AGRICULTURAL BIOTECHNOLOGY

Nancy K. Karanja
Nairobi Microbiological Resources Center, University of Nairobi, KENYA,

James H. P. Kahindi
United States International University-Africa, Nairobi KENYA

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Summary

Over recent years, biotechnology applied to agriculture has been considered a realistic alternative to improving efficiency in agricultural production. There is no doubt that the judicious use of appropriate biotechnological tools oriented to agricultural production will create positive impacts in developing countries. However, even though some promising results have been accomplished particularly for agricultural systems for domestic consumption and exports in developed countries, a solution to the problems of implementation—and technology transfer to the countries where it is most needed—is still a long way off. There are obvious benefits in the use of modern biotechnologies, for instance in plant transformation and the improvement of introduced traits such as herbicide tolerance and resistance to insect pests, livestock husbandry, conservation of agro-biodiversity, and decreased reliance on agro-chemicals. Yet technical, economical, and socio-political problems, and lack of know-how, limit the application of agricultural biotechnology in the developing countries. There is an urgent need to establish bilateral and multilateral cooperation between the developed and developing countries aimed at enhancing adoption and utilization of these new biotechnologies for agricultural development.

1. Introduction

Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by selection and breeding. An example of traditional agricultural biotechnology is the development of disease-resistant wheat varieties by cross-breeding different wheat types until the desired disease resistance was present in a resulting new variety. In the 1970s, advances in the field of molecular biology provided scientists with the ability to manipulate DNA (the chemical building blocks) that specify the characteristics of living organisms at molecular level. This technology is called *genetic engineering*. The technology allows transfer of DNA between more distantly related organisms than was possible with traditional breeding techniques. Today, this technology has reached a stage where scientists can take one or more specific genes from nearly any organism, including plants, animals, bacteria, or viruses, and introduce those genes into another organism. An organism that has been transformed using genetic engineering techniques is referred to as a *transgenic* organism, or a genetically engineered organism.

The population of the developing world stands at 4.6 billion and is expanding at a rate of 1.9% per year. Out of this population, 1 billion people are living under what the World Bank terms "utter poverty" since they do not get enough food every day. Africa, with a population of about 739 million, a population growth rate of 2.9% per year and an agricultural growth of 1.7% $year^{-1}$ is the region whose prospective food supplies generate the greatest concern. The prevailing socio-economic and political conditions being experienced by most of the countries in the sub-Saharan region of Africa means that they are not in a position to meet their current food demand. These countries are also suffering from a reduction in per capita arable land available for cultivation, hence fragmentation and degradation of over exploited soils. It has been projected that by the year 2150 the available arable land area will be 0.1ha per capita. Sustain human food requirement from that little available land can only be met through science-based and innovative technologies. Consequently, overwhelming interest exists in sustainable land-use systems that prevent or minimize soil degradation and restore the productive capacity and life support processes of degraded lands. Such a revolution in agriculture would involve increasing the productivity of major crops, reduction of chemical inputs (fertilizers and pesticides) into soil and their replacement with biologically-based products, integrating soil-water-nutrient management, and finally improving livestock productivity. In summary, the challenge is how to use new developments in modern sciences, communications technology, and new ways of managing knowledge to make complex agricultural systems of smallholder farmers more productive in a sustainable way. Agriculture, therefore, faces a double challenge; not simply of increasing food production, but of ensuring that the resource base is not further degraded. The approach taken now must move beyond the technologies of the green revolution. Tools and methods must be developed to define and overcome the complex constraints that limit agricultural production in the developing world. This is where biotechnology will play an important role. Efforts must therefore be directed effectively to the application of biotechnology to solving the problems of small and resource-poor farmers on sub-optimal lands. Field observations across Africa indicate that soil fertility depletion in small-holder farms is the fundamental biophysical root because of declining per capita food production, and soil fertility replenishment should be considered as an integral part of agricultural improvement. Therefore, choice of appropriate land use and use of science-based improved technology can enhance and sustain soil productivity and accentuate resilience of even fragile soils. The principle processes involved in soil resilience are:

- control of soil organic matter content;
- improvement in soil structure;
- increase in soil biodiversity;
- reduction in soil degradation and erosion rates below the soil formation rate; and
- increase in nutrient capital and recycling mechanisms.

Some of the technological options to achieve these include microbial inoculation (such as biological nitrogen fixation, mycorrhizal associations, biological control agents, and phosphate solubilizers), recycling of organic wastes, and agroforestry practices etc. Above all it is important to use improved crops and species with high agricultural potential, a feat being addressed through biotechnology.

