BIOTECHNOLOGY AND FOREST GENETICS: AN INDUSTRY PERSPECTIVE

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Abstract.--Biotechnology is not new to forestry or many other industries. Man has been using biotechnology, in its broadest sense, since he began domesticating crops. Recent advances, however, have made available new genetic and molecular techniques. The current excitement derives from their potential application across the spectrum of activities in forest industry--from producing wood through processing it to using wastes. Tree improvement, as an example, can be expedited and made less costly with techniques such as cell culture and gene transfer. Shortening the time required for selecting, breeding, and testing may allow forestry to benefit as much as or more than other industries dependent on plant material. In addition, forestry, for a change, may be on a par with other industries. New discoveries, or even genes, can be captured and used regardless of origin. Reaping dividends, however, requires that the scientific and industrial communities collaborate in selecting areas of work, choosing strategies, and planning research. The most promising areas must be identified; i.e., those with the most economic leverage. Coordinated strategies are likewise essential. Heavy spending on a narrow or applied front could be harmful. Biotechnology cannot replace other disciplines, rather it builds upon and provides tools for them. Balance must be maintained between fundamental and developmental work. Well-planned, far-sighted experimentation is more important than ever. Modifying or transferring genetic information provokes concern and questions. Precautions in executing research and deploying products are needed to avoid the perception that more problems are being created than solved. Without effective safeguards and education, the public may saddle the technology with unnecessary regulation. New knowledge, as accumulated, should be applied toward betterment of regulatory procedures.

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Biotechnology, in the broadest and oldest sense of the word, is not new to forestry or a variety of other industries. Early man applied and benefited from biotechnology when he began selecting desirable crop and animal variants, and took advantage of genetic variation to increase

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productivity. In more recent times, the word has taken on a somewhat more restrictive meaning in that new genetic and molecular tools have become available. Such tools enable us to alter organisms of interest more dramatically and precisely than ever before, and further allow us to effect change much faster than by traditional means.

Such developments, not surprisingly, have provoked a wave of interest and excitement. Prospects for application of the new techniques to a host of industrial and commercial activities are manifold. In the forest products industry, potential applications span the spectrum from reducing the costs of producing raw material and increasing the efficiency of processing and manufacturing to converting wastes into harmless residues, salable products, or energy. Replacing even part of the energy and chemicals needed to make and bleach pulp has considerable economic leverage. Indeed, first applications in forestry may involve altered organisms or enzymes for bleaching pulp and/or decolorizing effluents.

Also exciting is the rate at which biotechnology has been advancing. Ten or so years transpired before restriction enzymes were understood or became usable as something other than mere research tools. Developing *Agrobacterium tumefaciens* into a workable vector for transferring genes among dicotyledonous plants took roughly seven years. And now, we read about new developments and products literally on a monthly basis.

Advances have occurred, and are now occurring quite rapidly, in forestry as well as in other disciplines and industries. Witness that in early 1983, an entire issue of *Science* was devoted to biotechnology and its implications for science, industry, and society. The sole article on forestry mentioned a number of techniques and applications, but did not discuss isolation, modification, and transfer of genetic information. As clearly demonstrated by other papers in these proceedings, involvement in such research has since increased and progress has been substantial. Within the last six or so months, evidence has been presented that *Agrobacterium tumefaciens* can infect and transform loblolly pine *(Pinus taeda)*. The pace is thus rapid and undoubtedly will accelerate, as a variety of organizations and persons have worked to increase funding and support.

As a result, a number of opportunities and problems lie ahead, and we in research, education, and industry must prepare for them. My purpose then is to highlight a few accomplishments and explore some of the challenges.

CELL AND TISSUE CULTURE

The first area of concern is the art (and hopefully soon the science) of cell and tissue culture. Few coniferous species can be regenerated from protoplasts or single cells, and regeneration from organ culture has not proven an economical means for multiplying improved material. Even so, much knowledge has been garnered from efforts to accomplish such goals. What can now be gained from the experience? And, what direction should such research take in the future? What role should workers in the public and private sectors play?

Tree improvement has become an integral part of management in many forest regions, and generally is recognized as a worthy enterprise.

Improvement of southern pines essentially has become a business--a highly profitable one despite the considerable cost of entry and operation. Progress and profitability nevertheless remain limited by the lengthy reproductive cycle, the space and time required for testing, and the considerable expense associated with testing and selection.

Can tree improvement be expedited and made less costly by imaginative application of cell and tissue culture? The answer seems positive, provided we work together and focus talent on important issues. Doing so seems especially important in view of the economic situation facing us now and for the foreseeable future. Demand for raw material is no longer rising as rapidly as in earlier times, inflation has abated, and expectations have changed. The key to sustained profitability (and I might add, continued interest in research) may, therefore, rest on our ability to reduce costs of production. Indeed, lessening the time and expense of selecting, breeding, and testing may allow the forest industry to benefit from the new emphasis on biotechnology as much as or more than other industries dependent upon breeding and growing plants.

