UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC COMMISSION FOR AFRICA

NOTICE

Please note that the date and venue of the Fourteenth meeting of the Technical Preparatory Committee of the Whole and the Twenty - eighth session of the Commission / Nineteenth meeting of the Conference of Ministers have changed from Libreville, Gabon, 12-16 April 1993 and 19-22 April 1993, respectively, to Addis Ababa, Ethiopia, 26-30 April and 3-6 May, respectively.

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ECONOMIC COMMISSION FOR AFRICA

Fourteenth meeting of the Technical Preparatory Committee of the Whole

ECONOMIC COMMISSION FOR AFRICA

Twenty-eighth session of the Commission/ nineteenth meeting of the Conference of Ministers

APPRAISAL, MONITORING AND EVALUATION OF THE IMPACT OF BIOTECHNOLOGY ON AGRICULTURAL DEVELOPMENT IN AFRICA

I. INTRODUCTION

1. There is a food crisis in Africa. This has been mainly due to the poor performance of the African agriculture. The present trends in food production when viewed in the context of rapid popuplation growth in Africa, cause concern as to the capacity of the agricultural sector to meet the challenge of present and future food production needs in the region.

2. According to FAO, 1/ sub-Saharan Africa's population is estimated to grow at 3.3 per cent per annum between 1985 and 2000 to reach 675 million by the year 2000. The total demand for all food and agricultural products is projected to grow at 3.5 per cent annually between 1983/85 and 2000. In particular, the total demand for cereals, the most widely consumed group of commodities in Africa, is estimated to increase to 100 million tons by the year 2000. This would increase the deficit between domestic supply and demand to 17 million tons by the year 2000.

3. The problem of malnutrition is also expected to worsen with the number of people in sub-Saharan Africa below the 1.2 basal metabolic rate increasing from 105 million in 1983/85 to 137 million in 2000.

4. FAO projections and forecasts clearly suggest the nature and magnitude of the food production challenges which African agriculture faces in the 1990s and beyond and substantiate the need and urgency for major improvements in farm productivity. Agricultural research would have to transform African agriculture to feed the growing populations by making use of the new technology to increase production as well as increase exports for foreign exchange, supply inputs for agro-industries provide more employment and raise incomes in the rural areas. Of similar challenge is for such technology to be environmentally sustainable and economically viable.

5. Indeed, such technology is being recognized and emphasized as new and emerging technologies (NET), comprising innovative developments and applications in microelectronics, biotechnology, new materials, renewable energy technologies and other related fields; NET are having major and far-reaching impact on all economies, including those of African countries. These technological developments would bring about significant changes in terms of efficient production of goods and services which could lead to expanded markets.

6. In this connection, the capacity of Africa to appraise, adapt to and monitor these new technologies particularly biotechnology which has direct impact on agricultural development, depends on institutional and policy flexibility, skilled manpower, cooperation in real partnership and related management systems. For that, new strategies are therefore required and much more attention will have to be given to the application of biotechnology for improving the productive capacity of Africa's agriculture.

7. However, the major question remains: how can biotechnology be better applied to agricultural development? The problem is definitely a complex one. In searching for appropriate solutions, Africa has to take into account the links between trade and finance, between domestic and international policies, and between short-term action and longer term institutional and structural changes and transformation; the continent should also make use of the available and existing results obtained from biotechnology.

8. Within this context, the document tries to give an overview of the current potentials of biotechnology, analyses the present situation of African agriculture and the impact of biotechnology on agricultural development; it attempts to cast some light on a possible strategy, essentially based on building national capability in biotechnology, coupled with a strong cooperation and supportive inputs provided by Africa itself supplemented by the international community.

1/ FAO, Agriculture: Towards 2000 (revised version), pp. 62-70 and 85.

II. AN OVERVIEW OF THE CURRENT POTENTIALS OF BIOTECHNOLOGY

9. Whether biotechnology is developed within African countries to meet their specific needs or is adapted from international sources, the results may well be the same. However, the more important issue is whether any strategies or products are available at all to meet the special requirements of African countries.

10. This section focuses on the general aspects of research and development in biotechnology 2/ and potential applications to African food production rather than on the details of scientific processes. Only the main aspects of the various technologies dealing with plants, animals, micro-organisms, and aquatic life will be discussed. 3/ The references to literature are thus general in nature and given here to provide a guide for further information and needed policy and strategy formulation. 4/

A. Plant technologies

11. Selection of superior genotypes from existing crops of native populations of plants can provide plants with improved traits in relation to the environments in which they are best suited to grow. New laboratory techniques for selection and evaluation such as nuclear magnetic resonance (NMR) for non-destructive assessment of oil quantity in seeds and gas chromatography mass spectrophotometric (GCMS) analysis of chemical constituents can accelerate the development of improved varieties.

12. Because of the natural propensity for plants to produce secondary metabolites or concentrate some of their constituents under stress conditions, plants native to African countries represent a significant opportunity to develop new products for domestic use as well as for export. Some examples are sapogenins from saltbush (Atriples spp.), essential oils from Mentah arvensis and edible oils from Salicornia europea.

13. A recent publication of the U.S. National Research Council (1990) describes salt and drought-tolerant plants useful for food, fuel, fodder, fiber and other products that are currently or potentially useful in African countries. Stress tolerant selections from plants such as pearl millet (Pennisetum typhoides), saltgrass (Distichlis palmeri) and argan (Argania spinosa) may be the source of genes for stress tolerance that can be transferred into the genotypes of existing species or serve as sources for genetic transformation of highly valuable crop species.

14. Tissue culture techniques are based on laboratory studies which show that cells have a totipotency for regeneration to whole plants, possessing all of the traits of the original plant. Techniques have been developed to propagate whole plants from meristem tissues, single undifferentiated cells, haploid cells, and

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2/ Biotechnology is defined here as the "integrated use of molecular genetics, biochemistry, microbiology and process technology employing micro-organisms, parts of micro-organisms, or cells and tissues of higher organisms to supply goods and services".

3/ For more details and informations, see the monograph on "Biotechnology-revolution: A panacea or myth to African agriculture and food crisis?", Joint ECA/FAO Agriculture Division, January 1992.

