plant pathology	113	
e. Entomology/nematology	77	
f. Plant physiology	59	
g. Biochemistry	40	
h. Molecular genetics	74	
i. Agronomy/crop production	97	
j. Economics/business	35	
8. Your comments: Please add any comments you deem appropriate.		

† One respondent indicated no in-house increase.
‡ One company expects to hire their first scientist in biotechnology.
§ Total score based on priority rank 1 = 10 points, 2 = 9 points, etc.

replace traditional plant breeding. In fact, one respondent expressed concern about a lack of traditional breeders being trained at universities.

Question 5 asked about the number of scientists trained in biotechnology to be employed in the next 5 yr. Three companies indicated a 25% or more increase in their biotechnology staff. Three expected to increase from 10 to 25%, three by less than 10%, and three expected numbers to be stable. One respondent indicated that their biotechnology staff would decrease by more than 25%. This respondent indicated an increase (less than 10%) in traditional breeders. One company said they expected to hire their first biotechnology scientist sometime in the next 5 yr.

The sixth question dealt with the relative importance of traditional plant breeding vs. biotechnology when considering prospective employees. Thirteen of 16 of the companies said they would consider a candidate's ability in traditional breeding first, but would give some consideration to skills in biotechnology. One indicated that they would give little or no emphasis to skills in biotechnology. This company has no current in-house biotech program and no intention of beginning one. They anticipate increasing their plant breeding staff by 10 to 25%. Two companies indicated equal emphasis on traditional plant breeding and biotechnology. Both of these expected their numbers of breeders to be stable and their biotechnology staff to increase from 10 to 25%.

The final question asked the respondents to rank the importance of training in 10 disciplines for prospective plant breeding employees (Tables 1 and 2). Although the responses varied considerably, there was nearly complete agreement (15 of 16) that the most important area was traditional plant breeding. The other respondent indicated that plant pathology, entomology, and plant physiology ranked equally as top priorities.

I calculated an overall importance rating for each of the 10 areas by assigning a score of 10 for first priority, 9 for a second priority, etc. On this basis, the three highest rated were traditional breeding, statistics/experimental design, and plant pathology (Table 1). Molecular genetics scored similarly with quantitative/population genetics and entomology, ahead of economics/business, biochemistry, and plant physiology, but behind agronomy/plant production.

SUMMARY AND CONCLUSIONS

Two broad conclusions can be made from the survey. First, the major U. S. seed companies with plant breeding programs are already involved in biotechnology research. All 16 respondents at least have outside contract arrangements for such research; 13 have in-house programs. Further, the amount of biotechnology research will increase in the next 5 yr. Twelve of the 16 respondents said their biotechnology staff would increase during this time; only one said its staff would decrease.

The second conclusion, perhaps the more pertinent to this article, is that the need for traditional plant

Table 2. Responses of 16 companies asked to rank 10 areas of training for prospective plant breeders.

Area	Rank															
Traditional plant breeding	1	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1
Statistics/experimental design	4	2	2	3	2	2	6	5	2	2	4	3	2	2	2	2
Quantitative/population genetics	5	5	–	6	8	6	7	2	5	9	4	2	5	6	6	7
Plant pathology	6	4	3	2	3	4	4	3	3	6	1	5	6	3	5	3
Entomology/nematology	9	4	–	5	7	5	3	4	6	7	1	5	9	9	7	6
Plant physiology	8	6	–	10	5	6	8	7	7	8	1	7	7	8	4	9
Biochemistry	10	8	–	8	9	6	9	10	8	3	4	7	8	10	8	10
Molecular genetics	7	9	4	7	6	6	5	9	9	4	4	7	4	7	3	4
Agronomy/crop production	2	3	–	4	4	3	2	6	4	5	9	4	3	4	9	5
Economics/business	3	7	–	9	10	7	10	8	10	10	9	10	10	5	10	8

breeders will increase, not decrease over the next 5 yr. Twelve of 16 companies expected to increase their plant breeding staff, the same number that expected to increase their biotechnology staff. All of these companies want their future breeders well trained in traditional breeding, particularly in the areas of statistics, plant pathology, and agronomy. Troyer and Laub (1981) emphasized a need for management skills in plant breeders. Now, most want their new breeders knowledgeable in biotechnology as well. Because all 16 companies surveyed said they have outside contract biotechnology research, communication between breeders and biotechnology scientists is, and will continue to be critical. Graduate schools must find a way to add biotechnology training to the already full plant breeding curriculum. Students from universities who succeed in this challenge should not have problems finding jobs.

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The Challenges of Attracting Graduate Students to Plant Breeding

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ABSTRACT

The challenges of attracting graduate students to plant breeding are to induce more high school students to major in undergraduate plant science programs and to attract these undergraduates to graduate programs in plant breeding. The first challenge will require the formation of an assertive, symbiotic relationship between high school counselors, agricultural recruitment programs, and broad-based science education programs to overcome some of the student misperceptions of science careers. The second challenge will require the successful communication of the opportunities for plant breeding careers to undergraduate plant science majors. The effective involvement of undergraduate teachers with plant breeders, the use of internships and work programs, the formation of interdisciplinary teams, and the use of speakers' bureaus to facilitate this broader communication are suggested to enhance student recruitment efforts.

When Duty whispers low, Thou must,
The youth replies, I can.
(R.W. Emerson, *Voluntaries III*)

IT IS WITH GREAT HUMILITY that I approach this topic because there are certain aspects of one's life that illustrate the limitations of words. Regardless of how carefully crafted the statement becomes, the words remain a worldly tie that bind the essence to more mundane thought, not significantly majestic to describe one's feelings. I, as do most plant breeders, love my chosen field. It is only with some trepidation that one accepts the responsibility of communicating to others a strategy to attract students and the reasons why they, too, might wish to choose a plant breeding career.

To begin, it is necessary to define *plant breeder.* Johnson (1981) defined a plant breeder as "a scientist who utilizes an organized system of genetic manipulation to modify a plant species to make it more useful or acceptable for a specific end use." As Johnson (1981) noted, plant breeders are geneticists because genetics is one of the foundations of plant breeding. Not all geneticists, however, are plant breeders "because the objectives of their research are not breeding objectives." Plant breeding is both a science (defined in the *American Heritage Dictionary* as "the observation, identification, description, experimental investigation, and theoretical explanation of natural

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phenomena") and a technology (defined in the *American Heritage Dictionary* as "the application of science to industrial or commercial objectives"). Hence, the above definition of a plant breeder is a somewhat limiting definition.

It is presumed that it is desirable to attract graduate students to plant breeding and that those students will find rewarding career opportunities upon completion of their degrees. There is no presumption implied on the number of students that should be attracted as no predictions were found by the author on the number of plant breeders being trained relative to number of plant breeders needed in the future. In the popular press, there are articles alluding to the possibility that there will not be enough plant breeders in the 1990s (e.g., Whitmore, 1987); however, with the cyclical retrenchment of many commercial plant breeding programs and the redirection away from plant breeding of some university programs, there appears to be no clear trend. The need for more plant breeders when the World War II veterans retire has almost become a fable. These individuals are already retiring and the number of new plant breeders is at least adequate, if not in excess to meet the need. However, there will always be a need for highly qualified, new plant breeders to maintain and enhance the field, hence the challenge of attracting graduate students to plant breeding. It would be very useful to have predictions of how many plant breeders will be needed in the future so that appropriate action plans can be developed and used to attract both students and the financial support necessary for their training.

THE CHALLENGE: SUCCESSFUL COMMUNICATION

Fundamentally, the challenge of attracting graduate students to plant breeding is to share with them the opportunities and needs that plant breeders perceive in hope that they will share this vision and enter the discipline. It can be described as a process of successful communication. In this article, the challenge of attracting graduate students to plant breeding will be divided into: (i) the challenge of attracting more students to undergraduate science programs emphasizing plant biology and (ii) the challenge of attracting the best undergraduate students to plant breeding. In this context, the role of and challenge to the plant breeding discipline and the scientists therein, to universities, and to prospective students will be discussed.

It should be recognized that a student's decision to become a plant breeder is an evolving one and that plant breeding is predominantly a graduate school program. The author has met only two plant breeders who decided before high school that they wanted to pursue this career goal. The undergraduate students who apply to plant breeding graduate programs are usually from agronomy or related plant science programs. Far fewer applications come from more general programs such as biology, and even less from nonbiological science programs. When undergraduate enrollment in science (Green, 1989) and particularly agricultural science declines, the available pool for graduate students similarly declines. Hence, the first challenge in attracting graduate students to plant breeding is to ensure there is a sufficient pool of undergraduate students with appropriate backgrounds that can later decide to become plant breeders. This is primarily a challenge to the discipline, the student, and his/her counselors because the process begins long before the student may be aware of the science of plant breeding. Once students have made the decision to become a scientist, the challenge will be to attract those young scientists to plant breeding. This latter challenge is one for the discipline, the university, the scientist, and the student.

THE HIGH SCHOOL AND UNDERGRADUATE CHALLENGE: AROUSING AN INTEREST IN SCIENCE

It appears that a larger pool of qualified undergraduates is needed in the biological sciences, including agriculture, so that more and better students will potentially be available for graduate programs in plant breeding. The next consideration is: What should our role in agriculture be to help attract students to science, with particular emphasis on plant sciences? First, agricultural scientists must be aware of and support programs such as "Operation Change: Developing Human Capital to Secure American Agriculture." Operation Change is sponsored by the Office of Higher Education Programs, USDA, and by the Resident Instruction Committee on Organization and Policy of the National Association of State Universities and Land-Grant Colleges, and the American Association of State Colleges of Agriculture and Renewable Resources (Hartung, 1988). Operation Change provides for "a strategic planning and coordinating council for higher education in food, agriculture, and natural resources; a human capital need forecasting system; national and state initiatives to attract the best and brightest students from our pluralistic society; national and state faculty development programs dealing with enormous changes; and initiatives for innovation and revitalization of the curriculum in agricultural higher education." Second, agricultural scientists must form an assertive, symbiotic relationship with all scientific disciplines to attract more students to science. Because plant breeding is predominantly a graduate school program, many plant breeders who do not have undergraduate teaching responsibilities will need to form stronger ties with the undergraduate teaching faculty in their and related plant science departments. To develop a coordinated effort is an awesome task. It is extremely fortunate, however, that the needs of the nation and of the scientific community as a whole are similar to the needs of plant breeders. For example, the 1989 Annual Meeting of Sigma Xi, The Scientific Research Society, highlighted "Science as a Way of Knowing: The Undergraduate Experience" as the key topic of its meeting. Even some of the presentation titles used agricultural metaphors (e.g., "Cultivation, not Weeding: Nurturing the New Generation"). The need for better scientific training and more scientists is part of the national agenda (Brown, 1989; Atkinson, 1990).

As part of this national discussion, the American Association for the Advancement of Science (AAAS) has developed Project 2061, a project whose intended purpose is to achieve national scientific literacy (Rutherford, 1989). The main thrust of the project is to enhance science education that will lead to a more scientifically literate public and should encourage more students to consider science careers. The AAAS, representing all branches of science, is the appropriate organization to take leadership in fostering this agenda. Agricultural scientists as members of AAAS, Sigma Xi, and/or our professional societies, however, and agricultural universities should actively work for this common goal and ensure that the needs of agricultural science are included as part of the overall agenda for science. Agricultural scientists and universities also need to work more with the general public and educate them about our profession (Munn, 1989) and its impact. If agricultural scientists do not interact with these initiatives, they are not sowing the seeds for that future harvest that agricultural science and agricultural technology needs. Agricultural scientists will also be ignoring their rights of citizenship within the scientific community.

This joint scientific effort should begin with students as soon as they begin individual educational programs. A report to the Farm Foundation prepared by the American College Testing Program, Survey Services Department, Research Division (1989), concluded that most students from the "nonagriculture group had limited awareness of agricultural colleges, agricultural majors and agricultural careers." In addition, the nonagriculture group of students received most of their information on agriculture from the media (particularly television), and all high school students (including those intending to major in agriculture while in college) had misperceptions about agricultural careers and majors. Importantly, most high school students in the survey developed their interest in specific careers and career programs before their senior year. Hence, to attract more students to the biological sciences, efforts must be targeted to sophomore and junior high school students, and accurate information must be provided to counter misperceptions. The information must also be given to high school teachers and counselors who are guiding students in their career decisions.

Agricultural scientists need to continue taking advantage of existing programs to promote science for high school students. Both the Agricultural Research Service and the Cooperative State Research Service (CSRS) have programs that provide funding to hire high school juniors and seniors from minority groups to do summer internships in cultural science. The CSRS program will provide the salary for the individual and can provide some funds for supplies. Interestingly, these programs may not be fully utilized. Personal experience at the University of Nebraska over the past 3 yr suggests that only two scientists at my institution have applied for the internships.

The joint efforts to attract students to science begin with high school students, and should continue through undergraduate education. Many undergraduates begin as undeclared majors and/or change their majors during their undergraduate education.

Even if the efforts to attract more students into science succeed but fail to attract more students into plant breeding, plant breeders should not consider their efforts a failure. Agricultural progress requires a more scientifically literate society. If one considers some of the contemporary issues facing the implementation of agricultural technology (genetically engineered plants for food production, genetically engineered microbial releases, global warming, nitrate and pesticide contamination of groundwater, etc.) and the larger role society will have in their implementation (Farrell, 1989), it should be clear that a scientifically literate public is the best assurance of continued agricultural science and technology progress.

