NOTES ET DOCUMENTS

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Plants: Yesterday, Today and Tomorrow

Document of the Plant Breeding Unit

CIRAD

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The series "Notes et documents" is aimed essentially at informing members of CIRAD. Its distribution is therefore limited.

Contents

Doubly-Green Revolution: What are the plant breeder's commitments?

The international community has become more and more anxious about the serious weakening in yields and production in tropical agriculture over the last ten years. This anxiety is enforced by the fact that the decrease in population growth rates is very slow (Cairo conference).

These two observations have led us to predict the return of a food deficit in India, China and Southeast Asia in the medium-term, and in East Africa and Mexico in the short-term.

Besides this, the internal consumption of countries with high industrial growth, such as Thailand, Indonesia and Brazil is accelerating, causing us to predict a deficit in agro-industrial products (timber, rubber, oils...) for export or national consumption.

In order to rectify the current trend in stagnation of agricultural output in tropical areas, we must mobilise our energy and means of research. The dynamics being sought is aimed at a Doubly-Green Revolution, to ensure progress and sustainability whilst at the same time respecting the planetary environment.

The conditions for this challenge of a Doubly-Green Revolution were identified by a group of experts in May 1994, who came together to envisage reforms in the international agricultural research system. These experts formed the Conway group.

Their object is to obtain higher yields, at the lowest possible cost, with the least possible damage to the environment. At the same time, the best local resources (physical, biological or human) should be used to improve the living conditions of rural households, particularly the poorest, and to generate local economical activities and incomes. This must be achieved on a sustainable basis.

What contribution can be made by plant breeders at CIRAD? The scientific committee meeting of the plant breeding unit held on November 18th, 1994, led to a discussion on this very point. To reinforce the debate, the research workers at CIRAD established the sheets on "Plants: Yesterday, Today and Tomorrow" presented in this document. These contribute to the programme "Doubly-Green Revolution: aims, methods and patterns".

Situation

Main constants in tropical plant breeding

The plants taken into consideration in this study were all cultivated by our ancestors with a few exceptions such as oil palm, rubber plant, and Robusta coffee, whose cultivation only goes back as far as a century ago. Domestication of the cotton plant, maize and rice may be mentioned as going back to several thousand years ago, cocoa and pineapple to the pre-Columbian period and citrus to the 10th century...

Rational genetic improvement has only been practised for about the last century, although we may speak of selection programmes for cotton and citrus in a slightly earlier context. The "plant breeders" have inherited the monumental task of selection that was operated over the centuries by the "farmers-improvers".

All of these crops have, at some time or other, been through periods of wide dissemination which has led to great adaptation variability. This variability has already undergone a certain erosion, but it is still maintained. We may still exploit this by collecting local varieties in direct relation with the farmers, which is no longer possible for many plants in temperate countries.

We must also note that breeding for certain crops results in the exclusive use of improved varieties. This is the case, for example, of oil palm, rubber and cotton. But for other plants, such as coffee, cocoa and maize, local varieties are still widely cultivated. The use of improved varieties may still constitute an exception: less than 10% of the world's coconut palm groves have been planted with improved varieties.

Finally, certain innovations have enabled us to make relatively fast progress. But most plant breeders consider plant breeding as a continuous process.

Even when this progress seems spectacular, it still takes time for the user to apply new methods or to adopt new varieties.

CIRAD's breeding aims

Until now, yield has always been the main objective of plant breeding.

Resistance and tolerance to parasites has quickly become a priority. This consideration began at the turn of the century: with coffee rust in 1900, *Phytophthora* on pineapple in 1914 and on citrus fruits in 1920, Sigatoka disease on banana in 1940 as well as witches broom on cocoa plantations. The complete list would be very long. It seems that this aim is gaining more and more importance.

Improvement in plant physiology and architecture began a little later. Among the many examples quoted, we may mention varieties of oil palm with reduced growth in height, short stature varieties of rice and coffee, etc.

One of the main criteria for cash crops has always been quality; especially the length of fibre in cotton, taste and appearance of citrus and other fruit trees.

Genetic resources

The potential for plant improvement is developed from intra and intervarietal variability. CIRAD has carried out polymorphism studies using biochemical and molecular markers on many species (rice, sugar cane, sorghum, cotton, cocoa, rubber...) in order to find out more about the organisation of this variability and its spatial and varietal distribution. CIRAD participates in the conservation of the world's genetic resources and has international mandates for several species.

Breeding methods

The use of the most effective breeding schemes and experimental designs is essential for this work. CIRAD's biometry unit helps the plant breeders in this area.

Technological innovation

The development of hybrids and the control of vegetative propagation, especially with woody species, constitute two important steps in plant breeding.

Today, the CIRAD laboratories are preparing the progress of tomorrow: genome mapping, markers-assisted selection, vegetative propagation using in-vitro culture, haploidisation, genetic transformation...

Development

For cash crops, CIRAD has long been associated with companies which ensure the multiplication and distribution of its varieties: cotton, rubber, oil palm... This capacity for developing varieties must also be improved for food crops.

Proposals for the future

Will the plant breeder be able to take action for this new aim of a Doubly-Green Revolution? It is clearly apparent that various criteria define this objective. The answer must be an overall one for proper insertion into agriculture, with each criterion bearing a little weight in relation to the whole. But it is necessary to take practical and concrete action to determine the major factors to be considered in a multifactorial approach.

Increasing yields

The problem of yields reaching their highest point is never mentioned. No plant breeder doubts his capacity to obtain better yields by genetic means; this improvement may be acquired directly, by increasing production, or indirectly, by controlling harmful factors.

We should increase the yields of tropical crops: responding to ever-growing needs means reducing the pressure on fragile and under-productive marginal lands. We must remember that the notion of increasing demands is often forgotten in the northern countries whose already intensive agriculture satisfies these needs. But, obviously, increase in yields must be sustainable and at reasonable cost.

Reducing production costs

All plant breeders consider that there is much to be gained by substituting the use of costly chemicals by genetic control of parasites.

Varietal tolerance towards abiotic stresses—drought, flooding, acid soil...—also represents strong potential for reducing agricultural costs.

However, we may suppose that the more productive crops are, the more it becomes necessary to restore to the soil the exported elements. Already in Africa, the amount of fertiliser applied to the soil is insufficient to maintain soil fertility in cotton-growing areas. There are only a few less demanding plants, such as rubber, which do not cause any risk of soil deterioration.

Using local resources

Not only do local varieties represent particularly interesting elements among the genetic resources to be exploited, they are also a source of material for breeding which cannot be overlooked.

Local cultivars are a precious contribution to the creation of varieties in the field of "major crops"; we must also take into account the very large number of "minor species" whose potential for development has not yet been clearly defined. Should we limit ourselves to the improvement of major species or concentrate more on a large number of minor species? Would it be a wise choice to put the diversity of existing species in the background? Indeed, it costs the same to work on a major species as on a minor species. For the same amount of money, increasing the number of species comes down to putting less effort into each one of them. Forestry workers are particularly sensitive to such consderations: a large number of species are underexploited, not due to lack of interest but lack of funding.

Protecting the environment

Genetic control of parasites avoids the use of polluting chemical molecules. But environmental preservation also means recovering degraded areas and extending agriculture to marginal areas, by selecting new varieties which may adapt to these more difficult conditions. We may give the example of the oil palm's resistance to drought as well as rubber, rice and many others. Perfecting these cropping systems involves pluridisciplinary action.

Transgenic plants are a case apart. The incidence of their spread over natural tropical environments, where there are still many wild relatives has yet to be analysed.

Developing in a viable and sustainable way

It has been envisaged, for all crops, to cultivate varieties with polygenic, stable resistance. In order to maintain long-term perennial populations, these varieties must be resistant to destructive, abiotic factors, especially to wind and drought.

Developing in a viable and sustainable way means proposing varieties with good stability over time and space, taking into consideration the specificity of agricultural conditions in tropical areas, characterised by a very heterogenous environment.

Lastly, sustainability means ensuring that the farmer is constantly supplied with improved plant material.