4/ Also see: C.M. McKell, 1990, "Frontier research and development in biotechnology for food production in dry areas", NPI Plant Biotechnologies, Salt Lake City, Utah.

even naked protoplasts (cells with the cell wall removed) on specially prepared media consisting of agar, nutrients, a carbon source and a balance of plant hormones. 5/

15. A clean (sterile) working area and jars or culture tubes sterilized in an autoclave and a growth room or cabinet with suitable temperature control are the basic requirements to pursue the technology. Production is not limited by seasonal restraints as is field culture. Currently most of the commercially important horticultural (Vasil 1986) and forest species 6/ have been propagated in vitro using protocols developed for each species and variety.

16. Some of the possible applications with tissue culture technology include:

(a) Regeneration and multiplication of superior genotypes, such as those with drought tolerance, without running the risk of losing the superior genetic traits as would be the case if unselected seeds were used;

(b) Regeneration and subsequent multiplication of virus-free plants such as with potato and chrysanthemum;

(c) Culture and fusion of protoplasts such as those from a nitrogen-fixing actinomycete and a free-living soil streptomycete;

(d) Culture of haploid cells from anther tissues in male flowers for creating new genetic combinations that can further be selected in plant breeding;

(e) Cell cultures for the production of metabolites useful as dyes, flavours, pharmaceuticals and food additives; and

(f) Regeneration of whole plants after cells have been transformed by recombinant DNA techniques to make a crop species more productive or resistant to stress.

17. Clearly, the above applications of tissue culture techniques represent various ways in which the technology serves as a tool in plant improvement.

18. The experience of commercial horicultural nursery companies in the United States shows that large-scale propagation in vitro is justified economically only: where propagation by cuttings is costly and difficult; where propagation by seeds would involve undesirable genetic diversity; where the end product has a high unit value as in date palm; or where in dioecious crops (species with male and female flowers on separate plants) it is necessary to propagate only female genotypes as in oil palm, jojoba, pistachio, etc.

19. Because of the high labour cost inherent in most small, sequential batch tissue culture methods, the future lies in adapting bioreactor techniques for mass propagation of tissues in large containers filled with a liquid media utilizing a stream of filtered air to circulate the media among the tissues. In this fashion, the reactor can be operated continuously on a high volume basis until the plantlets are ready for transplanting to the greenhouse.

5/ Vasil, I.K., "Cell culture and somatic cell genetics of plants", vol. 3, Plant Regeneration and Genetic variability, Academic Press, New York and London, 1986, p. 512.

6/ Cocking, E.C., "The tissue culture revolution" in Plant Tissue Culture and Its Agricultural Applications, eds. L.A. Withers and P.G. Alderson, Butterworths, London, 1986, p. 3.

20. Gene mapping, a technology utilizing DNA analysis methods holds great promise as a tool for accelerating plant breeding and genetic transformation. This technology is based on the ability to identify DNA sequences in chromosome fragments of different lengths that are separated in an electrophoresis gel into characteristic patterns representing genotypic differences according to fragment length. Genetic probes prepared from particular DNA sequences "clone" with homologous DNA sequences from unknown genotypes to permit the mapping of areas of chromosomes or quantitative trait loci (QTL) for important traits.

21. For example, a map of tomato on which the chromosomal locus for stress tolerance has been determined can be used by the plant breeder to evaluate which of many offsprings from a cross between a highly developed commercial tomato and a stress tolerant wild type contain the desired DNA sequences for stress tolerance. 7/

22. Those that lack the desired DNA segment contributing to the trait can be eliminated from further time-consuming field evaluation. Highly developed genetic maps of corn (maize) and tomato are already available and work is underway to map cotton, rapeseed and other high-volume crops. As costs of laboratory analysis are reduced by refinements in techniques and automation this technology will be useful for breeding plants with better adaptation to arid environments in Africa.

23. Recombinant DNA technology is the most powerful and basic of all the biotechnologies. 8/. In essence this technology consists of transferring the appropriate sequence of DNA nucleotide bases (the gene) from one organism to another. The process is accomplished by first identifying a source of the genetic trait, "snipping" it out of the DNA strand with an appropriate restriction enzyme and then incorporating the DNA sequence into a vector or "transfer agent" and then putting the recombinant vector into a bacterial or eukaryotic cell.

24. The bacterial cell, often Agrobacterium tumefaciens, can then carry the gene along as it penetrates cells of the target species. Once inside the cell, the DNA sequence may be incorporated into the genome of the target species. Suitable vectors have not been developed for all crop species, especially the cereal grains such as corn and rice.

25. However, using electroporation or other membrane-permeable methods, protoplast fusion has been achieved which may change the need for vectors. A number of particle bombardment papers hâve been published in 1990 showing corn transformation with gene expression in regenerated plants.

26. Plant breeders at the Centro Internacional de Majoramiento de Maize y Tryigo (CIMMYT) have tried several methods involving extracting DNA from a donor corn variety and then soaking corn pollen in a solution of the DNA extract before pollination to transfer genes (as reported in IRRI, 1985). It is expected that this method will be successful in more distantly related species. A major problem is the incorporation of the transferred gene(s) in the genome of the target species and subsequent functioning in the processes of the whole plant.

27. To illustrate the remarkable potential of recombinant DNA technology, one of the early targets mentioned was to transfer nitrogen-fixing capability from a legume to corn which has a high requirement for nitrogen. This objective is unrealistic because of the loss in efficiency the corn plant would experience

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7/ Martin and al., 1989, "Restriction fragment length polymorphisms associated with water use efficiency in tomato", Science 243, pp. 1725-1728.

8/ Zaitlin, M. and al., 1986, Biotechnology in Plant Science, Academic Press, Orlando, FL.

if it has to divert energy to support the complete nitrogen-fixing process rather than storing it as carbohydrate in the grain.

28. However, the greatest difficulty is the task of transferring the 17 genes responsible for various steps the host plant must conduct in the symbiotic N-fixing process. The example is further complicated by the requirement for low oxygen levels in cells where nitrogen reduction takes place.