THE GRADUATE SCHOOL CHALLENGE: EXPANDING HORIZONS

Assuming there is a large pool of undergraduate students interested in continuing education into postgraduate training, the question becomes how to attract young scientists to plant breeding. First, it is useful to review how plant breeders have recruited students in the past and what has been the results of this recruiting effort. After talking to a number of colleagues, the current recruitment tools believed to be effective include: (i) well-supported assistantships, (ii) personal contacts with undergraduate workers on plant breeding programs and with former graduate students and colleagues who can recommend or identify students for plant breeding, (iii) having a graduate program or a specific plant breeding program recognized for its excellence, and (iv) distributing informational brochures on the plant breeding or departmental curricula and faculty. The annual meetings of the American Society of Agronomy is considered a key meeting for identifying potential students. The better programs also work very hard to ensure the graduate student application is processed quickly and courteously. Correspondence is rapidly answered and the nature of possible research projects and funding is explained.

The results of these recruitment methods can be viewed in relation to membership demographics of the Crop Science Society of America members (includes international members) who list C-1 and/or C-7 as their first or second choice for divisional membership (Table 1). Clearly, the divisions are not attracting members from the diversity of backgrounds that exist within the USA or internationally. There may be extremely important cultural and societal reasons why the membership does not mirror the national or international census data or even that of undergraduates

Table 1. Gender and race in percentage of Crop Science Society of America (CSSA) members and of those listing Division C-1 and C-7 as their first or second choice for divisional preference (C. Tindall, 1989, personal communication).

Race and gender	Div. C-1	Div. C-7	CSSA members
		%	
Gender			
Male	90	80	90
Female	8	15	8
Nonresponding	2	5	2
Race			
Caucasian	79	75	80
Black	2	1	3
Oriental	5	5	4
Hispanic	1	1	1
Nonresponding and other	13	18	12

in science programs (Green, 1989). Many current recruitment practices, however, favor attracting students with similar backgrounds to the majority of members by their use of either personal contacts or by only a limited number of students knowing the reputations of the plant breeding programs. There is need to ensure plant breeding is open to everyone who is interested in becoming a plant breeder. Outreach programs should not favor those groups similar to ourselves or who have been our past main source of graduate students. Plant breeders must recruit from the whole pool of possible applicants, not just part of the pool. Students should be evaluated for assistantships "by the content of their character" (Martin Luther King), not by their background, gender, or race. Similarly, potential students should judge plant breeding as a career opportunity by the content of its "character" and not rely on misconceptions.

As can be seen by the gender demographics, C-7 (biotechnology) has atttracted a larger proportion of women than C-1. Women remain an underrepresented group in both divisions, but are increasing in numbers in agriculture (Collins and Pesek, 1983). The greater proportion of women in C-7 is a very hopeful sign because membership in C-7 is very new and may reflect a smaller but more recent sample of our future membership. The greater proportion of women in C-7 may also reflect that biotechnology is better able to attract scientists from biology programs that appear to be more pluralistic than agricultural science. Interdisciplinary teams formed early between biology departments and biotechnologists.

As the interdisciplinary teams continue to expand and include more plant breeders, the communication between the various biological sciences will increase, which should increase the access of plant breeders to currently underrepresented groups. Interdisciplinary teams with their breadth of endeavors have and will continue to provide one of our best opportunities to attract graduate students. There is, however, both a positive and negative aspect to recruiting as part of an interdisciplinary team. On the positive side is the ability to have a larger and often highly competitive pool of graduate students from which to select and the ability to more broadly educate graduate students in the program. The future plant breeder will need to adapt emerging technologies to his/her program and will need to communicate program needs to those scientists developing new technologies. As mentioned earlier, plant breeding is both a science and a technology. Interdisciplinary teams can emphasize both aspects so that the students can have more choices for his/her research training. My predecessor, Dr. J. W. Schmidt who released more than 30 cultivars of wheat, barley, oat, and triticale, commented that it was no longer enough to train plant breeders who were only able to do one thing. He recommended that every graduate student be more broadly trained in part so they could better adapt to changing priorities.

The negative side is more subtle, but relates to the questions: What really constitutes a plant breeder? How should plant breeders be educated to be both the scientist and the technologist? Geographically, where is plant breeding research physically done?

Many students in interdisciplinary teams gravitate to the more basic areas of research with the perception that basic science is more exciting, competitive, and where future opportunities will be. Perhaps it is the author's bias, but it appears that, in many interdisciplinary teams in the public sector, the plant breeding aspects have decreased and many former plant breeders are becoming less applied researchers. This may be due in part to the success of commercial plant breeding; however, it may also reflect misconceptions by their administrators and their funding sources. A concern is that although interdisciplinary teams may be better able to attract graduate students, unless the team has sufficient size and scope, they may be less ale to properly educate graduate students to become plant breeders, especially to effectively compete in the technological aspects of plant breeding. For example, some universities have tried to meet competing needs by having one scientist be a specialist in many different areas (often requiring extensive laboratory and field research). In doing so they risk hiring someone who is a "jack of all trades, but a master of none." Sometimes, the position announcement almost implies the qualified applicant is an interdisciplinary team. Similarly, many universities have heavily invested in providing state-of-the-art laboratory equipment, but have not invested in state-of-the-art field equipment. Some plant breeding projects use antiquated and unrepresentative equipment. This does a disservice to attracting graduate students in that it makes plant breeding appear unworthy of priority funding. It also does a disservice to those students who, upon completion of their degrees, will work in the private sector where equipment is often more modern.

Trends in science and its funding sources are not new; however, they do have significant impact. Harlan (1957) commented on the impact of plant genetics on plant breeding. He said,

> The field of plant breeding actually suffered in a way from the greater knowledge we had acquired. Mendel's work was quickly accepted as an enormous advantage in plant science. It was a definite, tangible thing that seemed to take plant breeding from the arts and place it as a science overnight. It captured the imagination of all workers, and genetics at once became a field offering a prestige that both soothed and satisfied. A genetic paper gave new dignity to the author. We boys began to get our hair cut and our shoes shined. Everyone rushed in to the field of genetics, including many of us who never should have gone. The effect on plant breeding was calamitous. Good varieties were still produced, but explorations in the field of practical plant breeding were wholly neglected. A few of us eventually realized that there would come a day when the world would recognize the difference between a good geneticist and a poor one, so we went back to thinking about plant breeding. We have undoubtedly lost the resources of many good minds from this field for a time, but they will be back.

One of the challenges in attracting graduate students to plant breeding is to have outstanding plant breeding programs worthy of graduate student participation. Hence, the formation of interdisciplinary plant improvement teams requires adequate funding and personnel to utilize effectively the team members' strengths instead of highlighting their weaknesses.

Another potential drawback of trying to attract students with more diverse backgrounds to plant breeding is, will the students be willing to work at traditional plant breeding locations after completing their degrees? Will a student from a nonfarm background and who was educated in a university town find happiness in agricultural research centers located in rural areas? If the individual is satisfied, will their spouse, who may also be career-oriented, be happy in these locations? This concern should never affect our trying to attract students to plant breeding. It probably should, however, be recognized as a potential impediment and a challenge to the discipline and plant breeding institutions to attracting students with more diverse backgrounds.

MEETING THE CHALLENGE

Considering the above discussion, what are some of the specific actions that should be considered to meet the challenge of attracting graduate students to plant breeding? First, those programs that have worked in identifying graduate students must be continued, even with their perceived limitations. Second, plant breeders should not be satisfied solely by a continuation of such programs, but should endeavor to interact within their discipline, professional societies, and institutions; and to work with AAAS and other groups to promote science education and careers. This recommendation recognizes that occasionally some members of the above groups have criticized the scientific and technological credibility of agricultural science. Those questions must be answered and will promote agricultural science and technology. If program reputation is one of the best methods of attracting students, it behooves plant breeders to increase the reputation of their research capabilities—not only within the agricultural research community, but within the scientific community as a whole. Fortunately, this should be an easy task in that plant breeding is among the most measurable sciences and has great impact. There are also several plant breeders and geneticists who are members of the National Academy of Science and/or have received other highly distinguished awards.

Plant breeders must assertively enunciate to high school and undergraduate students the potential of becoming a scientist and a plant breeder. There are many mechanisms that could enhance communication with this target group. A speakers' bureau could be formed within the discipline and universities to make presentations to target groups of high school and undergraduate students with a science interest. Talks to general groups of students may not be effecftive (Beyrouty and Bacon, 1986) and could be left to the more generalist approaches of attracting students to science. The speakers' bureau should include graduate and undergraduate students (they are often closer to the target group and come from more diverse backgrounds than established professionals), as well as scientists from the public and private sector. In addition, the "speakers' bureau" should contain high-quality films and other video communications to increase the accessibility of the bureau, lessen the time commitments of the individual scientists, and highlight excellent speakers. Plant breeding programs often require many student laborers. With little additional effort, the research program could be described to these students so that they might become a shareholder of the program. Similarly, internships will allow students to learn about careers before they have to commit to the career development path. Plant breeding examples and guest lectures could be given in undergraduate courses, such as beginning genetics, which are often taught in biology departments and are required for many degree programs in the biological and agricultural sciences. Sigma Xi has the William Proctor Prize for Scientific Achievement and its recipient presents a lecture at its annual meeting. The prize is given to a "scientist who has made outstanding contributions to scientific research and has demonstrated the ability to communicate this research to scientists in other disciplines." Perhaps a similar prize for plant breeding with the lecture being given at the national meeting of the Crop Science Society of America and at universities and colleges (perhaps as a video recording or film) with strong biology programs whose graduates continue in postgraduate education would be a useful mechanism of attracting students.

In addition, we need to maintain the financial and facility resources of our plant breeding programs so the student can do competitive science and worthy graduate students will have support for their research. Excellent funding programs (such as the Pioneer Fellowships) for plant breeding that highlight plant breeding education are highly visible and flexible methods of attracting graduate students. Program resources should allow graduate students to pursue their research and not become additional technicians on the project unless that is how they are supported. The quality of the graduate student experience is important if one remembers former graduate students are future ambassadors for the department and program. They should be treated with respect and diplomacy.

As was mentioned earlier, the challenge of attracting graduate students to plant breeding is to share with them the opportunities and needs that plant breeders perceive in their field through a process of successful communication. Plant breeders must be enthusiastic with their science and dedicated with their technology. In their science,

> The heart should have fed upon the truth,
> as insects on a leaf,
> till it be tinged with the color,
> and show its food in every . . . minutest fiber.
> (S. T. Coleridge)

Plant breeders are explorers whose creed could be:

> We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time.
> (T.S. Eliot)

Their technologies create the "amber waves of grain" and the green revolution that make people strong and nations great. Their science and technology make a difference.

The goal will be to motivate students to change, to become plant breeders. In doing so, plant breeders must be very careful in this process of communicating so they effectively communicate to the students' goals and aspirations, not simply reiterate their own. Today's student having lived through the inflation of the late 1970s and the recession of the early 1980s may have different aspirations for financial rewards and security than those of the past (Green, 1989). As plant breeders, it is not ourselves we are attempting to change, nor is it our minds we are trying to open to new careers.

The greatest challenges to the student in efforts to attract them to plant breeding are: (i) they must be able to listen to the diverse opportunities they will need to decide among, (ii) they will be fair in their evaluation of these opportunities, and (iii) they understand their personal goals and what it will take to achieve them.

Communication is never simple. As a start, however, plant breeders could change the perception of graduate education or training and consider it an intensive career development program. This change in perception may imply a higher intrinsic worth of students, potentially allow students greater flexibility in their programs, and include a broader exposure to the various activities of the breeding program. Another change would be for each plant breeder to write down what attracted him/her to the discipline, then see if those reasons can be communicated to someone else.

Finally, my predecessor, Dr. Schmidt, commented that there will be three parts to the process of cultivar development that plant breeders will like. The first is making the cross because it requires all their creative and predictive talents as to what may come of that cross. The second is when they walk through their breeding nursery and see a line they *know* will be released. The third is when that line is grown on 3 200 000 ha (8 000 000 acres)—and they remember when they held all the seed of it in the palm of their hand. If plant breeders can continue to communicate the positive impact of their science and technology, of what they hold in the palm of their hand, there should never be any trouble in attracting students to plant breeding.

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Integrating Biotechnology into a Graduate Program in Plant Breeding—A Graduate Student's Perspective

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ABSTRACT

All plant breeding students should become conversant in some aspects of biotechnology. Some students should become proficient in biotechnology, by developing skills that will allow them to incorporate biotechnology into mainstream breeding programs. Some students should become specialized in biotechnology, but should be careful to consider potential problems in competing for jobs, designing a satisfying graduate program, and meeting expectations of plant breeding faculty. Incorporating biotechnology into plant breeding programs is appropriate for preparing students for jobs, giving them a sense of pride and excitement about breeding, providing an opportunity to experience new areas, and preparing them to be successful plant breeders. I urge plant breeding faculty to remember to convey their excitement about plant breeding, to help students contribute as scientists as early as possible, to be flexible in allowing students opportunities to try new things, to be open to students with different backgrounds, to avoid pigeonholing students, and to continue to foster a sense of team effort on breeding projects. As a graduate student in plant breeding who is attempting to develop some proficiency in biotechnology, I have found these aspects especially valuable: daily associations with students and faculty with a broad range of interests, an early background in basic science courses, and the opportunity to switch emphasis after my M.S. program. I encourage graduate students to avoid setting their goals too narrowly, to be open-minded toward students with different backgrounds and toward new ideas, to take advantage of the full range of experiences available, and to enjoy the applied focus of plant breeding.