Improving farmer's living standards

By taking the farmers' particular restrictions into account, the plant breeder is confronted by an apparent contradiction. It is often said that the varieties to be supplied to the smallholders must be hardy which would seem to mean simple. In fact, these are more sophisticated, genetically speaking, for they require great efficiency in a poor environment coupled with resistance to stresses and abiotic factors that the farmer cannot control.

Should we not therefore concentrate on obtaining two types of variety: one type adapted to intensive agriculture with inputs, and one less demanding type which would be more stable in its environment?

We aim to improve several varieties that are adapted to the cropping systems and financial capacities of the user. We should note that more and more farmers are seeking intensification, but, considering the diversity of agricultural contexts, the varietal offer must remain large.

Conclusion

The plant breeder is already responding to the demand expressed by the farmers. A new methodological arsenal is being set up to help him.

The steps that must be taken by the plant breeder require continuous effort. Any break in this continuity may cause us to question the results so far and, moreover, may compromise our capacity to respond to the new aims.

Already strongly committed, today's plant breeder will certainly prefer that we speak in terms of evolution, rather than a revolution. By sheer necessity, his intervention must go along with the direction that was already taken, centuries ago by all the farmers and research workers before him.

Banana

The banana plant is a herbaceous monocotyledon from the family Musaceae. In the wild it could grow permanently but it is used for semi-perennial cultivation.

The banana plant grows in open environments (woodsides and forest clearings) in humid, tropical regions. Wild banana plants are diploid and reproduce by sexual means.

Cultivated bananas are polyploid (diploid, triploid, tetraploid) natural hybrids of two species of *Musa: Musa acuminata* (genome A) and *Musa balbisiana* (genome B).

Most production is based on sterile, triploid clones that are propagated vegetatively.

Banana in the past

The centre of origin for bananas was located in Southeast Asia (the Philippines, Papua New Guinea, Indonesia), where they may still be found in their wild state today.

Domestication, which is very old, focused on parthenocarpic mutant types which had the advantage of being seedless. This characteristic was strongly improved right from the very beginning of domestication. These parthenocarpic, diploid types gave way to sterile triploids by spontaneous crossing. Depending on the respective supply of A or B genomes within these triploids, different genomic groups may be distinguished: AAA, AAB, ABB... Despite these different genomic formulas, triploid bananas have low genetic diversity compared with diploid ones.

From their centre of origin, bananas very quickly migrated towards the Indian peninsula, East Africa and the isles of the Pacific.

Among these, subgroups could be distinguished: AAA and AAB dessert bananas, AAA beer and cooking bananas in East Africa, and AAB plantains in West Africa and Latin America.

In the 16th century, bananas were introduced into Latin America from the west coast of Africa and the Canary Islands.

In the 19th century, the first dessert banana plantations were set up: in Latin America (San Domingo, Cuba and Jamaica), with the Gros Michel variety, and with the Petite Naine variety from the Cavendish subgroup in the Canary Islands.

These plantations were able to supply the European and North American markets which have been progressing since the 19th century. In 1915, Europe imported over 100,000 tons of bananas from Jamaica.

It was at this time that cultivation of the Gros Michel dessert banana started in West Cameroon. In the Carribean and Latin America, cultivation of Gros Michel bananas intensified from 1930 onwards. In the Canaries, the Petite Naine variety of the Cavendish type also became part of intensive production.

In 1940, wilt disease caused by *Fusarium oxysporum* appeared on the Gros Michel variety. This disease was fatal to plantations and was to cause the progressive disappearance of cultivation of this variety. Cavendish banana trees are naturally resistant to this disease and these were grown in Africa (Guinea, Côte d'Ivoire, Cameroon) and the French West Indies.

From 1960 onwards, there was a reconversion in varieties: all the Gros Michel banana plantations were replanted with cultivars from the Cavendish subgroup. From then on, all bananas for export were to be the Cavendish type.

Faced with the arrival of *Fusarium* wilt, banana-producing countries and multinationals started breeding programmes on Gros Michel for resistance to *Fusarium* wilt—from 1930 in Jamaica and 1950 onwards in Latin America, particularly in Honduras. These programmes came to use dessert hybrids.

In parallel with this research, IFAC (Institute of colonial fruits and citrus which is currently CIRAD's fruit and horticultural production department) began to implement cultural techniques adapted to the Cavendish variety in Guinea, Côte d'Ivoire, Cameroon and the French West Indies. These varieties offer possibilities of intensification: under certain conditions yields of 60 t/ha were obtained.

In the 1980s, a new disease, the Sigatoka or black leaf streak, appeared, not only on Cavendish bananas but also on plantains. Chemical control was mastered on Cavendish but because plantains are grown in peasant farming systems, these could not benefit from it. Control of this disease on the latter, then, came through breeding. INIBAP (International Network for the Improvement of Bananas and Plantains) was set up with the help of IRFA (Institute of research on fruits and citrus which is now CIRAD's fruit and horticultural production department), by a group of donors, one of which was France.

IRFA began its breeding programme on plantains and other banana trees in the 1980s. Other research centres, in particular those that had acquired a certain experience in improving the Gros Michel variety spread their selection programmes towards resistance of dessert bananas to Sigatoka disease but also towards bananas for local consumption (Brazil, Nigeria, Costa Rica...).

Absence of genetic diversity and sterility of cultivated triploid banana trees are factors limiting their improvement. Collecting was carried out in the 1980s by IRFA and INIBAP in the area where bananas originated from. For IRFA these concluded with a collection of wild and cultivated forms of diploid bananas which were to become the basis for future breeding programmes. This collection, established in Guadeloupe contains 350 accessions that have been identified and described from the point of view of their morphotaxonomy and genetic structure.

Banana today

Nowadays, bananas are cultivated throughout all humid, tropical areas. World production is estimated at 70 million tons among which only 10 million tons for export. Bananas, particularly cooking bananas, remain a mainly autoconsumable product and are for local commerce in most of the countries where they are produced. Uganda is the greatest producer of bananas with 8 million tons, followed by Brazil, India, Ecuador and Costa Rica.

Industrial plantations, mainly situated in Latin America, only represent 10 to 15% of the world's banana production. These plantations supply dessert, Cavendish-type bananas and reach average yields of 20 t/ha to over 40 t/ha.

Most plantations of bananas for local consumption are traditional and consist of varieties of cooking bananas or beer bananas for the local market. Bananas are often cultivated there along with other crops.

Banana breeding aims, firstly, to gain resistance to disease (Sigatoka disease and various viruses), parasites (nematodes) and pests (weevils) which are rife in these plantations. Quality of fruit is also an important criterion for dessert bananas.

Two radically different breeding strategies are developed.

One of these, based on the improvement of triploids, is used in the Honduras, Brazil, and Nigeria. This aims mainly for resistance to Sigatoka disease and begins with crossings between triploids and resistant wild or improved diploids, following the same scheme as that used to pass on resistance to *Fusarium* wilt disease with the Gros Michel variety. The triploids used must have residual fertility, which excludes the use of completely sterile Cavendish bananas. These crossings result in a certain dead end as they produce fertile tetraploids with the disadvantage of having a long cycle and other unfavourable agronomical characteristics. However, hybrids of tetraploid plantains with a good level of resistance to black Sigatoka disease are now being produced in the Honduras. These hybrids, which are often attacked by viruses, cannot be exploited today. Indexing methods are still being developed by INIBAP in collaboration with CIRAD's fruit and horticultural production department.

The other method, based on the improvement of diploids, has been under development by IRFA since 1982. Diploids are improved from within the collection on the basis of characteristics they have in common with cultivated triploid bananas and their resistance to Sigatoka disease. These diploids, once improved for the characteristics required, are doubled with colchicine, then crossed with another diploid in order to give triploid hybrids. This is how the first triploid hybrid varieties of dessert and cooking bananas which were resistant to Sigatoka disease were created in 1994. These are now entering into their validation phase.

Dessert banana obtained via this method produces bananas which are different from the Cavendish variety. The market for this new type of banana should develop.

In parallel to this conventional breeding programme, work on different biotechnologies is being carried out, not only with the aim of improving Cavendish, but also other banana trees. Studies on somatic embryogenesis, protoplast culture and transformation techniques are also well advanced.