29. In contrast, the current strategy is to limit the transfer effort to those traits that are controlled by a single gene or at the most a suite of genes located closely on the same chromosome. Some examples of current research and development efforts are to incorporate into commercial genotypes specific genes that control disease resistance, herbicide resistance, insect resistance, oil quality factors, regulation of specific growth stages, and simple stress tolerance mechanisms.

30. Complete commercial success has not yet been obtained but numerous single gene transfer projects have been undertaken and the results are in various testing stages under careful government regulations dealing with field testing of genetically-altered organisms.

31. Because of the complex multidisciplinary nature of the research required and the elaborate equipment needed to carry out the research, few African countries can successfully pursue recombinant DNA research. Furthermore, many of the crops suited for African land conditions are insufficient in market size to justify the expense of recombinant DNA research.

32. The best strategy may be to wait for further refinements in techniques that can be applied to low value or low volume crop species. As improved seed products from recombinant DNA technology emerge, some of them may be suitable for use in the African environments. When tailored DNA sequences and transfer systems are in place, substantial improvements may be possible in African land crops at a reasonable cost. Some examples may be improved drought tolerance in Stylosanthes, disease resistance in chick peas, or insect resistance in millet.

B. Animal technologies 9/

33. Multiple ovulation and embryo transfer (MOET) are relatively new approaches being developed for use in animal improvement. Superovulation may be hormonally induced in a female having the desired traits followed by artificial insemination with semen of a male also having superior traits. The resulting embryos are collected by washing them from the uterus.

34. Subsequently the embryos are frozen in liquid nitrogen where they can be kept for an extended period of time, while in the frozen condition the embryos may be transported to any place they are needed and implanted into surrogate mothers, not necessarily of the same species.

35. This technology allows opportunities for embryo micromanipulation such as embryo splitting with its potential for genetic research using multiple copies of a given genotype as well as a means for obtaining a higher rate of multiplication of improved animal genotypes for animal breeding than would have been possible under the traditional practice.

36. It also provides an opportunity to make genetic crosses that would not ordinarily be feasible. By using microinjection techniques it is then possible to transfer DNA into the embryo nucleus where it may become an integral part of the embryonic genome. Exhaustive research is needed to solve problems of DNA

9/ Babiuk and Phillips, 1989, Animal Biotechnology. Comprehensive Biotechnology, First Supplement, Pergamon Press, 260 pp.

fragment integration, persistence of the transferred genes in subsequent cell divisions and animal generations, as well as its applicability in large mammals.

37. By using semen from bulls with genetic resistance to high temperature, disease of insects common to African countries embryos could be produced from superior cows of other regions and then implanted into surrogate mothers within the environment where improved livestock are needed. The main elements of MOET technology have been developed and are available to be applied appropriately.

38. Gene mapping is a logical adjunct to MOET. Through the use of genetic probes specific for the Y chromosome, it may be possible to identify the sex of embryos and select males for meat production and females for milk production. Further application of gene mapping techniques provide opportunities to identify DNA fragment patterns associated with desired traits and to use the information to guide breeding of superior individuals adapted to the environments and kinds of feed available in African countries.

39. Recombinant DNA technologies appropriate to animal production concentrate on biosynthesis of growth hormones using genes from the main "food animals" to transform bacterial cells such as E. coli. The desired growth hormones are then produced biosynthetically by bacterial cells in a bioreactor system. The application of the technology is accomplished through injection of such hormones to regulate growth and animal output efficiency.

40. Several commercial companies now market growth hormones which can be injected directly into animals or incorporated into their feeds. Other hormonal systems that can be biologically synthesized through DNA technology are currently being researched. Many veterinary medicine products are being produced in bioreactors for use as animal health products. There may be opportunities for developing hormonal controls for animal adaptation to the stresses inherent in African environments.

41. Bovine growth hormone (Bovine somatotropin) injected into dairy cows has resulted in a 15 to 41 per cent increase in milk production depending on the rate and duration of injection. 10/ This product came onto the market for cattle during 1990.

42. Porcine somatotropin (PST), a biosynthetic hormone, is already on the market as a growth hormone for pigs. PST increases feed conversion efficiency by about 25 per cent and reduces tissue fat production by almost 70 per cent. A vaccine has been developed which elicits the production of antibodies against the luteinizing hormone release factor (LHRF). The result of injecting the hormone in uncastrated bulls and rams is an increase in the rate of growth.

43. Given the high cost of animal hormone research and the relatively high volume of research in commercial companies on the subject, it would seem that the best strategy for African countries would be to set up a group of African countries working collectively and following the progress of such research, to be aware of its side effects and to be prepared to test the suitability of products and strategies on animals and production systems that exist in the arid developing countries.

44. In addition to research on genetic improvement and growth/physiological regulation, a major research and development activity is underway in animal veterinary medicine.

10/ Reviewed by Babiuk and Phillips, 1989.

C. Microbial technologies

45. Bioreactor culture of specialized plant and animal cells or genetically-engineered micro-organisms is a major area of biotechnology research and development. This technology involves production of valuable biochemicals such as hormones, secondary metabolites, non-sucrose sweeteners, and other cellular products in large-volume industrial reactors. Also included in the list of possible bioreactor products could be microbial cultures useful for their biological activities in waste degradation and mineral digestion.

46. The application of bioreactor or automated culture technology to African countries can only be seen as a part of a larger effort in biotechnology research and development in which particularly valuable unique plant product(s) could be produced by cells in a bioreactor. However, once the necessary high cost research is completed and the processes tested, a bioreactor facility could then be established in any location where costs, facilities and market accessibility are favorable.

47. Microalgae production holds great promise as a means of increasing food supplies. 11/ Algae species such as Chlorella, Spirulina, Porphyridium and Scenedesmus have been studied for their protein, gamma-linoleic acid, pigments and polysaccharide contents in relation to rates of cell growth. Specially products such as bet-carotene are obtainable from Dunaliella viridis, a microalgae adapted for growth in saline lakes.

48. Culture of microalgae may be as simple as in controlled ponds or as complex as in highly automated industrial vats and reactors. Microalgae can be a source of human food, livestock feed and fish food, as well as a source of speciality chemicals and pigments for pharmaceutical use. However, economic aspects dealing with volume and value of products in relation to altenatives must be considered in any future research planning.