THERE HAS NEVER BEEN a more exciting time to be training for a profession in plant breeding. Agriculture needs changes—producers, consumers, and taxpayers are demanding improvements. At universities nationwide, a wide array of approaches to finding solutions are being pursued. Changes in agriculture require changes in the genetic constitution of our crops, and plant breeders will continue to rise to the challenge. Developments in biotechnology—the principles and techniques involved in cellular, molecular and in vitro approaches to studying and manipulating organisms—are very much in the spotlight today. The application of biotechnology to crop plant improvement has captured the attention of the public, and of many plant breeding programs at universities and in industry. I am attempting to develop some skills in biotechnology as part of my Ph.D. program in plant breeding at the University of Minnesota. My comments here reflect my perspective on incorporating biotechnology into graduate programs in plant breeding.

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SOME TRAINING IN BIOTECHNOLOGY BELONGS IN ALL PLANT BREEDING PROGRAMS

I am convinced that, at a minimum, all plant breeding students should become *conversant* in aspects of biotechnology. All those training to be plant breeders should develop an understanding of the concepts important in biotechnology, an ability to communicate with biotechnologists, and an appreciation for the possibilities and limitations for the use of the tools of biotechnology in plant breeding. Some plant breeding students should be encouraged to go further, to become *proficient* in some aspects of biotechnology. These students should develop skills sufficient to allow them to incorporate biotechnology into mainstream breeding programs. I cautiously believe that some students majoring in plant breeding should go even further and become *specialized* in biotechnology. Students whose primary interest is in biotechnology should carefully consider the implications of choosing to major in plant breeding. There is no question that plant breeding can provide a valuable perspective to biotechnology, but students who are only peripherally interested in breeding may want to consider other majors.

The notion that plant breeding students should incorporate biotechnology in a continuum ranging from a minimum of being conversant, to being proficient, and perhaps extending to being specialized in biotechnology, is consistent with general expectations that graduate students have for their training. The incorporation of various levels of training in biotechnology is also consistent with developing the attributes of a successful plant breeder.

PLANT BREEDING AND BIOTECHNOLOGY: A GOOD FIT

General Expectations

Graduate students in any field should expect that their graduate programs will (i) prepare them for a job that can lead to a satisfying career; (ii) contribute to their sense of pride, self-worth, and excitement about their profession; and (iii) allow them to try new things and extend their abilities in new directions. Biotechnology and plant breeding complement each other well in programs designed to meet these expectations.

Jobs. The recent job postings at the University of Minnesota confirm there are jobs for students at any place in the continuum from being conversant, to proficient, to specialized in biotechnology. All plant breeding students today need to become conversant in some aspects of biotechnology because all plant breeders, for at least a few years, will have contact with biotechnology. Public or private, breeders will be members of departments or research groups that will make decisions in areas where biotechnology intersects plant breeding: allocating resources, setting future strategies, releasing genetically engineered organisms, patenting plants, generating radioactive waste, and more.

Jobs for plant breeders who have developed some proficiency in biotechnology are available. This reflects a growing sense (in at least some quarters) that it is worth trying some "biotech" approaches. Breeders who are trained in biotechnology should be welcome in the ranks of mainstream plant breeders. And there *are* jobs for specialists in biotechnology, but students with a plant breeding major should realize competing for these jobs may be difficult. Some employers may not be prepared to consider plant breeding majors as a source of experts in biotechnology, and may not sufficiently value the perspective offered by plant breeding training. Unfortunately, some potential employers in areas outside traditional plant breeding may not respect letters of recommendation from plant breeding faculty. Thus, students intending to specialize in biotechnology should be cautious when choosing plant breeding for their major, and be careful to go into a plant breeding major aware of potential problems.

Sense of Pride, Worth, and Excitement. Applied breeding and biotechnology combine well to foster a good image for plant breeding students. Applied plant breeding aims to contribute directly to very real societal needs. This is a tremendous source of pride for applied breeders and for "biotechnologists" who apply their skills to plant breeding problems. Biotechnology, with an aura of being "glamorous" and "new," contributes to a sense of excitement. The challenge to keep up with the rapidly advancing fields in biotechnology and molecular biology adds to that excitement. Applied plant breeders must be careful to avoid letting "biotech" steal all the excitement, and remember to keep a fresh, excited attitude toward applied breeding. Plant breeding was a valuable and rewarding profession before "biotech" came along, and will continue to be, even when the furor over biotech fades. I urge plant breeding faculty members to let excitement about new developments and current challenges in breeding show in the classroom and while managing research projects.

Students, like everyone, are motivated by the sense that they are making a contribution. Applied plant breeding projects sometimes emphasize that many years of experience are needed before a breeder can expect to contribute. Students on these projects may get the feeling their only contribution is their manual labor, while biotechnology-oriented projects may have some appeal because they give students a chance to feel they can contribute as scientists much earlier. Plant breeders would do well to be sensitive to students' desires to participate as scientists, and should try hard to help students feel like they contribute to the research project.

Chance for New Experiences. Graduate school should be a place where students can try new things and follow paths they did not even know existed before coming to graduate school. Biotechnology can be an appealing new area for applied breeding students, and vice versa. Typecasting or pigeonholing students into narrowly defined molds needs to be carefully avoided by faculty and by students. Students should not confine themselves to familiar and comfortable areas, but should reach out to extend themselves.

Students will be more comfortable taking advantage of the freedom to try new things if they feel confident they can rely on the faculty for reasonable, informed advice. Current faculty members, experienced in applied plant breeding but not in biotechnology, may find it difficult to advise students choosing to emphasize aspects of biotechnology. I hope faculty will try hard to keep up to date by watching job trends and constantly reassessing the potential of new approaches.

Attributes of Successful Plant Breeders

Training in applied plant breeding and biotechnology makes a good combination for students attempting to cultivate the characteristics of a good plant breeder. I will paraphrase the list of attributes of a successful plant breeder described by Johnson (1981) at the 1980 CSSA symposium on "Meeting the Educational Needs of Plant Breeders," while discussing aspects of combining biotechnology training with a plant breeding graduate program.

1. *Thorough training in genetics and breeding.*
2. *Working knowledge in related disciplines.* Thorough training today requires being conversant in biotechnology, because molecular genetics has made tremendous contributions to genetics, and in vitro techniques are becoming standard practive in some breeding research. Developing proficiency in some aspects of biotechnology is clearly consistent with gaining a working knowledge of disciplines related to breeding. Specializing in biotechnology may be problematic if a student is not interested in complying with the requirement for thorough training in breeding, and compromises will probably need to be negotiated.
3. *Thorough knowledge of plant species involved.* This is important for any plant scientist.
4. *Vision, sense of mission and urgency.* Plant breeders do a tremendous service when they help students develop the sense of mission that has long guided breeders.

5. *Clear perception of breeding objectives and goals.* This understanding is obviously critical for plant breeders, and is also a valuable contribution applied breeders can offer to the larger community of plant scientists at a university. It is important to make this clear perception of breeding objectives available to all students, including those emphasizing biotechnology-related studies. Breeding courses must do a good job at teaching this, and must be accessible to plant science students, regardless of major. Open seminars, discussion groups, and similar forums are valuable for making breeding objectives clear, and effort should be made to extend a welcome to biotechnology-oriented students and faculty.
6. *Ability to organize, assess priorities, and innovate.*
7. *Ability to observe carefully and integrate.* These abilities are important to all professions. Biotechnology has much to offer students who are developing the abilities to innovate and integrate. The tools of biotechnology promise to contribute to innovative new approaches to breeding problems, and the ability to integrate the rapidly growing information generated by molecular studies can contribute to a breeder's struggle to understand the complex genetic and physiological processes that occur in crop plants.
8. *Blend of curiosity, patience, thoroughness, tenacity and ruthlessness in management of breeding materials.* Such a blend of traits is probably useful to anyone managing anything. Students with an increased emphasis in biotechnology may get only limited experience actually managing breeding materials. I believe this is acceptable, even when a student intends to be a mainstream plant breeder, but such students should discuss this with faculty. A student planning to get limited "hands-on" breeding experience should make sure faculty understand the plan, so that letters of recommendation from the faculty are consistent with the student's expectations.
9. *Ability to communicate with scientific and nonscientific communities.* The need for all plant breeders to be conversant in aspects of biotechnology is part of the need for good communication skills. Plant breeders need to be able to talk about biotechnology with other scientists and with nonscientists. Public policy decisions will be made on issues where biotechnology intersects with breeding, and plant breeders should be prepared to contribute to the public dialogue involved in making these decisions.

Thus, a program of graduate training in which students become conversant or proficient in aspects of biotechnology is entirely consistent with developing the attributes of a successful plant breeder. Students who intend to specialize in biotechnology-related fields, with only a peripheral interest in plant breeding, should recognize plant breeding majors are designed to optimize the development of these attributes, and should throughly examine this list. The extent to which these attributes are not compatible with a student's planned program should be discussed with those directing the plant breeding program.

Training in biotechnology can be successfully integrated into a plant breeding program. The outline of the components of a graduate program in plant breeding described in the 1980 CSSA symposium on plant breeding education provides a framework for discussion.

Components of Graduate Program

Defining Objectives. Fehr (1981) emphasized the importance of clearly defining the type of job desired after graduate school and the special training needed to compete successfully for such a job. The more clearly defined the objectives, the easier it is to design a graduate program. I believe students should avoid declaring their allegiances to a specific career path too early, however. Students and faculty should accept broadly defined objectives aimed at gaining a variety of experiences. This broad range is desirable, in part because there are questions about the nature and extent of contributions expected from biotechnology approaches. Also, graduate school should be a place to try out new things. A tremendous array of experiences is available at universities, and graduate students are uniquely positioned to take advantage of this. Finally, the prevalence of dual-career families today makes it dangerous to limit your options when you need to consider your spouse's career needs.

Course Work, Independent Thesis Research, Membership in Research Project Group. Rasmusson (1981) identified course work, independent thesis research, and membership in a research project group as the core of a plant breeding program, and I would like to offer an assortment of observations on these components. The opportunity to take courses in a variety of disciplines is central to the ability to combine training in traditional plant breeding and biotechnology. It may be easier to learn about biotechnology in classes, and hands-on experience is available in laboratory classes. It may be hard to get at the central issues in plant breeding, and nearly impossible to get hands-on experience, in a classroom. Applied plant breeding faculty can make a valuable contribution by developing some innovative approaches to providing experiences for students who are not members of a field breeding project. Another aspect of course work is that "biotech" courses tend to have extensive prerequisites, and also may not be compatible with field work schedules. Faculty should be aware of these issues so they can help students plan appropriately. They can also help by maintaining communication with departments in which these courses are offered, by easing up on labor requirements from students enrolled in these courses, and by offering some "in-house" courses on disciplines related to breeding.

The thesis project is a good place to integrate biotechnology and applied plant breeding. By addressing an applied breeding problem using tools from biotechnology, a student simultaneously pursues training in breeding and biotechnology in a truly integrated program.

Membership in an applied breeding group, in addition to providing valuable experience, often adds another less tangible dimension to a student's experience. Applied breeding projects often act as a team and students gain a sense of belonging to a group. I believe biotechnology projects would do well to foster a similar sense of team membership.

Professional Development. Troyer and Laub (1981) emphasized the importance of developing communication, management and interpersonal skills, and the need for professional development is gaining increased emphasis in graduate programs in many fields. Plant breeders and other agronomy-related sciences have, by virtue of their strong ties to public service, historically placed an emphasis on cultivating professionalism in their students. At the University of Minnesota, students in the plant breeding program enjoy professional development activities that outshine those of many other programs. Biotechnology-oriented projects at the University of Minnesota tend to have outside sponsors, and a valuable opportunity for professional development comes during presentations to these sponsors. Applied plant breeding projects should attempt to involve students in similar presentations to professional audiences lacking expertise in our fields.

ADVICE TO GRADUATE STUDENTS

I would like to summarize my perspective by listing some aspects of my experience that have been valuable, and by offering some advice to fellow graduate students.

As a member of the plant breeding program at the University of Minnesota, I have been immersed in diversity. The plant breeding program integrates students and faculty with a broad range of interests, and has close ties with groups as varied as the weed scientists and the Plant Molecular Genetics Institute. Thus, I am surrounded by variety, and on a daily basis I can draw from a mixture of applied/"classical" and basic/biotech researchers for knowledge and friendship.

I have benefited from an early background in basic courses, such as chemistry, physics, calculus, botany, etc. This was the result of a fairly heavy course load at the beginning of my graduate training, and also my undergraduate training at a liberal arts college, majoring in biology and chemistry. This background did not provide me with any experience in agronomy or field research, but it allowed me to hit the ground running in basic science courses (leaving me with plenty of energy left to learn about field work!), and led to the opportunity to take advantage of advanced genetics and molecular biology courses. My "nontraditional" background may become more and more the norm, and I believe similar students would be good recruits for plant breeding programs.

The opportunity to receive my M.S. degree working on a classical field breeding project, and then to switch emphasis and get my Ph.D. working in a more biotech-oriented lab, has been invaluable. Until more mainstream breeding projects incorporate biotechnological approaches, this may be the easiest way to gain a broad range of experiences.

This switch in emphasis meant that I have needed more time than some other students who maintained the same emphasis throughout their graduate program. I have been fortunate to have been allowed the flexibility to take the extra time—I plan to finish my Ph.D. program a little more than 5.5 yr after starting in graduate school.

Advice to Other Graduate Students

1. Take the basics early.
2. Don't be pressure into committing to a narrow path.
3. Be open to students with different backgrounds.
4. Show enthusiasm for new ideas.
5. Take advantage of the full range of experiences available.
6. Pay attention to the appeal, and to the limitations, of biotechnology.
7. Enjoy the "applied" emphasis of plant breeding (or change majors?).