Lastly, production of vitroplants has been fully mastered with banana plants. The market is estimated at 50 million vitroplants per year. Vitropic, a subsidiary of CIRAD, has a production capacity of 1 million vitroplants per year.

Banana in the future

Breeding bananas remains largely dependent upon the genetic resources collected and conserved in-vivo through a network with CIRAD in Guadeloupe, and in-vitro at INIBAP on a worldwide scale. New technologies will enable us to exploit these resources more efficiently.

We may imagine that genetic transformation will be used to introduce genes for resistance to disease and pests into the Cavendish variety very shortly. The banana's genome mapping will enable us to spot and isolate the genes involved in resistance. This research is being pursued at CIRAD. Genetic transformation associated with somatic embryogenesis and/or protoplast culture will allow us to create new, transgenic varieties, in particular for sterile banana trees.

All these new techniques together will lead to diversification of the bananas on sale to the consumer and a high quality banana production that respects the environment.

Citrus

The term "citrus" corresponds to three genera: *Citrus, Fortunella* and *Poncirus.* These are all from the family Rutaceae.

The large majority of citrus are diploid. Only a few natural polyploids are known about such as the Tahiti lime. Citrus are propagated vegetatively.

Their breeding systems are varied. With many cultivars, polyembryonic seeds are obtained, causing partial apomixis. In fact, the surnumerary embryos, coming from the cells of the nucellum, have the same genotype as as the mother plant.

Only two species *(C. medica* and *C. grandis)* have only monoembryonic seeds. With certain cultivars, gametophytic self-incompatibility systems and gametic sterility can be found.

Citrus in the past

Citrus originate from Southeast Asia where they have been domesticated since as far back as several thousand years ago. The Mediterranean basin constitutes a second important centre of diversification for certain species (sweet orange, mandarin and lemon). The pomelo is the only species that does not come from Asia as it first appeared in the Carribean region.

Distribution of citrus throughout the world came about very slowly. In the 12th century, citrus fruits were introduced into the north of the Mediterranean basin (lime, sour orange, lemon). Sophisticated horticultural practices such as grafting had already been mastered.

In the 15th century, sweet orange and mandarin were brought back from Asia by Portugese navigators.

From the end of the 15th century, citrus fruits were introduced into the Carribean region and the American continent.

In the 17th and 18th centuries, there was a fashion for orangeries in the great European courts. Cultivation in pots developed along with the elaboration of complex substrates. Citrus were thus used for decoration and perfumes.

At the end of the 19th century, and the beginning of the 20th century, the first industrial orchards were planted in Italy, Spain, North Africa and America. In the Mediterranean basin, sweet orange were obtained by grafting onto the runners of citron.

In the 1920s, the *Phytophthora* epidemic led to the adoption of rootstock cultivation, generally on sour orange.

In the 30s, *tristeza* disease caused great damage to the sweet-sour orange associations. The sour orange was therefore replaced by other rootstocks, in particular *Poncirus trifoliata* and its hybrids with *Citrus.*

The 50s saw the development of modern, efficient citrus fruit growing with the setting up of the first sanitation programmes for plant material. Many diseases of citrus are transmitted by grafting. It is therefore necessary to carry out sanitary selection or sanitation of the mother plants of propagated varieties.

The first cleaning technique used was the selection of nucella plants, as citrus diseases could not usually be transmitted by seed. Since 1970, this technique has been replaced by thermotherapy and micrografting of meristems.

The range of varieties cultivated during the first half of the 20th century can be characterised by a certain number of greater standards within which variability is very limited. The most commonly used rootstocks are the sour orange and the Cleopatra mandarin.

Clonal selection of natural mutations, the traditional method for improving citrus, does tend, however, to increase the variability of each of these standards, particularly as far as earliness, calibre and yield are concerned. This leads to strong agronomical and pomological diversification, especially for sweet orange, clementin and lemon.

A few colouration mutants (natural or induced) have also been created. Pink or red pomelos came quickly onto the market in the 1970s.

Sexual hybridization has been practised since as far back as the end of the 19th century. It turns out to be profitable for easy-peeler citrus such as mandarins, which are consumed fresh. Interspecific hybrids between pomelo and mandarin have been created (tangelo Nova, Orlando, Minneola). A few hybrids among mandarin have also proved to be interesting.

But the greatest progress obtained by means of sexual recombination concerns rootstocks, with the creation and selection of intergeneric *Citrus* x *Poncirus* hybrids which associate strong resistance to *tristeza* with high yields. Troyer and Carrizo citranges, *Poncirus* x orange hybrids, have undergone considerable development throughout the whole world.

Since the 1950s, work on polyploidy has been carried out to improve citrus fruits. It aims at obtaining triploid seedless cultivars, as Tahiti lime which is a spontaneous triploid. Triploids are sought from hybridizations between diploids and spontaneous tetraploids or from seedlings of crosses among diploids. Very few commercial cultivars result from these programmes. We may mention two grapefruit x pomelo hybrids: Melogold and Oroblanco.

Despite the diversity of breeding strategies, variety diversification still depends largely on clonal selection from somatic mutations fixed by vegetative propagation.

Citrus today

Citrus fruits are cultivated throughout the whole world between a latitude of 40° North and South, which corresponds to hot, temperate, tropical climatic areas. Environmental conditions are very diversified thanks to a widespread range of rootstocks. The estimated surface area of plantations is over 3 million hectares. The majority of these plantations are industrial, but there are also smallholder plantations intended for domestic consumption in Africa and Asia.

Citrus fruits represent the world's largest fruit production with over 83 million tons produced in 1994. Oranges make up 70% of this production. Around 35% of all citrus fruits produced is intended for transformation. The main countries producing them are Brazil, the United States and China.

More and more orchards are being established with healthy plant material. Crop rotation may be very fast, like in Spain, with the help of overgrafting. Insecticidal treatment is particularly widespread in areas where insect-transmitted diseases such as greening, *tristeza* and stubborn are rife.

The main criterion for selection today is thus resistance to diseases and pests. This resistance is sought, either in rootstocks or within cultivars, depending on the way the disease is transmitted.

For rootstocks, the main aim is resistance to *Phytophthora* sp., nematodes and *tristeza,* a viral disease which is particularly destructive to orchards. In the United States, resistance to blight, a degeneration disease, has also become a priority.

For cultivars, research is being made into resistance to greening, citrus canker, *mal secco* and leaf spot, depending on the region where these are grown.

Other aims are also being pursued: adaptation to different soil types and the cold for rootstocks, productivity and quality of fruits for cultivars. The criteria of selection are different according to the destination of production. Transformation involves highly productive varieties and fruits with a high sugar and juice content. Fresh fruit trade gives privilege to organoleptic qualities (flavour, acidity...) and pomological qualities (such as easy-peeling, seedlessness, colouration, etc.).

Conventional breeding methods for citrus are still widely used. But the recent developments in biotechnology has allowed us, on one hand, to increase the efficiency of breeding programmes and, on the other hand, to explore new ways of creating different classical varieties.

The first programmes for creating varieties using biotechnological support were set up at CIRAD in 1989. These concerned the improvement of rootstocks (resistance to diseases and adaptation to pedoclimatic conditions) as well as the diversification of the mandarin range (quality of fruit and duration of the production period). They called for somatic embryogenesis, hybridization and molecular markers development. The first ever somatic intergeneric *Citrus* x *Fortunella* hybrid vitroplants were thus obtained in 1994. Other combinations for cultivars or rootstocks also began. Spontaneous triploid mandarins were obtained by in-vitro saving of embryos which had been selected by flow cytometry.

In the United States, rootstocks derived from somatic hybridizations are currently under agronomical appraisal.

However, the rootstocks or cultivars resulting from these new programmes have not yet been used in production orchards. Most orchards have been planted with varieties that were improved by classical methods.

Citrus in the future

A great many of tomorrow's orchards will be planted at high density on dwarfing rootstocks in order to accelerate the beginning of production, reduce harvesting and pruning costs and increase yields.

The conquest or mere maintenance of production areas are important stakes, considering the increase in problems of salinity and phytosanitary conditions. It would seem indispensable to find genetic solutions to these restrictions. The levels of pesticide treatments have indeed got out of hand in certain areas.

Development of biotechnological methods will bring great progress to this area for years to come.