49. Nitrogen-fixing microorganisms: Rhizobium spp. have been cultured for many years as symbiotic inoculants for legume crops. Genetically improved cultures of legume inoculants with greater efficiency and specificity for target crops are being developed through selection and DNA transformation.

50. In the 1970s the ability to propagate the N-fixing actinomycete Frankia in pure culture opened the way to utilize the capability of this organism to inoculate non-legume trees and shrubs such as Alnus, Casurina, Ceanothus and Purshia, some of which are often found in arid lands in Africa. Other nitrogen-fixing systems involving blue-green algea (Cyanobacteria) and its symbiotic relationship to Azola in rice fields appear as opportunities for biotechnology research.

51. The biotechnology applications possible with these nitrogen fixing microorganisms include genetic selection and transgenic manipulation to increase their effectiveness in arid lands and host range. 12/ Improved methods for mass-production are also a priority.

52. In view of the natural deficiency of nitrogen in soils worldwide, any improvements in the nitrogen-fixing process and applicability to cropping practices would be useful, especially to African countries with arid soils of low N-status. Of particular interest may be the research in agroforestry practices that utilize genetically improved nitrogen-fixing trees and shrubs that can be interplanted with food crops.

11/ Richmond, A.E., 1986, Microalgaculture, in CRC Press, Boca Raton, Florida.

12/ Gresshoff, P., 1989, Molecular biology of symbiotic nitrogen fixation. CRC Press, Boca Raton, FL., 256 pp.

D. Aquatic systems

53. Aquatic culture systems for the production of food from such aquatic organisms as fish, molusca, algea and crustaceans constitute a significant opportunity for alternative to traditional crop plant and animal husbandry methods. Construction of ponds on land or retention enclosures in coastal areas provides a means of maintaining feed supply at the optimum and protection from predators and parasites. 13/

54. A full knowledge is needed on the life cycles of appropriate food species such as the Tilapia fish and shrimp in order to optimize conditions and cultural practices for their economic production.

55. Opportunities to increase the production of fish, shrimp and other marine life exist, using current and developing techniques whereby food requirements, disease control, growth regulation and genetic selection can be developed that will improve the biological efficiency of food species utilizing appropriate production systems.

56. Biotechnology applications such as transfer of genes for specific traits for disease resistance, growth regulation and nutritional value may make it possible to increase product value and reduce risks for aquatic food systems. Additional products such as biomass for fertilizers and residues for animal feed may be obtained as added benefits from aquaculture.

57. Aquatic crop adapted to sea water environments can be grown in marine tidal lands to increase food production. Currently the University of Arizona Environmental Research Institute has been conducting research in their laboratories and in coastal tidal lands on Salicornia europeae.

58. Many arid developing countries have coastal tidelands and marshlands that may be suitable for Salicornia production. This species yield high protein biomass as well as high quality edible oil from its seeds. Biotechnology applications to Salicornia include high-technology methods for selection of genotypes high in oil content and, in vitro vegetation propagation of the superior biotypes for use in detailed research on planting, nutrient requirements, harvest and oil quality.

59. Other plant species that may be cultured are kelp (algae) species, useful for their biomass and extraction of pectins and carbohydrates. Although naturally growing in areas of greater depth than tidelands, kelp species require management for optimal production.

III. PRESENT SITUATION OF AFRICAN AGRICULTURE AND IMPACT OF BIOTECHNOLOGY ON AGRICULTURAL DEVELOPMENT

A. Characteristics of African agriculture

60. In assessing the impact of biotechnology on African agriculture, it seems quite logical to start with the analysis of the characteristics of this sector: identify its constraints and determine to what extent these constraints could be alleviated or improved by the application of biotechnology results.

61. Problems associated with the depressed state of Africa's agriculture occur at both the national and farm levels. In spite of some of the advances known to have been achieved in food production in some parts of Africa, the continent generally lacks the ability to produce enough food to sustain its population, let alone

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13/ "Genetic engeneering news" in A Revolutionary in Biotechnology, edited by J.L. Marx, 1990.

food production for export. Specifically, there are certain fundamental problems some of which are the following:14/

(a) Inadequate and misguided government policies, which include trade restrictions, neglect of the local food production subsector, overvalued exchange rates, overtaxations, monopolistic marketing practices, unfavourable pricing policies and an overall low priority accorded to agricultural investments;

(b) Lack of effective institution and of land reform policy which is neglected in poor organization and a distressing lack of operations and management control, combined with inadequate facilities and equipment to weaken public sector services, such as education, research and extension services. Parastatals, particularly those marketing agricultural inputs and commodities, function poorly and depress producer prices. There is total lack of appropriate land reform and there is no adapted insurance scheme available for small farmers in the rural areas;

(c) Lack of pertinent agricultural knowledge: research information in the hands of extension agents is relatively small and consequently not suitable for small farmers. Appropriate technical packages are poorly developed, extension agents are often not properly trained and motivated while interactions between researchers, extensionists and farmers are almost non-existent;

(d) Unfavourable natural environment: fertile soils in Africa are limited to a few river valleys and high plateaus. The remaining soil is difficult to manage and large acreages are semi-arid. It has been estimated that, due to erosion, some soils would need 300 years of continuous use of fertilizer, in order to regain their normal productive capacity. In addition, one finds debilitating diseases and insects that are common only to Africa;

(e) The traditional structure of farming: most farms are small and rely on simple hand tools and human muscle power. Few inputs are purchased. Shifting cultivation, where fields rather than crops are rotated, is the traditional approach to soil conservation and maintenance of soil fertility;

(f) Increasing urbanization and population growth: urbanization has removed labor from agricultural production and changed eating habits in favour of imported foodstuffs. Rapid population growth rates are increasing overall demand for food relative to the willingness of the agricultural labor force to produce food under current policies, and in relation to the carying capacity ratio of the fertile land;

(g) International economic problems: demand for Africa's agricultural exports has declined and terms of trade deteriorated. Yet prices of imported inputs and consumer goods have all risen significantly. Oil price increases have been ruinous;

(h) Limited infrastructure: roads, bridges, storages, marketing facilities and transport are poorly built and maintained or non-existent;

(i) The historical legacy: agricultural support systems existing before independence were geared toward export crops. Food crops and local livestock were neglected. Moreover, ideas of functional education that were inculcated under colonial regimes - and continued by post-independence governments - have proven inappropriate for fostering economic growth and social development;

14/ Wutoh, J.G., 1990, "Integration of new biotechnologies into the existing social organization of the countries affected by the food crisis", paper presented to the UNCSTD/ABN Workshop on biotechnology for food production in dry areas, Dakar, Senegal, 8 to 10 October 1990, 20 pp.