I believe the goal underlying all our career objectives is to have the opportunity to do good work, to gain the respect of our colleagues, to act ethically, and (especially for plant breeders) to strive to contribute to societal needs. I hope plant breeding students remember to be open to diversity—in approaches, backgrounds, and career options. Plant breeding students should be prepared to pay attention to public opinion—applied plant breeding aims to serve the public good, and biotechnology provokes some public ire. It makes sense to be alert to public concerns. Plant breeding students should leave their graduate training ready to change their approaches, their specific objectives, or their focus as the demands of being a plant breeder change.

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Expectations of the Graduate Student

D. M. Bubeck*

ABSTRACT

The expectations of current plant breeding graduate students may be useful in predicting the impact of biotechnology on the future training of plant breeders. Graduate student training in plant breeding involves a balance of three modes of education: formal course work, research experience, and informal experience. A survey was distributed to graduate students in plant breeding programs at 25 land-grant institutions in the USA to assist in determining expectations of graduate students relative to the three modes of education. Particular emphasis was placed on the impact of biotechnology on students' education, future career goals, and attitudes toward biotechnology and private industry. Students in plant breeding took formal course work in biochemistry, cell biology, entomology, genetics, plant breeding, plant pathology, plant physiology, molecular biology, and statistics. For 29% of all survey respondents, >40% of the courses they took lectured on at least one aspect of biotechnology. Thirty-six percent of the students responding had a biotechnology component in their research. Eighty-eight percent of all respondents had plant breeding career goals, whereas the other 12% had plant breeding–related goals. Eighty-six percent of the respondents thought their graduate training was appropriate preparation for a job with a commercial company. Eighty-nine percent of the students responding believed some aspect of biotechnology will be profitable for use in a commercial breeding program at least by the year 2000.

THE "Impact of Biotechnology on the Future Training of Plant Breeders" should be an issue of concern to public institutions, private seed industry, and to those involved in agriculture worldwide. A symposium at the 1980 ASA meetings addressed the issue "Meeting Educational Needs of Plant Breeders." Symposia of this nature are valuable for evaluating the changing directions and priorities in the plant breeding world. Since 1980, there have been priority changes in plant breeding research conducted at public institutions. The advent of biotechnology has created a shift in some methods of plant breeding research. The "Impact of Biotechnology on the Future Training of Plant Breeders" symposium is an opportunity to take a step back and look at the direction we are taking in the training of plant breeders.

The expectations of the current generation of graduate students may be useful in predicting the impact of biotechnology on the future training of plant breeders. To assist in determining the expectations of graduate students, a survey was compiled and distributed to approximately 480 plant breeding graduate students at 25 land-grant institutions. Surveys were distributed to all plant breeding students in agronomy, crop science, or plant science departments at the 25 institutions in an attempt to survey future plant breeders, not geneticists or statisticians. The 25 institutions were chosen because each had at least five students in a plant breeding curriculum. The students were asked in the survey to answer questions according to the following definition of biotechnology—the use of technologies based on living systems to develop commercial processes and products such as techniques utilizing recombinant DNA, gene transfer, embryo manipulation and transfer, plant regeneration, cell and tissue culture, monoclonal antibodies, and bioprocess engineering (National Academy Press, 1987). The following 17 items were included in the survey:

1. Circle the degree for which you are a candidate.
   a. Master's
   b. Ph.D.
2. Country of citizenship.
3. Undergraduate major.
4. List the crop(s) you are currently working with.
5. Which of the following is the primary reason(s) you chose the university you are currently attending? (you may answer more than one)
   a. Opportunity to study under a certain professor
   b. It was my best assistantship offer
   c. The high quality of the plant breeding curriculum
   d. The high quality of supporting departments
   e. Other (please explain in one sentence)
6. List the number of course credits in your program of work/study for each of the following subjects, including every course you plan to take during your current degree program: biochemistry, cell biology, entomology, genetics, plant breeding, plant pathology, plant physiology, molecular biology, statistics, and any others.
7. Of all the courses you will take during your current degree program, give an estimate of the percent of those courses that lecture on at least one aspect of biotechnology.
8. Do you think your degree program (i.e., program of work/study) contains
   a. the right number of courses
   b. too many courses
   c. not enough courses
9. Do you think your degree program contains an adequate amount of formal coursework pertaining to biotechnology?

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10. Are you satisfied with the education you are acquiring at your institution pertaining to biotechnology?
    a. completely satisfied
    b. partially satisfied
    c. not satisfied
11. Does your graduate research consist of a biotechnology component? If you answer yes, explain briefly.
12. Of the time you spend on research, what percent is devoted solely to your thesis vs. general project responsibility?
13. Are you currently involved in a plant breeding discussion group?
14. What best describes your career goals?
    a. public plant breeder
    b. private plant breeder
    c. no preference, either a. or b.
    d. other (please state briefly)
15. Do you think your graduate training is appropriate preparation for a job with a commercial company?
16. When do you think some aspect of biotechnology will be profitable for use in a commercial breeding program?
    a. biotechnology already is
    b. by 2000
    c. by 2020
    d. never
17. Do you think that gaining skills in biotechnology would improve your marketability toward getting a job as a plant breeder? (briefly explain why or why not)

Following is a discussion of the survey results under the topics of background of survey respondents, formal course work, research experience, informal experience, and student attitudes toward biotechnology and private industry. The objective of this article is to summarize the impact that biotechnology is having on these aspects of graduate training.

BACKGROUND OF SURVEY RESPONDENTS

There were 189 respondents to the survey, and they were assumed to be a random sample of plant breeding students from the 25 institutions. The number of respondents from each of the 25 institutions ranged from 1 to 23; however, 18 of the institutions had at least five students respond. Of the 189 respondents, 36% were M.S. candidates and 64% were Ph.D. candidates. Sixty-five percent of the surveys were from U. S. students and 35% from international students. The respondents were from a wide range of undergraduate majors; however, 65% of the students had a B. S. in agronomy, plant science, soil science, or plant breeding. The students responding to the survey worked with a number of different crops: small grains (27%); corn (22%); soybean (19%); grass and legume forages (12%); edible legumes (9%); potato (3%); sorghum (2%); cotton (2%); tobacco (2%); and sugarbeet, sunflower, and sweet corn (2%).[1]

Students were asked for the main reason(s) they chose to attend the university they are currently attending. Thirty-four percent of the students said it was the opportunity to study under a certain professor. The high quality of the plant breeding curriculum was the reason for 29% of the respondents. Seventeen percent of the students said it was their best assistantship offer. The high quality of supporting departments was indicated by 12% of the students. Only 7% of the students indicated that it was because of proximity to family.

FORMAL COURSE WORK

Success in plant breeding depends on a working knowledge of numerous scientific fields. Fehr (1981) stated that "one must be able to integrate the sciences of genetics, statistics, plant pathology, entomology, and physiology for improvement of crop plants." It is the author's opinion that the sciences of biochemistry, cell and molecular biology should be added to this list if biotechnology is to be applied by plant breeders.

As part of the survey, students were asked to record the number of course credits in their programs of work/study (POW) for their current degree programs for the following areas: biochemistry, cell biology, entomology, genetics, plant breeding, plant pathology, plant physiology, molecular biology, statistics, and others (Table 1). The courses most frequently included in the *other* category were seminars, plant evolution, and general agronomy courses. The number of credits shown are on a semester credit scale. Quarter credits were converted to semester credits by multiplying by a factor of 0.6. Twenty-six of the 189 students did not respond to this question, primarily because their POW was not completed. The number of credits are shown for 59 M.S. candidates, 104 Ph.D. candidates, 60 biotechnology students, and 103 nonbiotechnology students. Biotechnology students have a research project on some aspect of biotechnology, as previously defined in this article; the nonbiotechnology students do not have a biotechnology research project. The division of these two groups of students does not necessarily mean that biotechnology students do not have a field-oriented project, nor that nonbiotechnology students have not had any biotechnology experience. The division, however, does provide a means to illustrate possible differences in the training and opinions of these two groups of students. Ph.D. students took 9.8 more credit hours than M.S. students. Seventy-nine percent of the respondents thought their POW contained the right number of courses. The average plant breeding student with a biotechnology project took 1.1 more credits in biochemistry and 2.0 more credits in

[1] Corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.; potato, *Solanum tuberosum* L.; sorghum, *Sorghum bicolor* (L.) Moench; cotton, *Gossypium hirsutum* L.; tobacco, *Nicotiana tabacum* L.; sugarbeet, *Beta vulgaris* L.; and sunflower, *Helianthus annuus* L.

Table 1. Average number of semester credits taken by students during their current degree program.

Subject	M.S.	Ph.D.	Biotechnology†	Non-biotechnology†
	credits			
Biochemistry	2.5	3.4	3.8	2.7
Cell biology	0.8	1.2	1.3	0.9
Entomology	1.0	0.8	0.6	1.1
Genetics	5.4	8.5	7.3	7.4
Plant breeding	5.5	7.6	5.8	7.4
Plant pathology	1.8	3.4	2.0	3.3
Plant physiology	2.9	3.0	2.9	3.0
Molecular biology	1.4	2.9	3.6	1.6
Statistics	6.5	7.5	5.7	8.0
Others	2.3	1.6	1.4	2.1
Total	30.1	39.9	34.4	37.5

† The biotechnology group are those students who have a research project in biotechnology and the nonbiotechnology group are those students who do not.

Table 2. Percent of courses which lecture on at least one aspect of biotechnology (see survey question 8).

Percent of courses related to biotechnology	Respondents: All students	Biotechnology students†	Nonbiotechnology students†
	%		
0–10	16.2	6.0	22.0
11–20	22.7	10.4	29.7
21–30	16.8	11.9	19.5
31–40	15.1	20.9	11.9
41–100	29.2	50.7	16.9

† The biotechnology group are those students who have a research project in biotechnology and the nonbiotechnology group are those students who do not.

molecular biology than the nonbiotechnology students. The average nonbiotechnology student, however, took 1.6 more credits in plant breeding, 1.3 more credits in plant pathology, and 2.3 more credits in statistics than the biotechnology students.

Students were asked to give an estimate of the percent of courses in their POW that lecture on at least one aspect of biotechnology (Table 2). Of the biotechnology students, 51% of them said 41 to 100% of their courses included an aspect of biotechnology, whereas only 17% of nonbiotechnology students gave this response.

Students were asked whether their degree program contained an adequate amount of formal course work pertaining to biotechnology. Seventy-eight percent of the biotechnology students said yes, whereas 22% said no. Of the nonbiotechnology students, only 53% thought their degree program contained an adequate amount of formal course work, and 47% thought they were not getting enough formal course work in biotechnology. The fact that 47% of nonbiotechnology students did not think they were obtaining enough formal course work in biotechnology illustrates the importance that students are placing on obtaining adequate formal training in biotechnology. Over all respondents, 40% of the students were completely satisfied, 53% were partially satisfied, and 7% were not satisfied with their education pertaining to biotechnology at their institutions.

The results of these questions indicate students are taking a large number of courses that pertain to biotechnology. Over all respondents, 61% of them have POWs in which >21% of their courses lecture on at least one aspect of biotechnology (Table 2). A large number of students, however, are still not completely satisfied with the biotechnology taught in the courses they take.

Troyer and Laub (1981) published an empirical curriculum for commercial plant breeders and indicated that among their plant breeders, there was about the same need for business courses as for botany, genetics, and statistics courses. The business courses included such specific areas as administrative management, agricultural business management, economics, personnel management, and principles of management. In 1981, Troyer and Laub pointed out the needs of their staff at Pfizer Genetics Inc. for management skills as a warning to future graduate students. Of the survey respondents, none indicated they were taking a business course in any of these specific areas.

RESEARCH EXPERIENCE

Students were asked if their graduate research consists of a biotechnology component. Thirty-six percent of the students have a biotechnology component in their research whereas 64% do not. Of the 104 Ph.D. students responding to this question, 41% have a biotechnology component in their thesis. Of all the biotechnology projects, 35% involved restriction fragment length polymorphisms (RFLPs), 33% involved tissue culture, and 13% involved isozymes; the remaining 19% included transformations, monoclonal antibodies, transposon tagging, haploid/doubled haploids, and gene expression/regulation. Considering the fact this this survey was sent only to plant breeding programs in crop science, plant science, or agronomy departments, a large number of plant breeding students are utilizing biotechnology in their research.

Graduate student research can be separated into two categories: thesis research and general project research. On many plant breeding projects this distinction is blurred. The students were asked, "Of the time you spend on research, what percent is devoted solely to your thesis versus general project responsibilities?" The students who have a biotechnology component in their research spend an average of 74% of their research time on their thesis and 26% on project research. Students who do not have a biotechnology component spend 53% of their research time on their thesis and 47% on project research. These figures are not surprising, considering the extensive amounts of time required for completing most biotechnology-related projects.

The students were asked what best describes their career goals. Over all respondents, 34% want to be public plant breeders, 20% want to be private plant breeders, and 34% would choose either public or private plant breeding. The remaining 12% would like a career in teaching, extension, consulting, or small private business. Of the biotechnology students, 37% want to be public plant breeders, 18% want to be private plant breeders, and 28% want to be either public or private plant breeders. In total, 83% of the students that have a biotechnology project want to be plant breeders; these students spend 74% of their research time on their thesis project.

INFORMAL EXPERIENCE

Contacts with fellow graduate students provides two important aspects of the student's informal training. First, graduate students are quick to acknowledge the assistance they have received from senior graduate students in many aspects of their training, from help on course work to ideas for research projects. The second aspect is the opportunity to assist other graduate students in this continuing process. Plant breeding discussion groups provide excellent opportunities for informal contact among graduate students. The students receiving the survey were asked if they were currently involved in a plant breeding discussion group. Twenty-eight percent of the students were currently involved, 29% had been at one time, and 43% never were involved in a plant breeding discussion group. These informal discussion groups provide an excellent opportunity for students and faculty to discuss issues such as the impact that biotechnology has on our training as plant breeders.