For citrus, research on somatic embryogenesis and somatic hybridization has already advanced considerably. The first somatic hybrids should come into use as rootstocks in commercial orchards in the near future.

Work on gene mapping is beginning to bring precise information about the location of genes with agronomical interest, such as the immunity gene for *tristeza.* This will go towards transgenesis, which is particularly interesting for varieties whose very heterozygotic structure does not allow us to use sexual reproduction for breeding. This work will also help towards finding ways of selecting markers.

Finally, flow cytometry, which has recently been developed on citrus fruits, finds its direct application for evaluating ploidy levels in plantlets resulting from sexual or somatic hybridization. Being able to spot polyploidy rapidly with the help of this technique allows us to use them effectively in breeding programmes.

All of these techniques together should lead to a greater exploitation of genetic resources and polyploidy in citrus.

Cocoa

The cocoa tree, *Theobroma cacao,* belongs to the family Sterculiaceae. Its growth is dimorphic: orthotropic and plagiotropic. It enters into production at between 3 to 4 years old. It may reach 12 m in height but never grows higher than 6 m in plantations.

The cocoa tree is diploid and contains self-incompatible and self-compatible genotypes. Three genetic groups may be distinguished.

The Criollo group comes from Central America and Mexico. It is characterised by its white cotyledons and provides fine, more aromatic cocoa.

The Forastero group (Upper and Lower Amazon) is very diverse. It may be encountered in its wild state in Upper Amazonia (Peru, Ecuador, Columbia), in the Amazonian basin (Brazil), in Guyana and Venezuela and along the Orinoco river in small, scattered populations mainly in flooded areas. The Forestero group is distinguished by its dark purple cotyledons which give "bulk" cocoa of average quality.

The Trinitario group, which is very diverse and heterogeneous, is a result of hybridizations between Criollo and Forestero. It produces cocoa of a quality in between that of the two previous groups.

Cocoa in the past

Domestication of the cocoa tree goes back as far as the pre-Columbian era, when Criollos were cultivated by the Central American Indians. Cocoa beans were used for the preparation of drinks but also as a form of money.

At the end of the 16th century, the use of chocolate spread throughout Europe with the consequence of expanding Criollo cultivation towards South America, the West Indies and then the other continents. Trinitario was discovered in Trinidad from where it spread through to other countries.

In the 19th century, Forestero and Trinitario replaced Criollo which were very susceptible to parasites. Lower Amazon Forestero were introduced in East Africa.

In the 20th century, the selection of Trinitario clones, propagated by cuttings, began in Trinidad, Central America and Indonesia. The yields were of around 1 to 1.5 t/ha.

In 1940, faced with the expansion of witches' broom disease in America, collecting was carried out for wild Upper Amazon Forestero genotypes in Peru and Ecuador in order to identify resistant plants. A few years later, the vigour, earliness and productivity (1 or 2 t/ha) of hybrids between the Upper Amazon Forestero and other genetic groups was discovered.

From 1950, mass clone selection was carried out in Trinitario populations in Cameroon by IRCC (Institute of research on coffee, cocoa and other stimulant plants which has now been integrated into CIRAD's tree crops department), but the distribution of cuttings remained a failure due to root problems.

Hybrids between introduced and local clones have afterwards been created in almost all the production countries. They involve Upper Amazon, Lower Amazon and Trinitario genotypes. Their yield is 2 to 3 t/ha. IRCC has been participating in the creation and the extension of such hybrid varieties in Côte d'Ivoire, Cameroon and Togo since the 60s. The limitations of this method are now beginning to appear. Genetic progress is getting weaker for productivity and has proved insufficient for resistance to disease and quality. The hybrid mixtures often prove to be too heterogeneous from an agronomical viewpoint.

Cocoa today

The cocoa tree is grown in humid, tropical areas, over 5 million hectares of which 50% are in Africa, 25% in Asia and 25% in America. The main production countries are Côte d'Ivoire, Brazil, Ghana, Indonesia, Malaysia, Cameroon and Nigeria. Small plantations predominate. They have a lifespan of 25 to 40 years.

The Forestero type provides almost all the common cocoa coming from Brazil, West Africa and Southeast Asia.

The annual cocoa production is up to 2.5 million tons. The value of the product before transformation is about 3 billion dollars.

Most of the producing countries have a research centre conducting breeding programmes. The selection criteria are vigour, earliness, productivity, bean size, quality and resistance to diseases and insects.

The main breeding method remains the selection of hybrids among clones that have been little improved or are even wild. Between 25 and 50% of plantations are established with hybrid varieties. Their average output in extensive cultivation for most countries varies between 0.3 and 0.8 t/ha and, in research stations, reaches 2 to 2.5 t/ha or even 3 t/ha for the best varieties tested.

New breeding methods have been developed since the 80s: hybridizations between doubled haploids and recurrent selection in Côte d'Ivoire, clonal selection by means of plagiotropic grafting in Malaysia and mass selection in traditional populations in America.

Research on genetic diversity of the species, with the help of markers (izoenzymes, RFLP, RAPD) and genome mapping is under way in several research centres. CIRAD has made good progress in this field.

Micropropagation, which is still difficult with this plant, is also being studied. Somatic embryogenesis would enable us to multiply clones as orthotropic plants.

At the present time the cocoa tree is still cultivated extensively. The green revolution has yet to take place.

Cocoa in the future

The major challenge for the improvement of the cocoa tree remains resistance to different parasites: pests (mirids, pod borer), diseases (black pod and stem canker, witches' broom, moniliasis) and viruses (swollen shoot). Maintaining a plantation requires costly phytosanitary treatment to fight against pests and diseases.

New methods (clonal selection, recurrent selection) and new tools (micropropogation, markers-assisted selection, genetic transformation) should provide an answer to these problems in the future.

Breeding of traditional Criollo, Nacional and Trinitario populations are also on the agenda to respond to the increasing demand for good quality cocoa.

Finally, molecular characterisation and evaluation of germplasm available from international collections (Trinidad, Costa Rica) would allow better management of genetic variability in breeding programmes, and the identification of parental genotypes with high resistance or exceptional quality. Further studies may be envisaged within the context of an international network for the evaluation of genetic material.

Coconut

Coconut, *Cocos nucifera,* is an arborescent monocotyledon from the family Arecaceae. It is a monoecious, diploid palm tree. In natural conditions it reproduces exclusively by its seed.

There are two groups of populations with different reproductive regimes: Dwarf coconut palms are preferentially self-pollinated and Tall coconut palms are mainly cross-pollinated.

The coconut palm, which is often known as the tree of life due to its many different uses, is at the heart of economic life for many people in tropical areas.

Coconut in the past

The most typical image we have of the coconut tree is of a palm with a long, bending trunk, growing beside the sea.

The coconut palm's centre of origin is still a subject of great discussion; it is said to have been located in Southeast Asia or Oceania. Domestication of it goes back to a long time ago and most of the present day coconut palms are more or less pledged to Man. This domestication was to favour certain characteristics such as the large volume of liquid endosperm and rapid germination that can be found in the Niu Vai type, in contrast to the Niu Kafa type, which is more apt to natural dispersal by floating, and supposed to be closer to the original wild coconut tree.

Helped by the fact that its nuts float, the coconut tree spread throughout the tropical areas, to where it could be found near the coast. Later on, human migration participated in its dispersal.

The coconut tree is a village plant, grown by many farmers over small areas. The nuts are consumed ripe or before maturing (coconut milk) but the other parts of the plant are also used in construction and the manufacture of various utensils.

From the 19th century onwards, copra (dehydrated, oil-rich endosperm) became part of an intense international trade. It became the greatest oilseed in the world around 1914. Later on, demographic pressure in the countries producing it, which were pushing for autoconsumption, and competition from soya and palm oil, reduced copra's share in the international exchange. From 1960 onwards, the latter began to lose its importance and this decline is still going on today. However, copra has maintained a considerable role, not only in the field of alimentation but also in industry (soap, cosmetics, lubricants...). Research on coconut improvement began in 1916, but it was only after the second world war that it came to any real progress.