(i) Prevalence of numerous diseases: through the developing countries of Africa produce reasonable tonnage of grains, roots and tuber crops, grain legumes, plantain and bananas; but over the past few years, there have been significant reductions in the yields of these crops due to diseases and pests or lack of improved seeds or other planting materials or lack of the appropriate technologies for mass production, storage conservation and processing. However, over 60 per cent of the world's plantain is produced and consumed in West and Central Africa and about 60 million people whose average consumption is 200 or more calories per day depend on this crop as a staple food; but the crop is seriously threatened by a virulent fungal disease called black Sigatoka (caused by the fungus Mycosphaerella fijiensis) which is estimated to cause yield losses of between 30 to 50 per cent;

(j) Lack of seeds and other planting materials: a major constraint in increasing root and tuber crop production in tropical Africa is the absence of a well-organized seedstock multiplication sector catering to the needs of the farmers. Root and tuber crop growers often produce their own seedstock. Seedstock produced by the farmers are of poor quality, often infested with viruses and nematodes and inadequate for the total demand. In the case of yams, for example, it is reported that in Nigeria the cost of seedstock consists of 20-30 per cent of the total production cost (IITA Report, 1992). Yam and sweet potato seedstocks are also stored for five to six months before planting. Storage losses are as high as 50 per cent in four to five months (IITA, 1992). Root and tuber crop seedstock, therefore, are usually scarce and expensive;

(k) Environmental stress as a major constraint in food production in Africa: optimum environmental conditions for maximum plant growth and development rarely occur in nature. Farmers all over the world, especially in African countries must constantly deal with plant stress avoidance/tolerance for adequate crop yields. Both in nature and on farmer's field, plants are continuously bombarded with soil (acidity, salinity, alkalinity, compaction, water-logging) and environmental constraints (rain, temperature) that often cause yield instability when uncontrolled. Quite often soil and environmental stresses trigger outbreaks of insects and/or diseases that affect crop yields. Too often these unstable yields occur in African countries where food availability means life or death to millions of people.

62. While there is a degree of variation between African countries, the problems listed above are common to most of them. The cardinal issue facing African policy-makers and biological scientists is how to solve those critical problems that relate to agricultural development?

B. Experiences and lessons from the Green Revolution in Asia for Africa

63. The use of high-yielding crop varieties with high levels of chemical fertilisers and irrigation, adopted as a package under a favourable policy environment underpinned the success of the Green Revolution in Asia.15/

64. Green Revolution technology, however, focused almost exclusively on grains, especially rice, wheat and maize grown mainly as monocrops. Other staple food crops, such as cassava, potatoes, etc., consumed mostly by the poor hardly experienced any increases in yield through the use of Green Revolution technology.

65. Although the technology is scale-neutral, government policies on credit, input prices, marketing, land tenure, etc., favoured its adoption more by the rich and large farmers than by the small resource-poor farmers. Also significant was the uneveness in production performance between countries of the region which adopted the same technology.

15/ Okigbo, B.N., 1986, "Towards a new Green Revolution: From chemicals to new biological techniques" in the Improvement of Tropical African Agriculture, September 1986.

66. Important implications followed from the above: small farmers hardly benefitted from the Green Revolution. So were those farmers who cultivated staple food crops other than wheat, rice and maize by-passed by the Green Revolution. The difficulty of applying Green Revolution technology in multi-cropping is due to the fact that the use of machines and high levels of fertilizers and pesticides increased the incidence of insect pests, diseases and weed problems and cause serious damage to the environment.

67. The Green Revolution brought about dramatic increases in grain production and the reduction of hunger in Asia in the 1960s and 1970s. It, however, did not solve the problems of malnutrition and food insecurity. It instead aggravated income disparities and social stratification.

68. Since the 1970s, yields of maize, wheat and rice have stagnated. In fact, a major challenge facing Asia since the Green Revolution has been to sustain the high yields attained in well-irrigated areas with adequate organization and marketing while improving yields in rainfed, upland and flood-prone areas that were almost by-passed by the Green Revolution.

69. The important lessons for Africa from the Green Revolution in Asia is that research must develop technologies which not only bring about significant increases in yields but also take into account the needs and circumstances, i.e., the whole environment of the farmer - whether large or small. Since, however, the constraints are more severe on the resource-poor farmers, and especially those in marginal, risk-prone areas in Africa south of the Sahara, they should be the central focus of research efforts.

70. So what are the critical issues for agricultural research and technology development in Africa? It would seem that a more clearly focused consideration of these issues must be viewed within the context of the present state of agricultural research in the region, the technology already available and how well it is adapted to the resources, culture and eco-system of the farmers. It is only within this context that issues regarding new policies, strategies and approaches can better be examined with respect to meeting future food self-sufficiency and food security objectives. 16/

C. The impact of biotechnology on agricultural development

71. The subject of biotechnology and its revolutionary opportunities have captured the imagination of the developed world. Indeed, governments and the academic, commercial and development communities of the developed countries are investing large sums of money and human effort to push back the frontiers of knowledge, utilize the new principles to make new products and develop programmes that utilize those products in projects to benefit mankind.

72. In the broadest sense, biotechnology is not new because numerous biological technologies have been used for hundreds of years such as fermentation in the production of wine, bread leavening through the action of yeast and improvement of plants or animals by selecting superior individuals and retaining them to propagate the next generation or using them to crossbreed with existing individuals to produce improved offspring. Scientific understanding of biological constraints have been loosened and the potential for food production is far beyond the Malthusian limits seen by the last century's demographers. 17/

73. Rather than defining biotechnology in the narrow context of recombinant DNA and bioprocessing techniques (Industrial Biotechnology Association 1984), it should be considered, as mentioned, as any

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16/ Feeding the future: Agricultural development strategies for Africa, Casin/Sasakawa Africa Association/Global 2000, Workshop 1989, Accra, Ghana, 1 to 3 August 1989.