Advances in molecular biology, genetics, and bacterial metabolism have contributed to the development of biotechnologies, particularly through the use of mutation and the selection of more effective and higher yielding strains. Since the mid 1970s, the breakthrough consisting of the discovery of endonucleases (restriction enzymes), ligases, and of gene-cloning techniques **(**see also – *Methods in Gene Engineering*), as well as the production of monoclonal antibodies by the hybridoma technique, paved the way for a "biotechnological revolution". These new techniques, known as genetic engineering or recombinant DNA techniques, not only contribute to a better knowledge of gene regulation and expression in procaryotic and eucaryotic cells, but also generate applications in many fields, including health, agriculture, improved nutrition, and animal health. In addition to conventional breeding through hybridization and crossing within the same species or between different species, recombinant DNA techniques can produce transgenic organisms (microbes, plant and animals) which contain new genes coding for useful substances or for desired new traits. Biotechnology applied to agriculture could be categorized as follows:

- microbial inoculation of plants and recycling of organic wastes;
- plant cell and tissue culture;
- fermentation and enzyme technology;
- protoplast fusion;
- recombinant DNA technology; and
- livestock-based biotechnologies.

2. Microbial inoculation of plants

The use of bacterial inoculants and of mycorrhizae would indeed have important consequences for agricultural, horticultural, and forestry production. Microbial inoculation involves the selection and multiplication of plant-beneficial micro-organisms, and applying them to plants, seed, or soil. The main uses of micro-organisms are as biofertilizers for improved plant nutrition and as biological control agents to combat pests, weeds, and diseases. The prospects for improving agriculture through the use of microbial inocula are very good. With the possibility of better yields, lower costs, and reduced dependence on chemicals, microbial inoculation of plants is likely to be of great importance, particularly in less-intensive, low-input agricultural systems in developing countries.

Nitrogen (N) is an essential and often growth-limiting plant nutrient. Crops take up N that is released to the soil solution as a result of atmospheric deposition, soil organic matter mineralization, crop residue decomposition and animal manure and inorganic fertilizer addition. Furthermore, N may become available through biological fixation. Only inorganic N, principally nitrate (NO_3^-) and ammonium (NH_4 +) is available for plant growth. Nitrite (NO_2 -) can be taken up but this N form is toxic to plants and is generally present in trace quantities only. A deficiency in nitrogen leads to yield declines or even a complete crop failure. An excess of nitrogen may lead to excessive vegetative growth, lodging, delayed maturity, increased disease susceptibility, low crop quality, and nitrate accumulation. Excesses may contribute to acid rain, destruction of the ozone layer in the stratosphere, the greenhouse effect, eutrophication of surface waters, contamination of ground water, and fish and other marine life kills, as well as blue baby syndrome in infants and amphibian mortality and deformations. The nitrate concentration in ground and surface waters is an important water-quality index. The U.S. Environmental Protection Agency (EPA) has set the Federal Standard for the maximum permitted amount of nitrate N in drinking water at 10 mg N per L or 43 mg NO_3- per L. It is important from both an economic and an environmental standpoint to manage N optimally. Thus, the two primary objectives of N management are:

- to have adequate inorganic N available during the growing season; and
- to minimize the availability of inorganic N during the fall, winter, or early spring, when N may be transported to surface and groundwater.

The atmosphere is about 78% N_2 by volume. This gaseous N is chemically stable and unavailable to most biological organisms. However, some species of bacteria can convert N_2 to N containing organic compounds. This process is called biological fixation and it is the primary mechanism by which nitrogen is added to the soil. Biological nitrogen fixation (BNF)(a process in which atmospheric nitrogen is fixed into organic compounds by certain micro-organisms) holds much promise for developing countries, and indeed is already being applied. For example, *Rhizobium* inoculants are produced for legumes grown for food, fodder, oil, and soil fertility enhancement and accounts for a large proportion of BNF in developing countries. In some countries, inoculants for forage, pasture, and food legumes are also produced. The extent to which externally applied inoculants are an accepted farm practice varies widely. In any case, inoculant use currently has its main impact on large-scale producers. Inoculants have had little effect on legume production where yields are poorest (i.e. at small-scale farm level in developing countries). When, as is often the case, nitrogen is not the yield-limiting factor, it is difficult to assess the potential of nitrogen fixation. Nevertheless, *Rhizobium* inoculation is considered a key component in the improvement of pasture legume production in South America, West Asia, and East, Central and, Southern Africa and it may prove beneficial elsewhere.