Contact with faculty members, other than the major professor and committee members, provides a second opportunity for informal experience. It is important for faculty members to create an environment where informal communication with graduate students is encouraged. A faculty member who shows an interest in the student by asking how their research or classes are going helps create such an environment. The final responsibility, however, depends on the student as "it is the responsibility of the students to force themselves out of the comforts of their research group to gain experience from other faculty members and students" (Fehr, 1981). Rasmusson (1981) stated that "one valid measure of quality in a graduate program is the degree to which students and faculty interact."

STUDENT ATTITUDES TOWARD BIOTECHNOLOGY AND PRIVATE INDUSTRY

Eighty-six percent of the respondents felt their graduate training was appropriate preparation for a job with a commercial company. For the most part, the private seed industry has concluded they cannot afford to overlook the tools of biotechnology, as indicated by Thorne (1990), who represented private breeders in this symposium. Students were asked in the survey to estimate when some aspect of biotechnology would be profitable for use in a commercial breeding program. Fifty-four percent of the respondents believed some aspect of biotechnology is already profitable for use in a commercial breeding program. Thirty-five percent said it will be profitable by the year 2000, 9% said by 2020, and 2% said never. Profitability from biotechnology, however, is often difficult to measure because there will not always be a marketable product involved, but rather information that could increase a plant breeder's efficiency. Generally, students were quite optimistic about the impact that biotechnology will have on private industry. Ninety-one percent of the students responding stated that gaining skills in biotechnology would improve their marketability toward obtaining a plant breeding position.

DISCUSSION

The average Ph.D. plant breeding student takes one or two courses in molecular biology or molecular genetics and many other courses in their POW lecture on at least one aspect of biotechnology. More than 40% of Ph.D. graduate students now conduct biotechnology experiments. These respondents with a biotechnology component in their research spend an average of 74% of their research time on their thesis. Because a graduate student's thesis tends to be narrow in scope, these plant breeding students should try to obtain adequate experience utilizing a number of other plant breeding approaches. For example, if the students intend to be plant breeders they must recognize the need to gain the necessary experience beyond the laboratory. Rasmusson (1981) stated "field experience for a plant breeder is a must; plant breeding is a field job. The type of student to have in plant breeding is one who is willing to obtain experience in agriculture if he/she has none."

In conclusion, the results of this survey indicate biotechnology has already impacted the education of plant breeding students; therefore, this symposium could have been titled the "Impact of Biotechnology on the **Current** and Future Training of Plant Breeders."

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Educating the Next Generation of Plant Breeders: Challenges of Integrating Plant Biotechnology

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ABSTRACT

Modern plant breeding has progressed by incorporating knowledge from many disciplines. It has become clear that developments in plant biotechnology have potentially significant application to plant breeding, but it has been and shall remain a challenge to determine how to best integrate advances in this field into graduate curricula. To gain a broader perspective on this topic, we surveyed public and private sector plant breeders and research administrators regarding their graduate and professional training experience and opinions on the utility of plant biotechnology in plant breeding programs. We report and discuss survey results and identify possible avenues for integrating plant biotechnology into graduate plant breeding training programs. The 508 responses were equally divided among the private and public sectors. Plant breeders were optimistic about the potential importance of their knowledge of plant biotechnology. Examination of course programs suggest plant breeders feel well prepared for their profession; however, there seems to be some need to increase exposure to plant pathology, molecular genetics, molecular biology, and cell biology. More recent graduates have incorporated some of these areas through graduate research activities. Opportunities for integration were apparent through seminar topic selection, modest course addition, and postgraduate training programs for graduate students and faculty. The goal of graduate plant breeding programs should remain constant: educating scientists, producing materials, and identifying knowledge leading to production of plant germplasm having the desired characteristics. This goal will be achieved by scientists trained to critically assess developments in plant biology and integrate them into plant breeding research programs.

SCIENTIFIC PLANT BREEDING is a relatively new discipline. It began as the application of the basic science of genetics to crop improvement. Over the years, plant breeders have continued to apply new genetic information, and information from other disciplines, to crop improvement. Plant breeders have taken advantage of advances in biometry, experimental design, plant physiology, plant pathology, quantitative genetics, cytogenetics, and computer science. Today, advances in plant molecular and cell biology, the parent fields of plant biotechnology, are at the threshold of application to crop improvement.

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The rapid development of plant biotechnology has caught the attention of most plant breeders and research administrators. The potential applications to crop improvement are broad and dramatic. Although it is clear that plant biotechnology has applications to plant breeding, integrating advances in this new field into plant breeding curricula and research remains a challenge. Plant biotechnology is very young, and much of it still involves development of techniques. Current methods for application to crop improvement are relatively rudimentary.

Given this background, we wished to consider the following questions: To what extent should plant biotechnology be integrated into graduate plant breeding programs? What are the needs? What avenues exist to facilitate this process? We surveyed private and public sector plant breeders and research administrators. We will report and discuss the results of this survey, and offer suggestions regarding integration of plant biotechnology into graduate plant breeding programs.

MATERIAIS AND METHODS

A survey was sent to agronomic and horticultural plant breeders at U.S. public institutions with graduate plant breeding programs, the University of Guelph, five international plant breeding research centers (IRRI, CIMMYT, ICRISAT, IITA, and CIAT), and approximately 70 companies with plant breeding research programs. The survey requested information in the following areas:

College Education. This area included information regarding the most advanced academic degree awarded to the respondent (degree and year), number of years enrolled in graduate plant breeding programs, major and minor fields of study, graduate course selection, graduate seminar requirements in plant breeding, primary orientation of graduate research activities, and the need for including at least one course in applied plant molecular and cell biology in plant breeding graduate programs. Respondents were asked to indicate areas of greatest strength and weakness upon completion of their most advanced degree and acquisition of most additional knowledge after completing their highest degree.

Postgraduate Training. Respondents were asked to indicate if they had postdoctoral training (Ph.D. recipients only), if they would be willing to obtain postdoctoral training in plant molecular and cell biology (all respondents), and if they had taken sabbaticals (Ph.D. recipients only).

Development of Research Program and Career. Re-

Table 1. Chronological distribution of receipt of highest degree among plant breeders responding to survey.

Years	Number	Percent
Before 1950	4	1
1950-1954	13	3
1955-1959	23	5
1960-1964	27	5
1965-1969	47	9
1970-1974	52	10
1975-1979	104	21
1980-1984	117	23
1985-1989	118	23

spondents were asked to indicate if knowledge of plant molecular and cell biology would be useful in their current and future breeding programs and their professional development.

Utility of Plant Biotechnology in Plant Breeding Research. Respondents were asked to assess the utility of personal knowledge in plant biotechnology as related to plant breeding, identify areas of biotechnology of greatest immediate significance to plant breeding, and select areas of plant breeding research, which should benefit from plant biotechnology.

Five hundred and eight responses were received. The respondents included 250 private sector and 258 public sector scientists, representing 64 companies and 55 public institutions, respectively. There were 442 Ph.D., 49 M.S., and 16 B.S. recipients. Table 1 shows the distribution of respondents based on year in which they received their highest degree.

In this report, the following definitions will be used: *plant breeding* is the art and science of the genetic improvement of plants (Fehr, 1987); *plant biotechnology* is the genetic modification of plants based on methods and principles developed in plant molecular and cell biology (Lee, 1990, unpublished).

RESULTS AND DISCUSSION

Plant breeders were generally optimistic regarding the potential importance of biotechnology. Seventy-six percent of respondents indicated that knowledge of plant biotechnology was somewhat or very important in making decisions regarding their current plant breeding programs. Seventy-eight percent believed the importance of understanding plant biotechnology would increase in the next 5 to 10 yr. A similar proportion (77%) believed knowledge of plant biotechnology would be important to their professional development. The enthusiasm for plant biotechnology reflected in these responses was particularly encouraging because only 6% of respondents indicated that their knowledge of plant biotechnology would be most useful in routine cultivar development. Most believed their knowledge would have greatest utility in planning and development of their total breeding program (51%), or assessing and selecting new technology (32%; data not shown).

Given this indication of current and future significance, there is a clear need to include biotechnology in graduate plant breeding programs. Although an introduction to biotechnology will likely be included in advanced undergraduate biology courses, the potential contributions are significant enough to warrant exposure to plant biotechnology in the context of crop improvement at the graduate level.

Table 2. Distribution of graduate courses taken by plant breeders responding to survey.

Course category	Percent†	Course category	Percent
Plant breeding	14	Computer science	2
Statistics	12	Mathematics	2
Plant pathology	8	Soil science	2
Quantitative genetics	8	Horticulture	2
Plant physiology	8	Cell biology	1
General genetics	7	Molecular biology	1
Experimental design	6	Seed science	1
Botany	5	Weed science	1
Biochemistry	5	Forestry	0.4
Cytogenetics	5	Agricultural mechanics	0.2
Agronomy	3	General business	0.2
Molecular genetics	3	Business management	0.1
Entomology	2	Accounting	0.0
Foreign languate	2	Other	1.2

† Average percentage of courses taken at graduate level.

The distribution of graduate courses taken by plant breeders is shown in Table 2. The areas of emphasis corresponded very closely to the list of courses suggested by Rasmusson (1981) as essential for Ph.D. candidates—plant breeding, statistics and experimental design, plant pathology, plant physiology, quantitative genetics, general genetics, and cytogenetics. Courses in biochemistry and botany received emphasis in some graduate programs; however, the parent fields of biotechnology—molecular biology, cell biology, and molecular genetics—have received relatively minor emphasis. This may be due to a lack of plant-related examples and information in these courses, which is a reflection of the relatively young stage of basic plant biology. If courses in plant molecular and cell biology were routinely available, would plant breeding students take them? The answer to this question should be affirmative, but it leads to another question. How many courses should be taken? Additional course requirements present a serious dilemma to students already faced with substantial course loads. In our survey, most (97%) respondents agreed that plant breeders should have at least one course in applied plant molecular and cell biology. Adding too many course requirements, however, will make it difficult for students to obtain appropriate levels of training in other areas important to plant breeding. Certainly, some compromise would be required if current average training periods (2.5 and 5 yr for M.S. and Ph.D. recipients, respectively; data not shown) are maintained. Perhaps it will not seem as necessary to add entire new courses in the future, as current courses undergo revision to include information regarding applications of plant biotechnology. It is likely that plant breeding, plant pathology, plant physiology, general genetics, and quantitative genetics courses will eventually include aspects of plant molecular and cell biology and examples of plant biotechnology applications relevant to the given discipline.

Table 3. Areas of strength and weakness upon graduation and areas where most knowledge acquired since graduation among plant breeders responding to survey.

Category	Strength	Weakness	Acquired knowledge
		%	
Plant breeding	32	4	20
Statistics	12	3	5
General genetics	10	1	4
Quantitative genetics	9	4	7
Experimental design	6	1	4
Plant pathology	6	4	9
Plant physiology	6	3	3
Cytogenetics	4	3	1
Agronomy	3	2	5
Biochemistry	2	6	1
Botany	1	1	0
Cell biology	1	5	5
Computer science	1	7	6
Entomology	1	4	2
Horticulture	1	1	1
Molecular genetics	1	8	8
Soil science	1	3	0
Accounting	0	4	1
Agricultural mechanics	0	3	0
Business management	0	6	4
Foreign language	0	3	0
Forestry	0	2	0
General business	0	7	2
Mathematics	0	2	0
Molecular biology	0	5	6
Seed science	0	1	1
Weed science	0	3	1
Other	0	2	1

In general, plant breeders feel that their graduate course programs provided adequate preparation (Table 3). Their indicated areas of strength upon graduation closely matched the course distribution in Table 2. Business-related courses, as a group, comprised the most prominent area of weakness (17% of total respondents). Similar results were obtained in an earlier survey by Troyer and Laub (1981). Among the science fields, areas of weakness included molecular genetics, computer science, molecular biology, and cell biology. Although our survey did not ask directly whether these areas were important to plant breeders, many respondents indicated that they had acquired the most additional knowledge in the areas of molecular genetics and biology after completing their most advanced degree. There seems to be a need to increase exposure of certain aspects in the basic biological sciences.

Graduate student seminars represent a special opportunity to integrate plant biotechnology information into plant breeding graduate programs. Our survey results indicated that all respondents had been required to present at least one seminar. Many (52%) indicated they had been required to present seminars on topics both related and unrelated to their research. Thirteen percent were required to present a seminar on a topic unrelated to their research, while 19% were only required to present seminars on a topic related to their thesis research. It seems there is ample opportunity to use student seminars to expand the horizons of both students and faculty by requiring topics unrelated to the students' research, and including topics in plant biotechnology. The dynamic nature of seminars also provides an opportunity for presenting "up-to-the minute" information that is not always possible in many courses. Finally, seminars provide a forum for open discussion and evaluation of new ideas that is not always possible in formal class settings.

Table 4. Orientation of graduate and postdoctoral research of plant breeders responding to survey.