17/ The Limits to Exponential Growth, Chapter II of The Limits to Growth, A Report for the Club of Rome's project on the predicament of mankind, 1974, pp. 45-86.

biological technique that uses living organisms, or substances from those organisms, to make or modify a product, to genetically improve plants or animals or to develop micro-organisms for specific uses. 18/

74. With this definition a continuum of technologies is included in biotechnology ranging from long-established use of living organisms in brewing and biological control, production of vaccines and cell growth regulators, to cell regeneration and recombinant DNA techniques for genetic improvement of micro-organisms, plants and animals. 19/

75. The main objective of biotechnology applications, e.g., in African countries, may well be to increase food production. But because of international economic influences coupled with environmental and social constraints, the objectives must be employed in the total context of the region's needs and resources.

76. In a strategy report prepared for the Stanford Research Institute, 20/ outlines the following three main objectives for plant biotechnology that seem to encompass all of the main reasons for engaging in agricultural research and development:

(a) The first is to improve productivity. By improving the yield potential of a product or crop, it may be possible to increase production over the amount currently obtained and thus gain a return on the investment for research and development still utilizing the same areas of land, manpower and resources. In the scale of importance for African countries, increasing yield is the highest priority, especially in stress environments where existing crop and animal yields are constrained by unfavorable environment;

(b) The second priority is to improve quality. By improving the quality of an existing product it may be possible to increase the value of the products or its content and uniformity of constituents. Whatever the improvement strategy the end result must be to increase consumer preference over unimproved products. Quality is therefore essential for products from developing countries to compete in world markets;

(c) The third priority is to reduce the cost of production by improving internal biological efficiency, increasing the ability of the organism to function in existing and marginal production environments or to improve the efficiency of response to cultural practices such as fertilization, nutrition, irrigation and use of pesticides.

77. Some special constraints of biotechnology are important to consider in assessing their applicability for improving food production in African countries. Too often these factors may be ignored when formulating programme goals and expected results.

78. Briefly, these constraints are: (a) research is expensive and may not always result in anticipated marketable products; (b) time is required to solve complex research problems; (c) commercialization of products requires coordination between research and development teams as well as adequate incentives and proprietary protection; (d) solutions to problems often involve inputs from both public and private research and development sources.

18/ Office of Technology Assessment, 1985, Innovative biological technologies for lesser-developed countries, US Government Printing Office, Washington, D.C.

19/ Persley, G., 1990, "Harnessing biotechnology for the third world" in Partners in Research for Development, No.3, pp. 7-11, The Australian Centre for International Agricultural Research, Canberra, Australia.

20/ Hall, P., 1984, "The role of biotechnology in the genetic modification of higher plants", Report No.1, Stanford Research Institute Proj. 7091, SRI International, Menlo Park, CA.

79. In contrast with the Green Revolution which mainly concentrated on information from the public sector about appropriate cultural practices necessary to improve the production of new high yielding plant varieties, biotechnology concentrates on a wide range of products mainly from the private sector such as seeds, inoculants, biopesticides, improved plants, and growth regulating hormones for animals, many of which are being developed for commercial markets (U.S. General Accounting Office 1989).

80. A large share of the research is being done in commercial laboratories with the objective of marketing products under patent protection. An important point to consider is that these new products must meet market competition and to be successful they must be superior in quality and be available at a reasonable price that represents their extra value.

81. While some may view this commercial protection as a threat to the time-honored tradition of free information through agricultural extension, others may view the commercial influence as an extra benefit and opportunity to work with many new and improved products. Those who are not in favour with commercial exploitation of biotechnology companies should remember that, without research and testing there might not be as many opportunities to obtain the benefits from new discoveries in biological science.

82. A valid criticism of the commercial companies is that they only work on those product opportunities that have substantial market volumes and profit margins whereby they can recoup their expenses. The unfavourable aspect of this situation is that some of the low volume, low margin, or non-market products common to developing countries are ignored. This problem may be partially solved by the international research institutes and public institutions assuming a greater role in improving crops of low market volume but for which there is a great societal need.

83. Given that this assessment deals with the opportunities for applying biotechnology to African countries, a reminder seems necessary that African lands have severe constraints to production of food. In addition to the obvious environmental stressess of drought, salinity and temperature extremes, there are others associated with such conditions as low national incomes, inadequate infrastructure and utilities, limited availability of investment funds, and traditional agricultural conservatism.

IV. MONITORING AND EVALUATION OF THE IMPACT OF BIOTECHNOLOGY ON AGRICULTURAL DEVELOPMENT: THE NEED FOR A BIOTECHNOLOGY STRATEGY

84. All technologies and all agricultural systems that can increase productivity per unit of input are of interest to African countries. Biotechnology that has helped to advance agricultural production and has advanced commercial production is uniquely able to increase agricultural productivity, and should be embraced in the developing countries of Africa.

85. Biotechnology has been used as a means to bypass or traverse in a shortened time, certain stages in agricultural development. African countries must therefore be concerned and are indeed concerned that delay in adopting this latest technology to agricultural development might put them even further behind the industrialized nations in agricultural development capabilities.

86. The introduction of biotechnology to African countries promises both considerable benefits and the risk of significant dislocations for them. The challenge is to give a decisive momentum to activities involved in the sustainable development and application of biotechnology for African countries and to avoid any adverse side- effects such as loss of germplasm, displacement of exports, substitution, negative impact on the labour market, etc.

87. Unfortunately, African countries have already begun to experience the negative impact of substitution processes to which applications of biotechnology give rise; for instance, cocoa butter production through tissue culture or via enzymatic transformation of palm-oil and the manufacturing of plant secondary

matabolites such as fragrances, and flavours constitute a serious loss of exports earnings for African countries which within few decades from now may not find markets for their cocoa, coffee, vanilla, palm oil, etc.