One example of such applications involves placing cell or callus cultures under stress, such as that provoked by low temperatures, restricted moisture availability, or toxins from pathogens. Testing and/or increasing selection intensity in culture can hasten identification and isolation of useful genetic variants. More entries can be evaluated in less time and space than in conventional tests. Approaches, such as protoplast fusion, can be used to increase variability. And, haploid material could be generated for use in research.

Realizing full benefit from such approaches, however, requires recovery of functional plants. Indeed, the utility of many new techniques will be limited until efficient, reliable means of organogenesis and embryogenesis are developed. Just how to effect that development most rapidly remains controversial. Some argue for allocating more funding and workers to the traditional empirical approach. Others hold that more emphasis should be placed on fundamental studies of differentiation. The problem of balance is serious, and need exists for work on both fronts.

What mechanisms control expression of the genes involved in differentiation? How do growth regulators, environmental conditions, and nutrients affect those mechanisms? What biochemical events occur in developing embryos and can we learn to provoke them in culture? Much remains to be learned, and answers to such questions will facilitate progress on cell and tissue culture, and perhaps hasten the day when we can generalize from an easily manipulated species to others of greater interest but difficult to culture. Knowledge about the processes and mechanisms of differentiations will also improve our understanding of growth in intact plants -- the components contributing to it, the underlying traits, and how they can be manipulated more easily. Adequate justification exists for continuing work on both approaches. We would be well advised, however, to provide somewhat greater support for work on processes and mechanisms than has been available in the past. Such a position, hopefully, would encourage continued movement of public sector scientists back to fundamental issues.

GENE ISOLATION AND TRANSFER

Another area of concern involves a set of techniques that has tremendous potential, that of isolating, cloning, modifying, and transferring genetic information. Work is progressing rapidly as indicated by another paper in these proceedings. Two specific strains of *Agrobacterium tumefaciens,* have been shown to infect loblolly pine and some bacterial genes were found to have been inserted into and expressed by the pine genome. Work on other gene transfer systems, such as micro-injection and liposomes, is also underway. Thus, we can expect within the near future to have available the technology to transfer single genes into the genomes of desirable trees. The ability to transfer the many genes presumed to control the most important traits, however, will not be within reach for some time.

Some other limitations should also be noted. Reaping dividends from such research, after all, requires that the gene be expressed at the correct time and place, that we can convert the transformed cell, callus, or organ to an intact, functional plant, and that we can multiply that plant, by sexual or asexual means, in a cost-effective manner.

Progress is also constrained by our understanding of only a very few forest tree genes well enough to attempt isolation and transfer. To some extent, this limitation can be overcome by borrowing genes for traits of interest from other organisms (for example, herbicide resistance from bacteria). This is one reason that biotechnology is so exciting for forestry. Within limits, new discoveries and even genes can be captured and utilized in forest research and development, regardless of origin. Thus, biotechnology may place forestry, for a change, on a par with other industries.

The larger problem nevertheless will persist for some time. Neither we nor other plant scientists know which genes are important or understand the activity of those that have been identified. Identifying genes and understanding gene action will not be easy, regardless of the plant or tree species. This aspect of biotechnology may well prove the most challenging. When considering plant genomes, one must contemplate which gene of perhaps one or more million is of interest. Several thousands or tens of thousands may be active in a particular organ or tissue at any given time. Which are active, what activates them, and how we capture the one of interest remain key questions. Such topics clearly deserve increased attention and seem best addressed by scientists in the public sector.

One might regard this situation, regrettably, as but one symptom of past neglect. The ebb and flow of research and education has been such that sufficient attention was seldom given to the basics of how trees grow. One danger inherent in the excitement about biotechnology, therefore, is that qualified workers will all rush to get on the "genetic engineering" bandwagon, reducing even further the magnitude of effort on fundamental issues.

Despite the many difficulties, work will continue and advances will occur. Before too long, useful genes will be moved into or among tree species, and their expression will be confirmed. Ensuring continued interest and support, however, will be as difficult as doing the research. The economic climate of the present and foreseeable future is such that first results must be winning ones -- preferably seen as shortcuts to increased profitability. Careful selection of goals and areas of investigation is, therefore, necessary. Important traits must be identified and research strategies set such that early efforts will produce findings and/or material that can be moved quickly from research through development to commercialization. Continuing collaboration between the scientific and industrial communities in selecting areas of work, choosing strategies, and planning research is essential to ensure that investments in biotechnology are worthwhile.

CHALLENGES FOR THE FUTURE

Balancing on the High Wire

The foregoing sections were intended to provide a sense of the opportunities presented by forest biotechnology. They also should have surfaced some problems that must be resolved before the promises can be realized. Significant among the problems is the perennial tendency to regard new activities as panaceas or bandwagons. Though the associated dangers were mentioned earlier, the need to resist such tendencies must be reemphasized.