The blue-green algae (cyanobacteria) are another source of biological nitrogen. They are distributed worldwide and contribute to the fertility of many agricultural ecosystems, either as free-living organisms or in symbiosis with the water fern *Azolla*. China and Vietnam have a long history of *Azolla* cultivation. In the past decade, *Azolla*, was introduced in paddy fields elsewhere in Asia including India, the Philippines and Thailand. The systems of *Azolla* application are diverse but always labour intensive. *Azolla* has an excellent potential for successful cultivation in irrigated deserts where, humidity is relatively low (e.g. certain -parts of North Africa and the Middle East). The utilization of inocula of free-living, blue-green algae, called algalization, is relatively easy but still limited. (For details about BNF technologies see, *Nitrogen Fixation Technology*).

Mycorrhizal associations (symbioses between certain fungi and the roots of vascular plants) can increase the rate of uptake of nutrients such as phosphorus and nitrogen from deficient soils. The production of mycorrhizal inocula may well be possible in developing countries but it is not a common practice. There is some research on mycorrhiza in several developing countries, including Thailand. Currently, there seems to be no direct economic advantage in using mycorrhizal inoculants in high-value crops. However, where the economic value of the crop is low, and where considerable amounts of phosphate would otherwise need to be added to the soil—as in the reclamation of acid phosphate-deficient soils of the tropics—then the use of mycorrhizal inoculants may become a practical and economic reality. Even when a good case can be made for the use of mycorrhiza, one needs to determine whether artificial inoculation or manipulation of the population of native mycorrhizal fungi by cropping practices is the best means to the end.

Microbial inocula are already used worldwide in the control of diseases and pests in intensive agriculture, and there is some scope for their use in less intensive, low-input agricultural systems in developing countries. *Bacillus thuringiensis* is already applied to some extent in developing countries, for example in the control of pesticide-resistant blackfly vectors of river blindness in West Africa, and for the control of cereal stem borers *Busseola fusca* and *Chilo partellus* in Kenya. The production of microbial inoculants is not very difficult; significant quantities can be produced in unsophisticated fermentors of modest volume. What is more difficult is the selection of effective strains which show consistent benefits and sustain biological activity. Quality control of the inoculants is very important and requires the development of rapid assays for biological activity (growth promotion or biological control) for use during product development and production. Furthermore, extensive regional trials would need to be conducted with the product to determine the environmental limits on biological activity, and to monitor the survival and dispersal of the inocula. Attention should also be paid to delivery systems in order to allow application by small-scale farmers.

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Biographical Sketches

Nancy Karanja is an Associate Professor, Department of Land Resources Management and Agricultural Technology (LARMAT), University of Nairobi, and a Consultant Urban Harvest Program the International of Potato Centre (CIP) Nairobi. She is also the Director of Microbiological Resources Center (MIRCEN), Nairobi. She obtained her B.Sc. (Agriculture) in 1977 and her M.Sc. (Soil Science) in 1980, both from the University of Nairobi; and her Ph.D. (Soil Science) in 1988 from Department of Soil Science, Reading University, United Kingdom. She has worked as a Principal Research Officer in the Department of Forest Soils, Kenya Forestry Research Institute (KEFRI) from 1990–93 and as a Senior Research Scientist in the Department of Soil and Water of Kenya Agricultural Research Institute (KARI) from 1979–90. Her research interests include: biological nitrogen fixation systems and their applications on farms; integrated nutrient management in particular organic matter dynamics; and soil biodiversity and the management of organic materials including solid waste (household garbage from the urban centers) for soil fertility maintenance.

James H.P. Kahindi is an Associate Professor of Natural Sciences in the School of Arts and Sciences , United States International University-Africa, and a researcher in the Nairobi Microbiological Resources Centre, University of Nairobi. He obtained his B.Sc. (Botany and Zoology) in 1984 and M.Sc.(Botany) in 1987 from the University of Nairobi; and his Ph.D in Microbiology from the Nitrogen Fixation Laboratory, University of Sussex, U.K. His research interests include; the biochemistry and physiology of associative nitrogen fixing systems e.g. *Azotobacter chroococcum* and *Acetobacter diazotrophicus*. He is currently undertaking research in the following areas: the characterization and biodiversity of indigenous strains of Bradyrhizobium-nodulating soyabean in Nitisols; the nitrogen fixation potential of *Acacia drepanolobium*; the development of biopesticides e.g. *Bacillus thuringiensis* for use in plant pest and disease control; and agricultural biodiversity and land use patterns with special emphasis on below ground biodiversity.