The first steps in this improvement were to collect and distinguish the main populations of cultivated Dwarf and Tall coconut trees. From these studies, intrapopulation breeding was carried out according to the different selection procedures (mass selection or in half-sibling families). The first interpopulation hybrids were made in 1920, but work in this domain remained to be followed up.

It was not until the 1960s that a programme dedicated to interorigin hybrids was set up by IRHO (Institute of research on oils and oilseeds which is now part of CIRAD's tree crops department). This led to the selection of efficient hybrids, some of which produce twice as much as the best of their parents.

Coconut today

Coconut palms are grown over 11 million hectares of the world's surface, 94% of which are in Asia and the Pacific. The two largest producers, the Philippines and Indonesia, account for 75% of planted surface areas. The world's copra production is as high as 4.9 million tons, to which may be added 3.8 million tons of "copra equivalent", which is consumed by the producer or converted into other products, such as grated coconut.

The coconut tree remains a village crop. Smallholder plantations predominate even though there are a few industrial plantations.

The main criteria retained for improvement are high copra production and earliness. Dwarf x Tall hybrids are especially interesting, not only for their productivity but also for earliness, inherited from the Dwarf parent.

In many countries, tolerance to disease represents an essential condition for development and, indeed, crop maintenance. We may note leaf decay in Vanuatu, lethal yellowing in Jamaica and various countries in Africa, *Phytophthora* in Asia. For these diseases, sources of tolerance are being identified. Adaptation to particular growing conditions such as drought or coral soils is a determining factor in certain regions.

Production cycle and economic context have made it possible for the Tall coconut plantations established during the coconut's heyday to exist still today. However, most of these are now getting too old.

Hybrids have proved their potential in extremely varied environmental conditions and cropping systems (smallholder plantations or large plantations). Seed orchards have been set up to produce these. However, their use in plantations remains minimal due to the coconut tree's low multiplication rate, cost of transporting the seeds and the atomised structure of cultivated coconut groves. Only 10% of the areas are planted with improved hybrid coconut trees.

In spite of the undeniable success obtained with hybrids, changes are slow and therefore, in many ways, the coconut palm of today is just like it was in the past.

Coconut in the future

The main challenge for the coconut palm consists of combining smallholder farming systems with production for export which is integrated into the world market and open to competition. From the point of view of creating varieties, the objectives remain the same: productivity and adaptability. But the future of the coconut palm also depends on diversification of its products. Restrictions linked to the different means of transformation will probably result from this. These restrictions may be interpreted by new breeding aims.

Besides this, the coconut palm is often cultivated in association with other crops, which explains the necessity to adapt to this cropping system. Tall x Tall hybrids may represent an interesting option in this respect.

A great effort is already being made to improve certain hybrids by using intrapopulation variability. In the best of these families there is a gain of around 15%. The next step consists of surpassing the limits of traditional populations by exploiting all of this species' variability. An ambitious breeding programme has been set up in order to do this. It is based on reciprocal recurrent selection and integrates two axes for the creation varieties: Tall x Tall hybrids and Dwarf x Tall hybrids.

Vegetative propagation by somatic embryogenesis is being developed today. This will allow us to distribute the best genotypes produced, thus ensuring the exploitation of intra-family variability. Furthermore, the potential for considerable multiplication by this technique is a definite advantage for a species like the coconut tree—a small production unit could thus replace hundreds of hectares of seed orchards. What remains to be perfected is a production procedure whose cost will compete with that of traditional propagation methods.

Coffee

The coffee plant is a shrub from the family Rubiaceae. It is 4 to 8 m high and has orthotropic stems and plagiotropic branches. Its reproductive life cycle is three years long. Two species are cultivated: *Coffea arabica,* which is allotetraploid, autogamous and whose varieties are mainly pure lines that can be seed propagated, and *Coffea canephora,* which is diploid and allogamous and whose varieties are seed propagated or clones.

Coffee in the past

C. arabica originates from southeast Ethiopia, southern Sudan and northern Kenya where it can still be found in the undergrowth of high altitude forests (at 1300 to 2000 m).

Its domestication in Yemen goes back to the 14th century. In the 18th century, coffee became a popular drink in Europe. Cultivation of *C. arabica* was thus introduced into Asia (India, Indonesia), America and East Africa starting from a very limited number of plants.

In the 19th century, the varieties cultivated reached a production potential of 0.3 to 0.8 t/ha (Typica) and 0.6 to 1.2 t/ha (Bourbon). Coffee-growing expanded in America. At the end of the 19th century, the outbreak of leaf rust in Asia and on plantations in East Africa caused a drop in productivity of between 30 and 50%. Average and low altitude areas were most affected as this is where the development of the parasite is most favoured. The American continent escaped this disease until 1970 and cultivation of *C. arabica* continued to expand there.

At the beginning of the 20th century, countries hit by leaf rust began to cultivate other species of coffee that were resistant and better adapted to low altitude areas. The Robusta variety of *C. canephora,* which grows spontaneously in the forests of Central and West Africa, quickly came into use due to its good rust resistance and productivity—up to 1.5 t/ha—in Asia (Indonesia, India) and Africa (Côte d'Ivoire, Cameroon, Zaire, Angola).

In parallel to the development of *C. canephora* cultivation, the first attempts at breeding rust-resistant varieties of *C. arabica* were made. These did not give satisfactory results due to the fact that new races of this pathogen appeared. Later attempts were therefore made based on introgression of resistance genes from *C. canephora* by interspecific hybridization and back-crossing.

From 1930 onwards, dwarf mutant varieties, better adapted to intensive farming but more demanding in terms of nutrition, were found in America. Their potential yield was 1.5 to 2 t/ha under the right growing conditions. These varieties were at the origin of the high density coffee-growing that developed back in the 1960s in Central America, before spreading to other areas.

Selection of seed-propagated varieties and clones of *C. canephora* began in Indonesia right from the beginning of its cultivation and in Africa in the 1950s. In Africa, selection led to varieties with a good yield (1 to 2.5 t/ha). The most productive are clonal varieties propagated by cuttings, and distributed in Côte d'Ivoire, Cameroon, Togo and Madagascar.

The coffee plant has made considerable progress since becoming domesticated, in terms of productivity and adaptation to environmental constraints, parasitic or otherwise. However the restricted genetic diversity of cultivated coffee has limited the possibilities of improvement, particularly for *C. arabica*. Research centres have felt the need to constitute collections of wild and cultivated coffee. Collecting germplasm and maintaining live collections began in the 1940s for *C. arabica* in Costa Rica, and in the 1960s for *C. canephora* in Côte d'Ivoire.

Coffee today

C. arabica is cultivated in humid tropical areas at high altitude, mainly in America (80%), but also in East Africa and Asia. It covers 7 million hectares. Its farming system is quite intensive in America and East Africa where both large and small plantations may be found.

C. canephora can be found over 3 million hectares in tropical regions at low altitude, in Brazil, West Africa and Asia. Extensive farming is dominated by smallholders.

The market for coffee, being the world's most exported agricultural product, is as high as 10 billion dollars, of which 70% is for Arabica and 30% for Robusta.

The main aims for *C. arabica* breeding are still productivity and resistance to main parasites and pests: leaf rust, nematodes, coffee berry disease, leaf-miners, coffee berry-borer. Product quality factors have also become important criteria: reducing the amount of cafeine and improving the flavour of Robusta, and maintaining the quality of varieties traditionally cultivated for Arabica. Finally, mechanised harvesting requires dwarf plants.

For lowland coffee, improvements in quality have been made via crossings of *C. canephora* with *C. arabica*. This programme, started in West Africa in 1970 by IRCC (Institute of research on coffee, cocoa and other stimulant plants, which has now been integrated into CIRAD's tree crops department) has led to the creation of the interspecific hybrid Arabusta. Despite the good results obtained with regard to quality, this programme was abandoned in 1985 due to the hybrid's poor agronomical performance (0.4 to 0.8 t/ ha). In 1984, research in Côte d'Ivoire was orientated towards reciprocal recurrent selection of *C. canephora* using Guinean and Congolese types. Important progress was made for productivity (2 to 2.5 t/ha) but little sofar for bean size and organoleptic quality.