Bending biotechnology to yield real accomplishments in forestry requires a concerted effort of individuals from many disciplines and organizations. Molecular biology is exciting, but significant challenges also lie in the more traditional areas of tree breeding, physiology and biochemistry. Thus, there is still need and perhaps even greater need for increased research in such disciplines.

The new techniques are not a replacement for other disciplines, rather they are new tools for all to use. Indeed, their most significant near-term use may be in enhancing our understanding of tree growth and development--differentiation in cell and tissue culture being but one example. Molecular biology has as much to offer forest genetics as the latter discipline has for the former. Never before have we seen greater opportunities for collaboration among disciplines.

Coordinated and far-sighted strategies are thus essential to maintaining reasonable balance between disciplines and approaches. Heavy spending or plunging for headlines along narrow or applied fronts can do more harm than good. Without continued emphasis on the traditional disciplines and fundamental issues, progress will be as short-lived as it has been dramatic. Achieving a balanced research agenda is also essential if we are to attract the few brightest students to forestry, and train them to investigate, develop, and implement this attractive, but complex technology.

Maintaining an appropriate balance will not be easy. Economic conditions have made funding for research harder to obtain. On the positive side, attitudes about research have also changed, and so-called hard science has become more popular. The research community may therefore find it easier to work on fundamental topics in both new and traditional areas than one might imagine at first glance.

The Sky May Fall

The emergence of forest biotechnology magnifies the traditional challenges about plantation monocultures and clonal forestry. Modifying and transferring genetic information naturally provokes concerns and questions from the public. Adding such concerns to the usual ones will generate more and harder questions.

Both our clients and the public will want to know more about what we investigate, what we produce, how we deploy it, and how it will affect the environment. Some actually may seek a role in determining what is done, why, and how. Not providing them information will create doubt and possibly fear. Inaccurate information or mere opinion will diminish credibility. Thus, well-planned and far-sighted research is more important than ever. Meaningful precautions must be taken in designing and executing research so as to avoid any perception that more problems are being provoked than are being resolved. We must also take the lead in educating our clients and the public. They must be assured of safety. Unless we accept and meet this challenge, all promises could be delayed or even forfeited. Without effective safeguards and education, the public may insist upon regulations that unnecessarily slow or complicate research, development, and commercialization. As responsible scientists, we must further provide accurate data to the agencies responsible for formulating and applying regulations. Our goal should be a responsive and responsible system of regulation that will satisfy public concerns and not inhibit sound research and development.

United We are Funded, Divided We Fall

As mentioned earlier, attitudes toward and the outlook for forest research have changed over the last decade. Funding, expressed in real dollars, has declined during most years, regardless of the organization--university, federal, or industrial. Some years have been better than others, but the average trend has been down or flat. Yet another trend has surfaced as well, that being the more careful choosing of research directions, the justification of expenditures, and the evaluation of payback. Just who does what research has also received more attention. Thus, public sector organizations are moving away from shorter-term, developmental activities to concentrate more on fundamental, longer-term issues. The Industry, on the other hand, is tending to concentrate less on hard science, and more on development and application. The outcomes have been several.

While cause and effect cannot be proved, one certainly can argue that such trends paved the way for increasing support of biotechnology. Most such research, regardless of the organism, was once conducted in a few universities, and largely supported by small federal grants. Now, many universities are establishing so-called Institutes of Biotechnology, aided by modest appropriations from their state legislatures. In addition, the U. S. Forest Service has initiated a modest program. Much impetus has also been lent by establishment of Competitive Grant Programs, first by the USDA, and more recently, the Forest Service. Thus, increased activity on the biotechnology front can be expected in universities, the Forest Service, and eventually, industry.

Some other outcomes are also of interest. The several trends have led to establishment of strong cooperative (and sometimes contractual) relationships between universities, the Forest Service, and/or industry. Witness the formation of herbicide, nursery, and pest management cooperatives among others in addition to the long-standing tree improvement variety. Moreover, the industry has become more involved **in** research planning at the state, regional, and national levels. The National Forest Products Association, for example, now has a National Research Committee and five Regional Subcommittees. A special subcommittee monitors biotechnology research. Industry representatives are prevalent on advisory boards, and are frequent participants in formal and informal research reviews.

While such involvement is not new, the interactions are more intensive and considerably more harmonious than in earlier times, and generally of mutual benefit. That is, the several communities have learned much about their individual strengths and weaknesses, and are acting to help one another meet their respective needs. The research communities desire to perform more and better research and need support. Industry desires to promote the quality of research and to maintain the flow of research information germane to its goals. With time and effort, such interactions can be further strengthened, and used to secure a balanced research agenda and make the promise of biotechnology become reality.