Level	Laboratory	Field	Equal combination	N/A
		%		
		A. Primary orientation		
M.S.	13	51	21	15
Ph.D.	11	51	26	12
Post-doc	10	7	3	81

B. Research involving molecular/cellular biology

Level	Year completed: Before 1974 Yes	Before 1974 No	After 1974 Yes	After 1974 No
		%		
M.S.	6	94	9	91
Ph.D.	11	89	15	85
Post-doc	4	96	12	88

The research component of graduate education offers considerable opportunity for integrating plant biotechnology into graduate plant breeding programs. This may be achieved through graduate research problems, cooperative project assignments, or brief (6-wk) project rotations through different laboratories. Our survey results indicated a majority of plant breeding graduate research activities were field-oriented, while a substantial proportion was an equal combination of field and laboratory projects (Table 4). The percentage of respondents whose research involved molecular and cell biology was slightly greater when comparing those who received their degrees prior to and after the mid-1970s, a time period corresponding to the beginning of many advances in plant biotechnology and its parent fields. The extent of laboratory research experience appropriate for plant breeding students is difficult to determine. In the future, important questions in plant breeding research may require more laboratory time for both graduate students and faculty. In cases where the research problem does not require laboratory work, 5- to 6-wk rotations to other research projects may provide a suitable method for acquiring laboratory experience in plant biotechnology. While project rotations are common practice in many basic biology graduate programs, they have rarely been attempted in plant breeding graduate programs.

The educational demands for plant breeding may soon exceed the capacity of the traditional graduate program. This has already occurred in many fields of basic biology, where graduate students routinely supplement their training through postdoctoral research. Currently, a postdoctoral position is not a routine component of plant breeding education. Only 18% of respondents indicated they had postdoctoral training.

When asked if they would be willing to take a 1.5- to 2.5-yr postdoctoral position, only 25% said they would, whereas 45% said they would not and 30% were uncertain. Sabbaticals, another supplemental opportunity, had been utilized by an even smaller percentage (11%) of respondents. We may need to become more receptive and supportive of postgraduate training opportunities.

CONCLUSIONS

Throughout their development, graduate plant breeding programs have gradually accumulated course requirements in genetics, statistics, experimental design, quantitative genetics, pathology, physiology, and other disciplines. Knowledge derived from those disciplines was critical to the genetic gains achieved for many crop species and they will continue to occupy a central role in future improvements. It has become increasingly clear, however, that genetic modification and gain in crop species and improved efficiency in plant breeding may be achieved by incorporating information developed in plant molecular and cell biology, and biotechnology. How will developments in these fields affect the training and education needs of plant breeders? How will graduate programs respond?

The objective of integrating plant biotechnology into graduate plant breeding programs should be basic literacy in the sciences that comprise plant biotechnology. It is unlikely that plant breeding graduate students will be called on to do basic lab work themselves. To be effective in research planning and development, however, they will need to recognize potential contributions of plant biotechnology to crop improvement, and to be able to communicate their needs to plant biotechnologists and basic scientists. Additionally, they will need to have sufficient understanding to integrate laboratory results into cultivar development programs. The desired level of literacy may vary with career goals of students, but all students should be expected to develop the ability to comprehend and evaluate plant biotechnology literature.

Development of plant biotechnology literacy as part of a graduate plant breeding program could be accomplished through formal courses, seminars, research problems, or less formal settings such as journal clubs and discussion groups. The optimal strategy may depend on the size, diversity, and commitment of the plant breeding faculty, and faculty from other disciplines. Each of these avenues presents its own challenges and opportunities.

Integration of plant biotechnology into graduate plant breeding programs should be viewed as necessary. Plant biotechnology offers plant breeders a greater understanding of basic aspects of plant biology, such as plant responses to light, extreme temperatures, water deficits, interactions with microorganisms and insects, plant growth and development, and gene identification and regulation. Overall, this knowledge will elucidate relationships between phenotype and genotype, certainly central to all plant breeding research. In addition, plant biotechnology should provide breeders with new tools. The key to successful integration will be well-trained plant breeders, capable of recognizing, adapting, and developing the appropriate tools for each challenge. Such persons will be vital to the continued success of graduate programs, and ultimately plant breeding and agriculture.

Integrating plant biotechnology into the core of graduate programs in plant breeding may be difficult. Plant biotechnology has to be viewed as a young, immature field. Consequently, it is difficult to define and to predict potential contributions, benefits, and direction. Likewise, the parent fields—plant molecular and cell biology—must be characterized as rather young and dynamic. Plant biotechnology is too often defined by the most recently developed techniques; techniques that may be and often are rapidly replaced. It is important that graduate plant breeding programs maintain a balanced focus between the pursuit of fundamental questions and development and application of breeding methods.

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Visualizing Groundwater Regimes of Different Scales

Groundwater regimes can be of the *local* type and of the *regional* type. In the local type aquifers are relatively impermeable and the boundaries of a groundwater catchment will more or less coincide with the boundaries of a surface water catchment. In the regional type aquifers are relatively permeable, and a single groundwater catchment underlies a number of surface water catchments. The difference in type, and in the effect of changes in groundwater recharge on water table levels, can be made visual with the aid of half a dozen paper plates with raised edges and a large tray.

In the local situation the groundwater catchment is represented by a paper plate painted black, held at a very slight angle from the horizontal, and the overlying surface catchment is represented by a paper plate with holes in it, held above and parallel to the black paper plate. It will be obvious that groundwater recharge through the holes in the upper plate will make the groundwater level on the black lower plate rise. When the recharge through the upper plate disappears, e.g., when high water use species such as lucerne or trees are planted (replace plate with holes by undamaged plate), the groundwater level on the lower plate will drop.

In the regional situation the groundwater catchment is represented by the tray, held at a slight angle from the horizontal, and the overlying surface catchments by three (more if you can manage!) paper plates with holes in them, held next to each other in a plane above and parallel to the tray. Recharge through the surface catchments will make the groundwater on the tray rise. But it will be clear that if the recharge in only one of the small surface catchments is eliminated, e.g. by planting lucerne or by reafforestation (replace one of the plates with holes with a plate without holes), the water table on the tray will not be greatly affected. To affect a regional groundwater table *all* (or almost all) the surface catchments will have to be treated with high water-using species.

Where dryland salinity is a problem, such as on the northern Great Plains where the water table has risen into salt-bearing layers, the demonstration can be elaborated upon by mounting a salt cellar on a match box on top of the black plate and on top of the large tray representing the groundwater catchments. It can then be explained that, when the surface catchments provide recharge (have holes), the groundwater table can rise into the salt-bearing layers and become saline. When the recharge is eliminated (no holes), the water table will drop and eventually become fresh again, and the salt can safely stay where it is.—JOOST BROUWER, *Department of Soil Science and Geology, Agricultural University, P.O. Box 37, 6700 AA Wageningen, the Netherlands.*

Visualizing the Hydrologic Effect of Deep Ripping

The hydrologic effect of deep ripping soils can be made visual with the aid of two flat sponges. Put one sponge flat on your outstretched hand and explain that the sponge is like a good topsoil. Your hand underneath is like a plow layer or dense subsoil, quite solid but with some cracks or other large pores such as old tree root holes. The subsoil limits crop root growth. Like the sponge, the topsoil will absorb water until more or less saturated, after which it will start dripping and the water will leak away through the cracks out of reach of the crop roots.

Deep ripping will break up the subsoil and is like creating a second sponge underneath the first. Leakage from the original first sponge will be absorbed by the second sponge and the first sponge is unlikely to be waterlogged. Because the second sponge is easily penetrated by roots, more water can be stored for later use by the crop. Both these facts will enhance crop growth.

As there is less waterlogging there is also likely to be less runoff. What the effect of deep ripping on drainage to the groundwater will be, will depend on the situation: if there is saturation at the bottom of the second sponge (ripped zone), ripping can cause faster horizontal flow to preferential flowpaths leading to lower horizons, thereby increasing deep drainage.—ROBERT H. M. VAN DE GRAAFF, *ACIL-Australia P/L, 854 Glenferrie Road, Hawthorn, VIC 3122, Australia,* and JOOST BROUWER, *Department of Soil Science and Geology, Agricultural University, P.O. Box 37, 6700 AA Wageningen, the Netherlands.*

Zero-Goal Fund Drives

Eight of 28 students (29%) enrolled in my 3-credit Forages class received a failing grade the fall quarter of 1989. At a cost of $47.68 per credit for class tuition, these students "donated" $1144.32 to the University of Minnesota, Waseca (UMW) in tuition money that resulted in no credit.

In an attempt to reduce the failure rate, I decided to make lost tuition a more visible issue during the following Winter quarter class by promoting a "UMW Way Fund Drive," where the contributions goal in the Forages class at the end of the quarter would be zero dollars.

Beginning the third week of classes I prepared a transparency with vertical bars denoting current "donations," based on projected numbers of students who would fail if letter grades were assigned immediately. The first contribution amounted to $4863.36, "donated" by 34 students who had either failed the first lab exam or had disregarded the first lecture assignment.

I updated the class donations periodically, reminding the students of the potential tuition loss. The final result? Twenty two of 64 students (34%) failed the course, donating $3146.88 to the University. Perhaps this is another good example of how difficult it is to motivate students, but many of their evaluatory comments were encouraging. The Fund Drive "gave us incentive to work harder; tells us how much money is really being wasted by students who don't care; is a good idea; is an interesting way to get the point across." Maybe I'll try it again one more time!

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NEWSFEATURES

New Mulches Help the Environment

More growers are discovering that new biodegradeable plastic mulches break down to be an effective and environmentally sound choice for their crops.

Prompted by environmental concerns, the agricultural plastics industry has begun making biodegradeable plastic mulches available to growers.

"Most growers now use plastic mulch that doesn't break down in the fields. The refusal of some landfills to accept this plastic—plus the cost of removing it at the end of the growing season—is stimulating interest in new biodegradeable mulches," says Bob Hochmuth, an IFAS multi-county extension specialist based in Live Oak, FL. Plastic mulch, which covers crop beds and helps conserve moisture, is a standard growing method in Florida for many high-value crops such as tomatoes and peppers.

To gauge their suitability for Florida fields, Hochmuth is now comparing four types of biodegradeable plastic mulch with standard nondegradeable products. He has concluded that the use and selection of these new materials will depend on the type of crop being grown, the length of the growing season, and whether another crop will be planted in the same bed.

Some plastic mulch products begin to break down after 25 days whereas others protect the plant bed for 40 to 60 days or longer.

"The rate at which the new plastics break down into water and carbon dioxide—mainly through photo degradation—depends on the amount of ultraviolent light that hits the plastic. This, in turn, depends on whether the crop is upright or vining," says Hochmuth.

Vining crops, like watermelons, cover the plastic and slow the degradation process while upright crops, such as eggplant or tomatoes, expose the mulch to sunlight and enable it to degrade more quickly. The new mulches will work under Florida conditions, giving Florida producers a way to stay comeptitive while helping to protect the environment.—CHUCK WOODS, reprinted with permission of IMPACT, the Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Farmers Break New Ground

If farmers haven't had enough reasons to begin using no-till or minimum tillage farming practices, they do now.

With the rapid approach of the 1990 deadline for compliance with the Food Security Act of 1985, every farm participating in federal programs must develop an acceptable soil conservation plan.

Conservation tillage is one way to protect soil from erosion and comply with these new federal regulations, says IFAS extension agronomist David Wright.

"Conservation tillage farming, which places seed in the ground without prior tillage, will help keep you in federal programs—including commodity supports and crop insurance—and it should save you money too," says Wright.

"Whether we call it no-till, minimum tillage, or conservation tillage, the goal of this program is to conserve soil moisture and protect soil from wind and water erosion," explains Wright.

"Conservation tillage leaves a residue on the soil to protect it from erosion. Other conservation measures such as terrace and grass waterways also help prevent erosion."

More than 400 farmers from the Southeast discussed the use of conservation tillage and multicropping at the recent Southern Conservation Tillage Conference in Tallahassee and at the IFAS North Florida Research and Education Center in Quincy.

Most people still prepare their seedbeds traditionally, by chiseling, plowing, or harrowing the ground, then working it several times to prepare it for the planter.

"With no-till, there's only one tractor trip across the field when it's planted," says Walter Vidak, a no-till farmer.

Vidak, a partner in Pascua Florida Corporation, has used conservation tillage practices successfully since 1980 on the corporation's 1700-acre farm near Tallahassee.

"I think the fact that we've been using no-till on corn and soybeans since 1980 and getting good yeilds should be of interest to growers throughout the region," says Vidak. "I believe cotton and peanuts could be grown in this manner, too."

Vidak says no-till is finding its way onto more farms in the Southeast. With no-till, a farmer can save about $20 to $30 an acre on labor and equipment costs.

"It's got a place in every operation," notes Vidak. "However, I would not recommend placing 100% of your acerage in no-till the first year. It should be a gradual process based on your own experience and that of others. One thing you have to remember is that no-till requires a higher level of management."—CHUCK WOODS, reprinted with permissionof IMPACT, The Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Environmental Education for All

"Television has an immediacy, an ability to create compelling images that allow people to understand the complex issues that affect the environment," says Lin Foa, project officer for

Race to Save the Planet at Annenberg/CPB Project, the major funder of the series and television course. "This was a very real factor in our decision to fund a television course about environmental issues."

In 1986, a Hewlett Foundation study confirmed the need for an easily accessible environmental science course: only about half the 3000 two-year and four-year colleges in the USA had environmental science course offerings. Many others indicated a willingness to use a course like *Race to Save the Planet* through their biology, ecology, politics, or geography departments.

"While our first goal is providing students with access to the best possible course materials," continued Foa, "we are delighted if these materials can help everyone better understand the environment—whether they are in a classroom or in their living room."

The Annenberg/CPB Project was established to make a college education accessible to learners everywhere through the creative uses of technology. For more information about *Race to Save the Planet* or other Annenberg/CPB television courses, call 1-800-LEARNER.—Reprinted by permission from the RACE TO SAVE THE PLANET newsletter (Issue 2, Winter 1990). RACE TO SAVE THE PLANET, a prime-time PBS series and television course, premieres on PBS in October 1990.