For *C. arabica*, the varieties have been obtained by intra and interspecific hybridizations followed by several cycles of selfing or back-crossing with one of the parents. Two important varieties have been created according to the latter method, Catimor (Central America, Columbia) and Icatu (Brazil). They have been distributed in these countries since 1985 (Catimor) and 1992 (Icatu). Their yield is around 2 to 3 t/ha. The Java variety, which is resistant to coffee berry disease, was improved in Cameroon by IRCC. It produces yields of up to 1.5 to 2 t/ha. From the 1980s onwards, F1 hybrids between wild Ethiopian accessions and cultivated lines were exploited in Cameroon and Central America by IRCC. The Ruiru 11 variety, which is a heterogenous mixture of F1 hybrids, became distributed in Kenya from 1985 onwards. This variety is reproduced by manual pollination.

All these methods depend on the exploitation of a large genetic variation. Collecting of wild plants, maintaining and evaluation of germplasm must remain a priority for all coffee research centres.

In the 1970s new technologies were developed. Research on micropropagation, using microcuttings and somatic embryogenesis, are being improved from that time on. Studies on genetic transformation and genome mapping using RFLP markers are under way.

For *C. arabica* the use of improved varieties is generalized, whether they be traditional or modern and productive. However, plantation yields are still highly variable: from 20 to 100% of yields produced at research stations. There is still a large demand for varieties with resistance to main diseases and pests.

C. canephora's situation is less favourable as only 5 to 15% of plantations are established with improved varieties. In general, their average yield does not exceed 30% of what can be achieved at experimental stations.

The situation is therefore one of contrast. The improved varieties of *C. arabica* are being largely exploited, whereas the selected high-yielding varieties of *C. canephora* are still being underexploited due to the socio-economical context of their cultivation. One may conclude that the green revolution has already started for *C. arabica* but has yet to be realised for *C. canephora.*

Coffee in the future

Cultivation of *C. arabica* has always been affected by diseases and pests. Research is being orientated towards varieties with multiple resistance thanks to exploitation of F1 hybrids, among others. Obtaining these implies hybridization between parents with complementary resistance genes to diseases and nematodes. Hybridization also enables us to exploit heterosis that has been observed in crosses between wild and cultivated varieties.

The use of micropropagation techniques, which already started in East Africa and Central America, will enable us to propagate these hybrids of *C. arabica* more rapidly.

The discovery of male-sterile parents could also be exploited in the not too distant future for producing hybrid seeds.

Genetic transformation may play an important role in the introduction of genes for resistance to insects.

The major problem with *C. canephora* remains the quality of the product. Selection within advanced progenies of interspecific hybridization with *C. arabica* is still going on. This should lead to high quality varieties that are better adapted to low or medium altitude.

Cotton

The cotton plant, *Gossypium,* is a small, perennial shrub (1 to 1.5 m high) from the family Malvaceae. Within the *Gossypium* genus about fifty species may be recognised, four of which are cultivated for their fibre. *G. arboreum* and *G. herbaceum* are diploid. *G. hirsutum* and *G. barbadense* are tetraploid. They are self-pollinated species.

Cotton in the past

The tetraploid species, which are at the origin of most of today's cultivated cotton plants, originated in tropical America: Ecuador and the north of Peru for *G. barbadense* and Mexique and Guatemala for *G. hirsutum.* Domestication goes back to a long time ago. Archaeological digs have proved that cotton fibre was already used as far back as three thousand years B.C.

Cultivation of *G. barbadense* remained limited to South America until the middle of the 16th century. The development of international trade then began to favour its distribution throughout the world. The first varieties cultivated provided cotton that was quite long but not very fine.

G. barbadense made its appearance in the United States around 1785 under the name of Sea Island, a type originating from Barbados. Sea Island was a cotton plant with a very long cycle, and low productive potential, but exceptional fibre quality. In the United States, selection aimed at types with extra long fibre developed until the beginning of the 20th century, when cultivation stopped due to boll weevil attacks.

In the second half of the 19th century, cultivation of *G. barbadense* developed in Egypt from work on selection between a recent Sea Island introduction and a type that had been introduced much earlier, giving birth to varieties of Egyptian cotton. One of these varieties, introduced into the United States around 1900 was at the origin of shorter cycle varieties which helped cotton growing to start up again in that country from 1950 onwards.

Although it was introduced into Africa very early on (18th century), cultivation of *G. barbadense* only began to develop in the south savannah region and in the north in the 19th century. Selection of it in West Africa and Maghreb (Algeria, Morocco) was made in 1970 by IRCT (Institute of research on cotton and exotic textiles, which has now been integrated into CIRAD's annual crops department). In regions where pressure from parasites is very high (center of Côte d'Ivoire and Togo), this cotton plant gives low, irregular production in areas where *G. hirsutum* cannot develop. The arrival of synthetic insecticides which made *G. hirsutum* seem much more attractive, caused this cultivation to disappear in the 1960s.

For *G. hirsutum* several subspecies may be identified in its centre of diversification. The subspecies *latifolium,* which is commonly known as "the Upland cotton plant", is at the origin of cultivated varieties. It is insensitive to photoperiod and may be cultivated according to an annual production system. Perennial, photoperiodical races which were encountered in subspontaneous or wild conditions in Mexico, Latin America and the West Indian arc, were little exploited.

Distribution of *G. hirsutum* from the 16th century onwards ran parallel to that of *G. barbadense,* but cultivation of it only really took off in the 19th century. Many varieties were thus created in the United States using introductions from Mexico and Guatemala. These very diverse varieties (early and late types) resulted from selections or hybridizations. At the beginning of the 20th century the arrival of boll weevil changed selection aims: short cycle varieties with early fructification were required.

Up until the middle of the 20th century, selection of *G. hirsutum* was mainly carried out in the United States. The cotton plant's present variability can be attributed to the introductions and mixes made in that country.

New research centres were created in the middle of the 20th century in cotton producing countries. Breeding programmes were orientated in several directions according to the local requirements: large capsules (Brazil), Okra types (Australia), hybrid varieties (India), and cluster (Uzbekistan).

Selection of *G. hirsutum* began in tropical Africa in 1946 when IRCT was set up. Productivity was thus the main criterion for selection. Breeders tried to obtain varieties with quite long cycles which would compensate for boll worms attacks on the first flowers. Increase in yield was around 50% compared with production from local populations.

From 1975 onwards, progress made in the field of phytosanitary protection, especially when pyrethrin appeared on the market, made it possible to envisage reducing the cotton plant's cycle. Earlier types which used the short African rainy season to better advantage began to appear.

In the 1980s, morphological studies demonstrated the interest in genotypes with a reduced proportion of vegetative branches. These varieties reached high yield potentials.

In parallel to increase in productivity, breeding focuses on the technological characteristics of fibre. Up until 1960, only fibre length was taken into consideration. After a time, considering the progress in the precision of measuring instruments and the evolution in cotton mill procedures, the parameters of quality (length, fineness, strength) were studied in detail. In Africa, at the beginning of the 1970s, it became possible to offer a range of varieties corresponding to the best qualities of their category on the international markets.

Ginning outturn (weight of fibre compared to the weight of cottonseed) was also bred for. A high yield made it possible to lower fibre production costs. Progress has been spectacular; ginning outturn has gone up from 34 to 35% in 1950 to 42-44% today, with certain varieties producing up to 45-46% in factories in some countries.

Cotton today

Today, cotton is grown in intensive, irrigated systems in most of the countries where it is produced, but also as an upland crop in tropical savannah regions. It is grown over 32 million hectares. The main producers are China, the United States, India and Pakistan.

Annual production is around 20 million tons of fibre, of which only 6 million tons are exported. The main exporters are the United States, Uzbekistan and French-speaking Africa.

The *G. hirsutum* species accounts for 91% of world cotton production due to its excellent capacity for adaptation and its high yield potential. The *G. barbadense* species contributes to 5% of world production. It is mainly grown in arid regions under irrigation, for a relatively small market for fibre of an excellent quality. Lastly, 4% of the world's production comes from diploid species grown in Asia (India and Southeast Asia).

Cotton improvement focuses on the classical method for breeding self-pollinated plants: pedigree selection of pure lines. However, the criteria for this improvement have changed. Fibre quality is a determining factor. Cotton is now a high technology product and must therefore adapt to the industry's demands and new cotton mill techniques.