88. The commercialization of biotechnology, as with all other innovative agricultural activities, because of its capital-intensive nature and international competition, leads to ever-increasing dependance on private sector research and development investment. Securing returns on investment is conducive to privatization of know-how and to pressures for stringent regulatory mechanisms (patenting).

89. Whilst African countries cannot prevent such applications of biotechnology advances in the industrialized countries, they can, at least, limit their negative impacts. This presupposes the virtual discontinuation of Africa as a trading partner and supplier of raw-agricultural materials to the industrialized countries and the creation of a self-contained African regional market within which autonomous and authentic development can be pursued. Africa would have to move away from the false assumption which have, up to now, dominated the development thinking of the continent.

90. The preceding short description of positive and negative considerations pinpoints the need for the adoption of innovative strategies and mechanisms to appraise, monitor or evaluate the impact of biotechnology on African agricultural development. What kind of international cooperation should be foreseen in this case remain a question of paramount importance.

91. Development or transfer of biotechnology in Africa is not only hampered by the inadequacy of financial resources but by the insufficiency of mechanisms to analyse global technology trends, inadequate science and trained manpower, unfavourable legislative, political and socio-economic frameworks.

92. Within this context, African strategy should include both the provision of direct support for biotechnological research and the fostering of a climate where biotechnology can thrive - or not thrive, as the case may be. A large part of that climate will depend on a government's policies for building national capability and strengthening or developing international cooperation.

A. Building national capability

93. The strategy to build local capability in biotechnology to serve agricultural development in Africa should be viewed under the following elements:

1. The political will

94. Governments should accept and commit themselves to the development of biotechnology. In fact, contrary to developed countries where biotechnology research is controlled by the private sector (Multinational corporations), governments will have to play a very important role in the absorption of appropriate biotechnology in Africa at least during its introduction phase. Furthermore, if biotechnology in Africa is to be geared to the improvement of agricultural development at the small farmers level, there is no doubt that this could be done only with the public sector's assistance.

95. Also, most biotechnologies in developed countries are oriented to the production of substitutes to export commodities with little attention to food crops. Solving the food crisis in Africa should therefore be one of the main objectives of biotechnology absorption and appropriation, therefore, this can be done only through government intervention. In short, governments should be willing and committed to assist the development of biotechnology so that appropriate supportive inputs can be provided to biotechnology research programmes.

2. Formulation of appropriate policy

96. It is necessary for each African country to determine its priorities in term of agricultural development and drawing maximum advantage from available resources.

97. In this regard, measures should be taken to create an appropriate policy framework which will include the following:

(a) The setting up of broad objectives and goals of the national biotechnology programme and policy for managing access to relevant biotechnology;

(b) The definition of the relative roles of public and private sectors in research and commercialization, as well as policy regarding intellectual property rights;

(c) The establishment of inventor certificates in order to maintain the nature of biotechnology-based innovations as a public good and at the same time to reward researchers;

(d) The establishment of guidelines for biotechnology research with due attention to safety and environmental consideration;

(e) The establishment of an organizational machinery to implement the national biotechnology programme for agricultural development;

(f) The establishment of appropriate mechanism for cooperation in the research programmes at subregional, regional and international levels.

3. The identification of priorities

98. The uses of biotechnologies described here as well as many others could be applied within Africa to increase food production in the short, medium and even in the long term and alleviate the food crisis; but priorities have to be determined.

99. Research priorities in biotechnology are currently determined by commercial prospects and the global strategies of multinational corporations rather than by what is good or desirable for the poor in Africa. Biotechnologies can be fruitfully employed to develop varieties which require lower inputs of agro-chemicals such as fertilizers, pesticides that would be more appropriate for millions of small and marginal farmers in Africa.

100. But instead of developing such varieties, it has been developing seeds resistant to proprietary pesticides, hence making them more dependent on chemicals. These trends, therefore, suggest that the pro-poor potential of biotechnology will not be exploited to serve the interest of small and marginal farmers.

101. African countries should identify certain areas and priorities and well-defined research targets in view of their development objectives, available resources, capability and technological feasibility. In short, African countries should concentrate on building capabilities in well established, proven and relatively simpler techniques, mainly those leading to increased agricultural productivity through tissue culture, genetic engineering, MOET, BST and PST, aquatic culture, or increased efficiency in food processing.

102. In African countries, priorities in biotechnology programmes for agricultural development should attach importance to the development of low input sustainable farming systems to benefit marginal and small farmers. These farmers operate generally at the subsistence level and are naturally risk-prone. However,

it is likely that the acceptance of new varieties will greatly improve if they are developed in cooperation with local farmers, using their knowledge to improve local farming systems.

4. Human resources development

103. Training of scientific and technical manpower is the most crucial element of a strategy to build local capacity. In the immediate future, African countries should train enough biotechnologists abroad while taking action to create strong faculties of well-qualified experts in interrelated disciplines that constitute biotechnology, in their local universities. This objective would not be achieved unless there is an appropriate political and social environment conducive to persuade African scientists to return from abroad.

104. In African countries, the diffusion of research results has often been a bottle-neck in the adoption of new technologies. In the case of biotechnologies, care must be taken to ensure speedy and effective diffusion of technologies. This is possible through the training of extentionist workers, the linkages between biotechnology programmes and rural development agencies.

105. Additionally, because of the rapid progress in biotechnology, access to basic scientific information is needed. But, given the trade secrecy of biotechnologies by multinationals, the flow of this information through usual channels will remain very restricted. Therefore, alternative sources of information through network systems sought be sought.

B. Strengthening international cooperation

106. Regional and international cooperation is certainly one of the means of promoting biotechnology transfer for agricultural development to Africa. Regional and international cooperations can in fact be set up considering the common problems encountered, carrying out joint research projects and obtaining results applicable to countries within a region or subregion.

107. Such cooperation has the advantage of involving industrialized and developing countries within the framework of bilateral or multilateral agreements, patents policy, as well as private institutions including multinationals. Joint ventures and co-financing of projects by public and/or private national and international institutions are better ways of sharing technological know-how.

108. As far as African countries are concerned, while making great efforts to train experienced scientists and highly qualified engineers, they would in the short run depend on licensing inventions and collaboration with multinationals until they are able to build up their own centres and research teams.