New Ion Thermochemistry Database Available for PCs

A new computerized database package with thermodynamics information on the positive and negative ions in the gas phase has been developed by NIST. Designed for personal computers (PCs), NIST Standard Reference Database 19A and 19B, Positive and Negative Ion Energetics, **provides rapid access to important information on charged atoms and molecules.** Evaluated data on the thermochemistry of positve ions and negative ions are presented separately in the database package, each with its own software and documentation. Database 19A, Positive Ion Energetics, contains approximately 5000 values for ionization energies of molecules and radicals, along with enthalpies or heats of formation of the corresponding neutral species and ions. Values for proton affinities of about 1000 molecules also are provided. Database 19B, Negative Ion Energetics, includes data on electron affinities and gas phase acidities of molecules, and enthalpies of the molecules and corresponding ions. Data on about 2000 species are given. The NIST ion energetics database package is available for $130 from the Office of Standard Reference Data Programs, A323 Physics Bldg., NIST, Gaithersburg, MD 20899; telephone: (301) 975-2208.

Charts Simplify Understanding Pollution

Understanding and conveying to others the overall problems of pollution in our environment today has been greatly simplified by the publication of the Pollution Chart Set. The set consists of four 28 by 22 inch full-color charts on Air, Water, Noise, and Solid Waste Pollution.

Pollution data has been digested and boiled down to the bottom lines and presented in an easy-to-understand visual presentation. The charts show the sources of pollution, what they look like, and what they are doing to our environment and health. This information has been compiled by leading environmental experts and illustrated by leading science illustrators.

The Pollution Chart Set is filled with hundreds of illustrations, graphs, data sections, and future projects. They are ideal for professional and educational presentations, and are in everyday use by educators, industry, local governments, health agencies, and concerned citizens.

The set (four charts—Air, Water, Noise, Solid Waste) is available for $27.50 (postpaid) from Scarfo, 1114 Osborne Road, Downington, PA 19335, or for more information call (215) 269-5406.

SELECTIONS FROM THE BOOKSHELF

Modern Agriculture: Science, Finance, Production and Economics—*Edited by David P. Price.* SWI Publishing, P.O. Drawer 3-A&M, University Park, NM 88003. 1989. 361 p. Hardcover. $34.50.

This book contains an extensive amount of subject matter, ranging from the futures market to the effects of water temperature on the production of fish, and from tree pruning to a rather detailed section on artificial insemination. As I read through the book, however, it was never clear exactly what audience the editor was attempting to address.

The book is divided into four sections. Section one, entitled "Finance, Business, and Economics," consists of 33 pages divided into five chapters. It was refreshing to see the inclusion of chapters on finance and accounting in an otherwise production-oriented book, because this is an area that many production agriculture books neglect. Unfortunately, each chapter offers no more than a cursory overview of complex subjects and provides no identification of author(s), original source of information, or suggestions for further reading. I finished reading this section of the book with a concern that some readers may gain just enough superficial knowledge to get into trouble in areas such as the futures market.

The second section, entitled "Agronomy," is divided into 11 chapters, each written by a different author, totaling 116 pages. It covers such agronomic subjects as soil fertility, irrigation, field crops, tree fruit and nut production, tropical crop production, and entomology. The chapter on economic entomology is the only chapter in the book that provides a list of sources for further reading and consistently cites original sources of information. Most evident in this section is the superficial coverage of topics and poor editing. There is no consistent format for individual chapters in overall layout or for referencing figures and tables, and grammatical errors greatly detract from the flow of this section. Inconsistencies in selection of topics for this book are highlighted by the fact that nearly one-half of the book is dedicated to animal production and only a small part of one chapter in the "Agronomy" section (Chapter 15, Tropical Crop Production Systems) discusses the production of forages.

The remainder of the book is committed to animal production and is divided into two sections. "Feeds and Feeding" consists of five chapters, and is excerpted from a previous book written by the editor. It appears to have been added to this book with minimum editing (Chapter 17A?).

The final section, "Livestock Production," consists of nine chapters and discusses the traditional topics of poultry, dairy, beef, and swine production with the addition of two chapters on livestock reproduction and a single chapter entitled "Aquaculture and Mariculture." The authors in this section are not always provided, sources of original information are not identified, and no supplemental reading references are listed. In particular, I found the chapters on livestock reproduction to be unsuitable for college level courses and too detailed for most livestock producers.

The appendix contains tables that were not referenced in the text but mysteriously appear at the end of the book. Several tables have the footnote "adapted from NRC with modification by senior author." The identification and explanation of these modifications would be appropriate. Although the glossary is a nice addition, some definitions are too narrow in scope and a few are simply erroneous.

Even if one overlooks the major editing deficiencies and content inconsistencies of this book, the question of proper audience remains. The material is too shallow and diverse to be used in university courses and too nonessential for producers. A possible use might be for high school vocational agricultural courses that give no more than a superficial exposure to a wide array of agricultural subjects. However, using this poorly edited book, which inconsistently identifies sources of original work with young impressionable students, would also be inappropriate.—MARVIN H. HALL, *Department of Plant, Soil, and Entomological Sciences, University of Idaho, Moscow, ID 83843.*

The Geography of Soils. Formation, Distribution, and Management. 2nd Edition—*Donald Steila and Thomas E. Pond.* Rowman and Littlefield Publishers, Inc., 8705 Bollman Place, Savage, MD 20763. 1989. 239 p. Hardcover. $34.50.

As the authors state in the preface, this book is intended to be a soils reference for liberal arts students. Minimal prior knowledge of soils or physical science is assumed. The book is structured around the standard topics found in most pedology or soil geography texts: three introductory chapters on soil characteristics (weathering and mineralogy, organisms, organic matter, soil air and water, etc.), one on soil classification, and seven chapters devoted to 10 soil orders. Entisols, Vertisols, and Inceptisols are grouped together within one chapter, as are Alfisols and Ultisols. Although the latter grouping is logical and perhaps preferred in a text written at the introductory level, from a purely genetic perspective I would like to have seen the discussion of Vertisols split out as a separate chapter.

The book contains three brief appendices: (i) clay mineral structures, (ii) horizon nomenclature and symbols, and (iii) soil color. One of the book's strong points is its lengthy (36 p.) and quite complete glossary. Books that overtly state "up front" that they are primarily reference works should then "put out" by having a lengthy reference section of some sort; this book does just that. Words defined within the glossary are explained in language that can be understood by most beginning soil scientists or environmentalists. Simplicity, brevity, and readability, however, has in places been taken so far as to lead to potential confusion. One example, "B horizon: a horizon that forms below an A, E, or O horizon" (p. 197). (A better, more complete definition of the B horizon is found, however, within the body of the text).

Unlike more advanced pedology texts, the authors have chosen to discuss *Soil Taxonomy* taxa only down to the suborder level. This tactic works well, as it makes the chapters on the soil orders concise and readable, yet provides enough information for readers to "grasp the system" of *Soil Taxonomy.* Most chapters devoted to a soil order, e.g., Aridisols, have subsections devoted to climate and vegetation, pedogenesis, and land use, and also provide a typical profile description. Unfortunately, the text lacks current information on changes in *Soil Taxonomy.* For example, the new order Andisols is not mentioned in the text. As other examples, Humox and Orthox suborders of Oxisols are included, when in fact they have recently been abolished. New suborders (Perox and Udox) are not discussed. Likewise the kandic horizon, an amendment to taxonomy that has been in use for several years, is not mentioned. As the text is not designed to be a current statement of the status of soil taxonomy, these shortcomings can be recognized and understood.

A major strength of the text is the clear, concise, and readable manner in which basic soils concepts are explained. Steila and Pond have a gift for writing at the introductory level. Few texts will be as easily comprehended by the beginning soils or land use student as this one. Especially noteworthy for their accuracy, completeness, and readability are the sections on soil organisms and cation exchange. Finally, the text is amply supplied with maps of soil distributions at many scales, perhaps justifying the use of "Geography" in the title.

The Geography of Soils is an appropriate text for undergraduate students interested in acquiring more knowledge about soils, land use, and physical geography. It is neither overly detailed nor difficult to read. Perhaps its best use may be as a recommended, supplemental text in beginning graduate soils courses, for those students who have a limited background in soils and need a quick "catch-up" or refresher text. Its cost ($34.50), however, may be a bit prohibitive for a book of this size and length, thereby limiting its use as a supplemental text in certain classes or for certain individuals.—RANDALL J. SCHAETZL, *Michigan State University, East Lansing, MI 48824-1115.*

The Nature of Properties of Soils—10th Edition—*Nyle C. Brady.* MacMillian Publishing Co., 866 3rd Avenue, New York, NY 10022. 1990. 597 p. Hardcover. $52.00.

I begin reviewing this text about soil with a quote from another book about soil. Firman Bear begins his book *Earth* with "Soil, like faith, is the substance of things hoped for, the evidence of things not seen." So it is with any text purchased by a student. There is hope for learning, and within any book is evidence of real things, as yet unseen by most of those who read the words and study the diagrams. It is for us, the instructors, to make those "things not seen" come alive and bridge the chasm between the pages and the mind.

As I look at the book shelves in my office, I see three other books titled *The Nature and Properties of Soils.* These are the 7th, 8th, and 9th editions. I once had an earlier edition—now lost somewhere—from which I gained my first insights into the science of soil. The presence of these books reminds me of a career that spans about 30 years. I have sought the answers to many "things unseen" during those years, and tried to pass my answers (and those of others) to many students studying the *Stuff of Life* (Bear again) for the first time, and later in their careers as students. Throughout those years, *The Nature of Properties of Soils* has remained a primary reference—a source book as well as a text. The 10th edition promises to continue serving such purposes.

The new edition is, like earlier editions, well supplied with tables, figures, and photographs. I counted 102 photos, 274 figures, and 98 tables. Ten of the photographs are of the soil orders, exclusive of Andisols, of which no one has yet supplied a photograph, apparently. These are in color, as are two of LANDSAT imagery. The LANDSAT imagery is included to emphasize that high tech can be useful in the business of soil survey and making judgments about the land. In addition to the tables, photos, and figures, the book includes a 20 page glossary of about 670 terms, a periodic table of chemical elements, a table that shows conversion of non SI to SI units, and a table of atomic weights. Each chapter has a list of references and several study questions.

Chapters on topics associated with soil formation and classification (geology of soils, their formation and classification, and mapping of their geographic distribution) appear early in the book, where I think them to be most appropriate. This knowledge serves as a base for all other understandings of soil science. These chapters are quite inclusive—moreso than in most of the textbooks on the topic of introductory soils that are available today. The chapter on soil classification has been updated to include the Andisols, and it now has a section devoted to the evolution of soil classification systems per se, replacing the section on soil classification in the USA that appeared in the 9th edition.

There are 16 remaining chapters in the 10th edition. Two that appeared in the 9th edition are not in the new book. These two chapters were devoted to lime and its soil-plant relationships, and to organic soils (Histosols). The section on lime is now included with the topic of soil reaction, and that of organic soils is within a chapter that, in the 10th edition, is entitled "Soil Organic Matter and Organic Soils." The 16 chapters are considered in the following sequence: Physical Properties of Mineral Soils, Soil Water, Soil Air and Temperature, Soil Colloids, Soil Reaction, Organisms of the Soil, Soil Organic Matter and Organic Soils, Nitrogen and Sulfur, Phosphorus and Potassium, Micronutrients, Losses of Soil Mositure and Their Regulation, Soil Erosion, Fertilizers and Fetilizer Management, Recycling Nutrients Through Animal Manures and Other Organic Wastes, Soils and Chemical Pollution, and Soils and the World's Food Supply. These are traditional topics for a "beginning soils" text and from what I can tell, all are updated and are more throughly illustrated than in the 9th edition.

The topics I have found most difficult for the novice student to grasp are those that deal with soil colloids, soil water, and soil taxonomy. Students new to college experience don't seem to be able to visualize the chemistry of the clays or the energy concepts of soil water. They are simply bored by soil taxonomy. Of all texts on the market, I think *The Nature and Properties of Soils* does best in these areas. For example, description and diagrams of the silicate clays, their formation, charge development, and distribution are really excellent, both for the beginner and for the "pro" who occasionally needs a reminder of these things. In addition, energy concepts of soil water are explained concisely without burdening the student with all the details of soil physics used to derive this concept. Methods to measure soil water are clearly described in a way that should enable the beginner to handle them well. The chapter on soil taxonomy is about soil classification, and I'd expect my beginning students to find it less than exciting. It remains, however, an excellent summary from which the instructor can obtain current information on the subject.

A discussion of soil associations, complexes, and catenas is part of the section on soil classification and survey. This is the only place I find metioned the classes of natural drainage of soils. This seems to be a topic assigned small importance in textbooks for beginning students. I have prepared handouts on natural drainage for my students to supplement the text. I think that to understand the natural drainage of a soil enables one to understand its formation and to predict its response for many uses. It serves as a better parameter on which to base predictions of soil response than does any one of the factor of soil formation, individually. It deserves, I think, a greater coverage in books of this type.

My opinions on the 10th edition are decidedly positive. Of all books available on the general topic, I think this book has the best "balance." It does not neglect pedology in the pursuit of the topics more directly related to the economy of agriculture, or to the "environmental" scene. Conversely, it does not neglect edaphology in the pursuit of understanding of the theories of pedology. Previous editions have been somewhat higher in price than competing books. I don't believe this to be true with this edition. Its price appears to be very similar to that of at least one competing text that has recently been updated.