With regard to *G. hirsutum,* the selection aims for fibre quality are very diverse according to transformation procedures: 1 3/32" in length, strong but fine fibre for open-end spinning, 1 1/8" long strong, mature fibre for ring spinning. The main restriction for cotton-growing is now phytosanitation. This type of cultivation alone consumes one quarter of all insecticides although it only accounts for 2% of the world's cultivated surface area.

Resorting to transgenesis may bring a solution to this problem. In the United States the first transgenic varieties will soon be distributed. These bear resistance to insects and herbicides. CIRAD's department of annual crops is doing research on *Bt* genes and protease inhibitors in order to breed better resistance to insects.

In Africa, other breeding objectives are being considered. CIRAD's annual crops department quickly became interested in glandless cotton plants. This glandless trait, discovered in the United States in 1954 has the advantage of providing seeds without gossypol, which is a toxic compound making the seed unfit for consumption. With the installation of modern oil-mills, development agencies are beginning to realise how profitable the cottonseed's oil and protein wealth might be; this could be a really important by-product of crops as it represents one fifth of fibre value.

In the 1980s, the interest in glandless varieties was to be confirmed. Breeding this characteristic into African cotton plants led to the creation of a glandless variety with a high ginning outturn and which was well adapted to local conditions.

This variety is now most commonly grown in Africa where it covers 300,000 hectares. Paradoxically, farmers appreciate it for its own qualities, rather than its glandless specificity. The African economic context does not make it possible to really prove the seed's nutritive worth.

Throughout the world, only improved varieties are grown for the tetraploid species. Every year, 1.5 million hectares are reported as being cultivated with varieties created by CIRAD in Africa, America and Asia.

The cotton plant is at the origin of a truly green revolution in Africa. Supported by the active creation of varieties, production has been undergoing a steady increase since the 1960s. The agricultural landscape of the savannah region is changing, the farmer too.

Draught cultivation, the use of pesticides and fertilisers, the arrival of herbicides in certain countries and the grouping together of farmers in village associations are all factors for sustainable economic development and the irreversible socio-cultural changes that the cotton industry has introduced.

Cotton in the future

The development of cotton-growing in Africa is accompanied by undesirable effects on the environment. Soil is being degraded due to the biomass not being restored and chemical fertiliser, whose price has increased considerably due to the fact that grants have been suppressed, are being used less and less. The use of pesticides, although rather limited, causes pollution problems.

Faced with unfavourable short-term consequences, plant-breeding must be orientated towards the creation of hardier varieties which are resistant to the biotic and abiotic constraints of the environment.

Different kinds of biotechnology, especially genetic transformation, may contribute to resolving these problems. The creation of transgenic varieties which are resistant to insects and can be used in the context of rational pest control, is under way in France, the United States and Australia.

In general, work on genome mapping and the cotton plant's physiology will bring the necessary knowledge for better use of genetic resources and its adaptative capacity. Lastly, considering the demographic evolution and the food problems that this will cause, we may imagine that glandless varieties will be put to their full use in the future.

Eucalyptus

Eucalyptus are woody, perennial dicotyledons, either trees or shrubs, from the family Myrtaceae. They belong to the genus *Eucalyptus* which is rich in over 550 different species divided up into eight subtypes representing perfectly identifiable "natural" groups. The majority of cultivated species belong to the subgenus *Symphyomyrtus.* Although they are quite varied from their agronomical and technological characteristic viewpoint, these species show great homogeneity with regard to their biological functioning. They are diploid, monoecious species and preferentially cross-pollinated. Reproduction is usually achieved via the seeds, or, more rarely via suckers. Many interspecific crosses are possible.

Eucalyptus in the past

The natural area for this genus stretches from the Philippines to Tasmania, east of the Wallace line.

Eucalyptus trees form the main characteristic element of the Australian continent's tree flora, where they occupy very varied habitats from the alpine chain in the south west to the coastal fringes, from the dry inland to rain forests.

Their great plasticity has made it possible for them to colonise mediocre soils in restrictive environments. The main factors limiting their extension are climatic or biotic ones: the extreme drought of the central deserts, frost at altitude, and the saturating humidity of the tropical forest which favour development of pathogenic agents.

The diversity of the environments occupied is accompanied by a great variety in forms. *E. oxymitra* is a small tree or multistemmed shrub of about 1 to 4 m high. It can be found in central Australia on skeletic soils and fields of dunes. *E. regnans,* which can be found in Victoria State and in Tasmania, is the highest broadleaved tree in the world. Certain trees grow to over 100 m high. Its trunk, which is perfectly straight and branchless can provide up to 180 cubic metres of wood. Between these two extremes there is a whole range of species from the characteristic multistemmed mallees of the dry south to the many trees which dominate the rainforests, growing up to 30 or 40 m in height.

As is generally the case with forest species, domestication only began recently.

In the 18th century, *Eucalyptus* trees were introduced into Europe for the first time. But their use in plantations only began during the second half of the 19th century.

At the end of the 19th century and the beginning of the 20th century, the first large scale plantations intended for timber production were set up in South Africa and Brazil. From that time onwards, interest in the species never ceased to grow.

Introductions were made over a very vast area with a certain degree of success depending on the pedoclimatic conditions of the regions where it grew. The main ecological limits for the use of eucalyptus in production plantations were the cold, high equatorial humidity and drought.

Forestry techniques were relatively varied and depended not only on the end product (firewood, posts, wood for grinding, timber...) but also on the plantations' technological means.

It was in industrial plantations that the highest degree of sophistication was achieved: complete clearance of the land, tillage, fertilisation, mechanical or chemical maintenance, partly mechanised harvesting. But in the majority of plantations, only lightly maintained and entirely manual silviculture, without inputs, was practised. Annual productivity variation was enormous: from 5 to 40 cubic metres per hectare.

In the Congo, development of industrial cutting techniques in the 70s made high increase in productivity possible. These techniques were quickly adopted in Brazil, South Africa and by all the large companies.

Rural plantations evolved only slightly, if at all. The lifespan of plantations that were managed and pruned regularly over 5 to 10 cycles, and cost of replacement, were obstacles that were difficult to overcome.

Until the beginning of the 60s, batches of seeds from Australia or exchanges between countries using them, were often of dubious origin. Seedlings used for plantations came from the first introduction plots without any particular attention being paid to the choice of seed-producing trees or to the risks of inbreeding.

The need for diversification, especially for marginal areas, and concerns about not having the best genotypes, led breeders to intensify analysis of the genus' genetic diversity. Several collecting campaigns were carried out from 1960 onwards.

Seed collecting was particularly concerned with sampling, in a precise and systematic way, the genetic diversity which existed in stands. They were mainly conducted by the Australian and Indonesian forestry services as well as by Brazilian research organisations (EMBRAPA, Empresa Brasileira de Pesquisa Agropecuária) and French ones too (CTFT, the tropical forestry technical centre which has since become CIRAD's forestry department).

Some of the collections thus made have been evaluated in the context of international provenance trials. The results acquired contribute largely to knowledge about diversity and genetic structure of the genus. A lot of trials are still going on and are continuously being set up in introduction areas. In this way, CTFT has done tests on 128 species, over 1000 provenances and about 3000 batches of various wild *Eucalyptus* material.

These trials show the unsuspected importance of interprovenance and interprogeny variability as well as the necessity for strict selection of genotypes. They have led to the introduction of improved wild material into artificial populations, whose production increases significantly.

Breeding began in the 60s with selection of the best provenances and the achievement of population varieties in artificial plantations. From 1980 onwards, clonal varieties developed. The results of this breeding were mainly exploited by great industrial plantations.

Eucalyptus today

Eucalyptus trees are now cultivated throughout tropical and subtropical, indeed, temperate, areas from latitude 45° North in France to latitude 45° South in New Zealand.

Four main ecological zones may be distinguished: humid, tropical areas at low altitude (the Congo, Zaire, northern Brazil, Indonesia), dry tropical or subtropical areas (the Sudano-Guinean fringe and Nordeste of Brazil), humid, subtropical and high altitude tropical areas (South Africa, southern Brazil, the African mountains) and the Mediterranean area (France, Spain, Portugal, Israel, Morocco, Argentina).