109. In fact, a fruitful cooperation needs to be established between African and industrialized countries to mitigate the effects of technical secret and harsh competition for the appropriation of biotechnologies through patents and exclusive exploitation rights; cooperation with reciprocal benefits will no doubt contribute to an equitable distribution of returns from the application of biotechnologies for agricultural development.

110. However, as observed earlier, experience of developed countries may not always be suitable for African countries. Therefore, the strengthening of South-South cooperation could be very useful also. For instance, training of African biotechnologists in industrialized countries raises the question of priorities, but the experiences of developing countries notably in Asia and Latin America (India, Brazil, Malaysia) which embarked upon biotechnology programmes in the 1980s may be more appropriate and complimentary.

111. Nonetheless, cooperation among African countries is very important since it enables:

(a) The undertaking of research programmes of common interest jointly to avoid duplication and save scarce resources;

(b) The pooling of resources and capabilities which may enable African countries to undertake projects they might not be able to do individually;

(c) Strenthening of the already existing institutions for common goals (ICIPE, ITTA, etc.).

112. Given the initial high cost of investment needed for infrastructural facilities, African countries will stand to gain by pooling their resources to create regional or subregional research and/or training centres rather than embarking on the establishment of poorly equipped and inefficient national institutions. The latter should be strengthened to carry out adaptive research using the results of the former.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

113. Biotechnology offers several interesting opportunities for achieving agricultural development and self-sufficiency in food production. In plant production, biotechnology can contribute to improved nutrient availability and to control of pests and diseases, providing desease-free seeds which can be high-yielding, pest resistant and which can stand harsh environmental conditions. Biotechnology can also contribute to an improved local processing of agricultural raw materials through fermentation.

114. In animal production, appropriate biotechnology can improve livestock production in farms of all sizes in three ways: (a) through improvement of animal nutrition; (b) through improved animal health; and (c) improved animal reproduction. Although genetic engineering of plants and animals may be feasible today, the major benefits are likely to emerge in the future. However, application of a particular biotechnology to agricultural or animal production must be carefully considered.

115. Since current agriculture has concentrated on the large-scale farming systems, agricultural biotechnology may be more readily and easily adopted by large-scale producers than by the small-scale farming systems. It is therefore essential to develop specific criteria for the selection, introduction and application of biotechnological innovation to be able to improve food production at both the small-scale and large-scale farm levels.

116. Although Africa's food crisis is confronted with problems associated with traditional agriculture practices essentially characterized by colonial, political, social, structural, economical, technical and environmental factors, the cardinal issue facing African policy-makers and biological scientists is how to solve those critical problems that relate to agricultural development.

117. Concerning the Green Revolution which succeeded in Asia, the important lessons for Africa is that research must develop technologies which not only bring about significant increases in yields but also take into account the needs and circumstances, i.e., the whole environment of the farmer - whether large or small. Since, however, the constraints are more severe for the resource-poor farmer, and especially those in marginal, risk-prone areas, they should be the central focus of research efforts.

118. So what are the critical issues for agricultural development in Africa? It would seem that a more clearly focused consideration of these issues must be viewed within the context of the present state of agricultural research in the region, the technology already available and how well it is adapted to the resources, culture and eco-system of the farmer. It is only within this context that issues regarding new

policies, strategies and approaches can be better examined with respect to meeting future agricultural development with food self-sufficiency and food security objectives. 21/

119. However, to exercise its choice, a mechanism must be created for the study and presentation of the options to African countries so that the latter may select the most suitable policies designed to bring about the desired end. Building national capability and strengthening subregional, regional and international cooperation should characterize the African strategy for monitoring and evaluation of the impact of biotechnology for agricultural development.

120. Building national capability for biotechnology for agricultural development means: political will from African Governments which should accept and commit themselves to the development of biotechnology which can be considered as a tool for food production; creation of an appropriate political and social environment for scientists return and creativity; formulation of appropriate policies for improvement of agricultural productivity; establishment of appropriate mechanism for cooperation; human resources development by training manpower, by establishing and equiping national or subregional and regional universities and research institutes for development and promotion of biotechnology for agricultural development.

121. Regional and international cooperation are needed for promoting environmentally and economically sustainable biotechnology transfer and as a means for realizing its promises in reversing the current pathetic situation of malnutrition, hunger, famine, diseases, poverty and death.

122. Through international cooperation and support and encouragement of twinning of high education and research institutions, biotechnological centres can be established and maintained, joint advanced training programmes and investigations undertaken, international biotechnology network established, Biotechnology database and information exchange services developed and advice in formulating national policies and programmes in biotechnology for agricultural development provided to governments.

B. Recommendations

123. Most African countries have very limited capacity to appraise, adapt to and monitor biotechnology which has direct impact on agricultural development.

124. This is why African countries need to build national capability and strengthen or develop international cooperation.

125. Building national capability means political will or commitment from African Governments, formulation of appropriate policies, identification of priorities and human resources development.

126. Strengthening or developing international cooperation means joint ventures and co-financing of projects by public or private national and international institutions, cooperation within the framework of bilateral or multilateral agreements, patents, as well as private institutions including multinationals.

127. In a parallel direction, some mechanisms are required to facilitate access to new and already existing biotechnological products and processes in African countries, while protecting the legitimate interests of their inventors.

21/ Feeding the future: Agricultural development strategies for Africa, Casin/Sasakawa Africa Association/Global 2000, Workshop 1989, Accra, Ghana, 1 to 3 August 1989.

128. These mechanisms could include patents and/or licensing arrangements, and other contractual agreements. International development agencies like FAO, could play a crucial and useful role in facilitating such access, and in negotiating for the licencing of new technologies to apply to commodities important to African countries.

129. In addition to these mechanisms, there is a need to support social science research on the economic assessment of the impact of biotechnology on African agricultural development, especially in relation to:

(a) Potential negative effects from substitution of African commodities by agricultural products produced in industrialized countries;

(b) Determination of priorities for investments in biotechnology on agricultural development;

(c) Social and economic returns to investments in public and private sector using biotechnology as a tool for agricultural development.