The 10th editon of *The Nature and Properties of Soils* is an outstanding text. I predict that about the time I retire, an 11th edition will be ready. In the meanwhile, the 10th edition will be as marked up from use as the earlier three.—DAVID LEWIS, *University of Nebraska, Lincoln, NE 68583-0914.*

SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management—*J. G. Arnold, J. R. Williams, A. D. Nicks, and N. B. Sammons.* Texas A&M Univeristy Press, Drawer C, College Station, TX 77483. 1990. Illus. 142 p. Hardcover. $65.00.

SWRRB is a computer model developed for simulating hydrologic and related processes in rural basins. The purpose of the model is to predict the effect of management decisions on water and sediment yield for ungauged rural basins. The model is comprehensive, covering all aspects of the hydrologic cycle: surface runoff, percolation, return flow, evapotranspiration, snowmelt, transmission losses, pond and reservoir storage, sedimentation, and crop growth.

The package includes eight 360K byte microcomputer diskettes and a hardcover book. The book provides complete documentation of equations used in the model and program structure. A detailed description of model inputs and outputs is given, along with several example watersheds. The diskettes contain all source codes in Fortran and the executable files, and a program for entering data from the keyboard. Compilation is not necessary unless code changes are made. The diskettes also have soils and weather data required to run the model. There are weather data for 134 weather stations in the 48 contiguous states and the District of Columbia, except Vermont. There are data for almost 14 000 soil series. The programs will run on most IBM-PC compatibles and require less than 256K RAM memory.

The documentation is straightforward and well-organized. Examples for entering data and interpreting the results were easy to follow. The description of the model, however, is very technical and is written for someone who is well versed in hydrology.

The model is very sophisticated and would be satisfactory as a research tool. It would not be practical as a teaching tool, however, unless used as part of an assignment out of the classroom. To input data for a watershed with four sub-basins would require more than 300 entries. Sample data for a watershed near Chickasha, OK, is included on the diskettes. Running the model to provide monthly data for this watershed with four sub-basins took almost 25 minutes on an IBM Model 70 microcomputer with a 80386 20MHz processor. On an IBM Model XT microcomputer with a 8088 processor, it took more than 2.5 hours. The printed output was 18 pages.—RICHARD P. WALDREN, *Department of Agronomy, University of Nebraska-Lincoln, NE 68583-0914.*

Earth—*Revised by H. Wayne Pritchard and Wallace E. Akin,* University of Oklahoma Press, 1005 Asp Ave., Norman, OK 73019. 1990. Illus. 308 p. Paperback. $14.95

Earth is a book first written in 1962. It has been recently revised to bring issues such as acid rain, disposal of wastes, and the world food problem into discussion of stewardship of the planet. The classification of soils according to *Soil Taxonomy* has also been partly updated. The intent of the book is to provide information about our planet so that the conservation (soil-land) stewardship concept may be emphasized. It is a book written in layman's terms, but that describes very well the finite limits of our planet and the damage (existing, current, and potential) the activities of our species have inflicted on it. From this, it is presumed the layman will be more aware of hazards, hence more willing to support, both financially and morally, the efforts in soil and water conservation, and in other environmental issues.

The book is divided into 14 chapters. These chapters have prophetic names—perhaps even poetic names such as "The Soil Beneath Our Feet," "A Blade of Grass," "The Soil in Man," "The Breath of Life," etc. Each chapter has beneath its title a quote from the Judeo-Christian tradition (Psalms, the book of Genesis) or from writers such as Pearl Buck, John Milton, or Ralph Waldo Emerson. "The Earth is the Lord's and the fullness thereof; the world and they that dwell therein," sets the stage for the Preface. The final chapter, "Land, Food, and People," begins with a quote from James Norman Hall, "The thing that numbs the earth is this / That man cannot devise / Some scheme of life to banish fear / That lurks in most men's eyes / Fear of lack of shelter, food and fire for winters cold, / Fear of the children's lacking these, / This in a world so old."

Within the chapters of the book are included many bits of information, usually called *facts* that describe the various situations suggested by the chapters. For example, in "Planet Earth" a discourse on the universe, its age, the great distances, and a suggestion of its future, places the Earth in the context of the rest of the planets, suns, and galaxies. Another example in "The Man With The Plow" is a map of the USA that shows the vast extent of damage from wind and water erosion. Various dates of significant legislation favoring conservation are included, as are acerages within projects such as the Small Watershed Program. In the chapter "The Land on Which We Live," it is pointed out that the FAO has accounted for 33 000 million acres on earth (a figure I had not seen before). Of this area, 3000 million acres are suited for "cropland"; 5300 million acres are in meadow or pasture; 8700 million acres are in forests and woodland; 1000 million acres are termed unused; and 15 000 million acres are "waste or built over land." there is no way for the reader to verify these quantities because the sources are "selected readings" and are not referenced in the text.

But then it's not that kind of book. Its style is to attend more to the "feeling" side of the land ethic than to the rational side. It is very well written for this purpose. Few scientific articles or memos from the national SCS office ever garner much "emotional" support from the public (or from those working in conservation for that matter). This book is able to touch that side of thinking, and for those who do most of their "thinking" through "feeling" this book should have great appeal if they're looking for information to support their ideas about the conservation ethics, land stewardship, and our responsibility for the quality of our own environment.

If *Earth* were to be an appropriate text, I think it would be for a course in the social sciences rather than in earth science. We are developing a course that will be entitled "Earth in Crisis" or something to that effect. Topics will in part at least be selected from the "Worldwatch Report." There is much of what we might aim at with that course in this book. In the part of "Earth in Crisis" that I teach, I plan to use the book, at least for now, as a recommended reading.

In summary, if a book that uses poetic phrases such as "But death was the inhibiting factor" or "In this struggle for existence," and starts its chapters with phrases like "and God said: Let the waters under the heavens be gathered together in one place, and let the dry land appear. And so it was." is useful to you, this is a very useful book. I would not use it as a book to support rational application of the scientific method.—DAVID T. LEWIS, *University of Nebraska, Lincoln, NE 68583-0914*

The Soil as a Reactor—*Jorg Richter*. Catena Verlag, D-3302 Cremlinger, West Germany. 1987. Illus. 192 p. Paper.

This is an English translation of a German text. The basic concept of the text is to treat the soil as a heterogeneous chemical reactor, not unlike the approach of a chemical engineer. There are six chapters and an appendix. The chapter titles in order are: Introduction, Heat Conduction in Soils, Gas Regime of Soils, Soil Water Regime, Regime of Matter in Soils, and Looking Ahead. At the end of the introduction, the intended audience's background is stated as being "familiar with the basic terms and measuring methods used in soil physics and soil chemistry. Special prior knowledge of mathematics is, however, not required." Despite this disclaimer, partial derivatives are used throughout including partial differential equations starting in chapter 3. Admittedly, their use is limited, primarily as motivation for approximations or numerical solutions. I would suggest the appropriate background is exposure to ordinary differential equations and physical chemistry (including both thermodynamics and kinetics).

The Preface to the German edition states that, "This text has been based on a series of lectures. . . ." Although the book may have been based on lectures, in no way can it be considered a modern text. Some of the pedagogical elements an instructor might like to see in a text are missing. No problems are present for students to work out nor are example calculations demonstrated. Limited references to both the English and German literature are given at the end of each chapter.

Most of the material covered (with the exception of chapter 5) is fairly typical soil physics material at a level somewhere between a first graduate course and an advanced course. Chapter 5 emphasizes soil chemistry with attention to kinetics. The approach of the author is intuitive rather than rigorous, which means the student had better be very familiar with the topics. The author has tried to integrate the book around a few key concepts. This would be a laudable goal if one of these (the concept of state variable) were not seriously misused.

Simply, state variables are independent variables that are directly and unambiguously linked to the total energy of soil-water solute system. Early on, the author declares "moisture content and bulk density state variables" (p. 17). Unfortunately, the former is definitely not a state variable (as expected based on hysteresis) and I suspect the latter is not, although I have not seen formal proof one way or the other. But, declarations of this sort are not trivial. Unfortunately, there are too many errors of this kind. Additional problems consist of using terms without defining them, oversimplification to the point of error, ignoring key processes, use of approximation without attention to sources of error.

As an example, on p. 72 the author incorrectly attributes the phenomena of hysteresis in the soil water characteristics to a failure to achieve equilibrium. On p. 103 when discussing *Q/I* relations of potassium the statement is made that $\Delta K = 0$ is the only point on the graph of ΔK vs. activity representing equilibrium. What the author should have said is that this represents the activity ratio with no net adsorption or desorption of K. A last example is the inclusion of PH_3 as a gas to occur in soils under anaerobic conditions. These examples are only a small fraction of the total number of errors that I found. These range from the more grievous (e.g., incorrect use of state variables) to the annoying (e.g., PH_3).

In summary, this book is unsuitable as a text. The book has some value as a reference. However, the reader should be prepared to be misled or check all results independently. I do not believe enough information is given to allow many of the calculations to be carried out that are illustrated graphically. Furthermore, it is highly likely that significant errors would creep in if this text alone were the basis for original predictions.—JOSEPH SKOPP, *Dep. of Agronomy, University of Nebraska, Lincoln, NE 68583.*

Forest Ecology—*J. P. Kimmins*. Macmillian Publishing Co., 866 Third Ave., New York, NY 10022. 1987. Illus. 524 p. Hardcover. $55

When I received this book as Book Review Editor for JAE, it seemed to be outside the realm of a book I would expect to have reviewed for the journal. I planned to pass it on to our library. One noon hour, however, I read the book rapidly to see if soil was given a place in the ecosystem by the author. My past experience with ecology books has led me to believe many ecologists do not believe the soil to be part of the ecosystem. I was delighted to find in *Forest Ecology*, the best one-chapter summary of soil science I have ever read. So, I spent more time with the book and found the soil chapter was accompanied by other excellent discussions in the various sections of the book. I have since used the book as a primary reference in a short course on forest soils that I teach and as a recommended reference on the topic of soil genesis for freshmen through graduate students. Because I have found this book to be so useful, I concluded that others might also.

Forest Ecology is organized into three parts: Part II has five "sections." These are divided into chapters. Each chapter has a summary. The Preface answers the question as to why the book was written and the intent of each part and section in developing the message of the book. This is an excellent technique. Following it, there can be little doubt about the content of the book as well as the organizational and writing skills of the author. The three parts are followed by 32 pages of references—about 1120 in total, and two appendices that provide common and scientific names of plants and animals mentioned in the book. The book is well illustrated. I counted 102 tables, 219 figures, and 35 photographs. Many of the figures and some tables are full page in size. All effectively illustrate points made in the text.

Part I discusses man and the forest. "Forests were the evolutionary vessel in which was distilled the origins of that most remarkable of all animals: *Homo Sapiens*." The relationship between mankind and forests is discussed with a great deal of understanding of the interdependence of the human and the biosphere. The philosophical quandry as to whether the human is or is not part of the biosphere reiterates the argument one hears many times—who is responsible for what has happened to the life support system on Planet Earth? The same questions asked of foresters here could well be asked of agronomists, or of anyone who attempts to manage the environmental system with incomplete knowledge of all actors therein—soil, climate, microorganisms, plants, and animals.

Part II is about ecosystem functions, genetic and evolutionary aspects, physical factors, biotic factors, and change (quoting from the Preface). I was impressed here by the fact that although most examples are taken from forestry, the principles of the science of ecology are clearly illustrated, and could apply to whether one was growing crops such as those of agronomists or foresters. Processes, energy concepts, storage, and living organisms are all effectively shown in clear relationships, one with another. Enough is said, and in a clear enough fashion that I completed the section feeling very knowledgeable, yet aware of much that I did not know, and that may never be understood by the human mind.

The subject of soil as part of the physical environment is headed "Soil: The Least Renewable Component of the Ecosystem." "Soils is not an inert, physical phenomenon. It is a dynamic physical-chemical-biological entity. This must be recognized if ecosystems are to be managed intensively for plant crop production." If the wisdom of that statement were grasped, I suspect we would have many times fewer soil-related problems in the environment. Erosion, water contamination, structural failures, and all manner of cropping problems might be avoided if those who use the land appreciated the soil system. Kimmins does an excellent job of making sure forest ecologists recognize this. All the standard topics of soil science (physical, chemical, biological properties, water organic matter, weathering and soil development, nutrients, fertilizers, erosion, and soil and man) are included with the exception of soil classification. But then the names of soils are not nearly so important as is an understanding of how all these things go together to provide an entity that is a vital part of the ecosystem. This is the strength and uniqueness of this chapter.

Herein lies the strength and uniqueness of this book. Most of the "facts" are available in many places. His concept of the "big picture" and his ability to project this through a book are unique in my experience with those who write textbooks. The majority of writers in my experience tend to fragment subject matter and put each fragment in a little box, with few suggestions that they somehow all play a part and affect each other. A few writers of textbooks seem to have the talent to transfer to others their concept of the "big picture"—the continuum of which all aspects of earth (and probably the galaxies and universe) are a part. Kimmins is one of the best of the latter type of writers, I think, and has written what I found to be a truly outstanding textbook. It is a book about science that is written by an author who knows his subject extremely well, and who can express the poetry within living systems.

Part III considers how the information in Part II can be used to manage forested landscapes. This can also extend to the environment in general. Classifications, modeling, and renewability of natural resources are discussed. The concluding statement defends the concept of man as part of ecology. "The human race is as much involved with ecology in its day to day existence as is any other species of animal, and, together with other species is destined to adjust to the environment or ultimately succumb in the evolutionary struggle. It appears high time that economics and ecology walk the same road and that an ecological approach be adopted for all aspects of human activity."

I hope the reader of this review can tell I found *Forest Ecology* to be an outstanding book, useful in many areas of the natural sciences, both as a text and as a reference.—DAVID T. LEWIS, *University of Nebraska, Lincoln, NE 68583-0914.*