The species planted depend on the area under consideration but their plasticity and numerous possibilities of intercrossing leave a wide variety of choice of plant material for marginal or intermediary areas.

The total surface area of plantations is estimated at over 15 million hectares, about 60% of which are for rural forestry. Annual wood production is around 100 to 120 cubic metres. This has almost doubled over the last twenty years.

The main criterion for selection is growth, which remains the determining factor in the plantation's economic worth. Research into increasing the volume produced whilst at the same time reducing the length of rotation is being made. Adaptation to silvicultural conditions is also an important factor: resistance to cold in France, adaptation to humidity and heat in equatorial regions... A few breeding programmes also take into account the quality of the wood: paper quality and physical and mechanical properties. Resistance to pests, which are still relatively few on *Eucalyptus,* is only a minor preoccupation.

Plantation material remains entirely made up of seeds. These seeds are produced in orchards (of families or clones) but more generally in mere seedling populations. Much extension is still being carried out with "wild" seeds harvested from stands. Clonal varieties of pure or hybrid species are now being developed in large industrial plantations.

Sophisticated breeding schemes such as reciprocal recurrent selection are currently being established.

Rural forestry is undergoing a certain stagnation period. A few programmes have set themselves the target of creating improved population varieties. In this way, a network of seed orchards has been formed in Madagascar. This network foresees improvements over several generations according to a recurrent selection scheme. Seeds produced with each new generation will be distributed at low cost by a public organisation.

Eucalyptus in the future

In rural plantations, the aim of improvement is still to increase average productivity. The methods are well-known: from the use of seeds produced in clones or families seed orchards. The State should use these to benefit the whole of rural forestry. The main stumbling blocks remain funding for these programmes and distribution of their results.

In industrial plantations, improving the technological qualities of wood is essential. This requires the mastery of reliable measuring techniques that can be used routinely on large numbers. This will lead to a diversification in the uses of wood, especially timber. The conquest of new plantation areas is another important stake. Rational use of the genus' genetic diversity for creating hybrids will make it possible to extend eucalyptus silviculture.

Evaluation of genetic resources, which is well advanced for the major species, is far from being finished. Important genetic findings may still be obtained by merely screening material. This work therefore remains a priority.

Serious reflection about worthwhile characteristics of these genetic resources will make it possible to establish a basis for creating the genotypes of the future.

Programmes for recurrent selection are still very few and not very advanced. Although the basic principles ruling these schemes are well-known, applying them requires technical and theoretical work: improvements in grafting, acceleration of earliness, quantitative analysis of unbalanced cross-breeding plans that put several parent populations at stake, proving correlations between young and adult stages and between characteristics, management of small populations, constitution of a selection index...

Different kinds of biotechnology are being applied to accelerate or perfect classical breeding work. Several teams including CIRAD's forestry department are working on the establishment of genetic maps and research into molecular markers.

Also, in-vitro techniques are being developed with the principal aims of rejuvenating older trees, setting up banks of genes and obtaining artificial seeds later on.

Besides this, certain teams envisage genetic transformation, particularly for resistance to herbicides and a reduction in lignin rates.

Forests

Tropical forests have always been used and worked by Man not only for wood, but also for fruit, honey, different materials and medicinal products. Not only have the means of exploitation greatly evolved over the years, making it possible for us to speak of forests of the past, present and future as different "varieties", but also the very aspect and definition of forestry has changed.

The term "tropical forest" is applied to very different biological realities ranging from dry to evergreen forests; there are also more particular forms which exist such as high altitude tropical forests and mangroves. In this text, only evergreen or semi-deciduous forests that have been and still are used for commercial timber are considered.

These rainforests are different from one continent to another: Asian forests have about twice as much biological diversity as African forests; Latin American forests are of medium interest. Besides this, Asian forests consist of 40% widely used species of Dipterocarpaceae whereas African forests are built up around several large, useable trees. The biological characteristics of forest ecosystems have also affected the development of forestry systems in the different continents.

Forests in the past

For a long time, forests were considered as pools from which products such as gum, spice or wood could be taken unlimitedly. The Chinese began working the forests on the north coast of Java in the 14th century, the Dutch wood company was founded in 1602 for exploiting the forests of the "Dutch Indies". Colonial countries have been researching into tropical forest wood and exploiting it for over 500 years: the English, in India, the Spanish, in America, and the French, in Africa. Wood for fleet construction was an important factor.

In the last century, exploitation was made by industrial companies who had been given long leases for forestry management, often in a colonial context (like the first forestry permit in Java in 1620). The aim of production was mainly timber. Great destruction had already taken place in easily accessible forest areas such as the teak forests in Java and Côte d'Ivoire. Limitations were quickly imposed and arrangements were planned in Asia and Africa. The first attempts at controlling forestry were made in Côte d'Ivoire.

However, technical difficulties such as setting up road infrastructures, treefelling and loading wood, transport, reduced the impact of exploitation until the middle of the 20th century. Only areas with easy access could be exploited, and only trees with average diametre trunks were felled.

Forests today

The growing demand for wood by industrialised countries and the development of young, independent States has contributed to unprecedented deforestation in tropical regions. The colonial heritage, development of cash crops and demographic pressure are all causing forest ecosystems to be turned into agricultural land.

Tropical rainforests constitute a threatened wealth today. Decreasing surface areas are forcing governments to develop exploitation means in order to preserve the wood production potentials of tropical forests. Indonesia, for example, has established a regulated forestry system in which forestry workers are given a set maximum for exploitation, may not return to the site before 35 years and must do enrichment work. However, economic pressure and technical developments (the chainsaw) have intensified deforestation.

The rights and situation of local human populations in forest planning are only rarely considered. Programmes for moving human populations in highly populated areas to virgin forest areas is also causing rapid forest deterioration in Burkina Faso and Indonesia.

Forests in the future

Tropical forests are now considered as being much more important on a planetary scale. Wood is no longer considered as the only forestry product; we also expect other products from forests such as fruit, gum and rattan; fauna management is part and parcel of forestry management. Finally, forests seem to be a warranty for maintaining a favorable environment for Man on this planet, and are the last reserve of biological diversity that he may be able to use to his advantage in the future.

Forestry systems and management must be orientated towards these multiple aims. Local populations must participate in a management plan, setting it up and reaping its benefits. Scientific knowledge for applying these new management methods are insufficient, however. The dynamics of regenerating natural or man-made ecosystems is not yet fully understood and the impact of human practices on biological diversity, such as intraspecific genetic diversity, remains unknown.

The elaboration of sustainable management practices is therefore the State's main objective for tropical forest planning, as indicated by the Rio Convention. The stakes in research are considerable not only for the study of ecosystems and the way they function, but also for developing methods for participation by local populations in forest planning, considered as a component in national and regional development.

Groundnut

The groundnut, *Arachis hypogaea,* belongs to the family Fabaceae. It is a herbaceous annual plant characterised by the underground development of its fruits. This unique fructification is due to the activity of an inset meristem responsible for the formation of a gynophore which takes the ovules underground.

Several botanical types may be distinguished: the Virginia and Runner types with alternated branching, of bunch to runner habit, and the Spanish and Valencia types with sequential branching and bunch habit.

The groundnut is a self-pollinated allotetraploid.

Groundnut in the past

Originating in the foothills of the Andes, the genus *Arachis* is found in this region on many different types of soil, from 650 to 1450 m of altitude and under semi-arid to humid conditions of over 2000 mm of annual rainfall. The adaptation of the genus to these highly contrasted environmental conditions proves the genetic variability of the wild species.

The first traces of the plant's use go back as far as 1500 B.C., in Peru. Its cultivation gained the whole of the South American continent. It reached Africa and India in the 16th century. Its introduction into the United States would seem to have been of African origin.

The first commercial export of groundnuts, from Senegal to France, dates back to 1840. This was the beginning of an important world trade which quickly became orientated towards oil-mills in Europe and for direct consumption in the United States.

In Senegal, selection work began in 1920. Its development helped us to understand the impact of environmental, technical and commercial constraints on the plant breeder's variety choices.

From then on, increase in productivity seemed to be the major objective of selection. Lines selected from local populations or introductions are of the late, running type.

From 1930 onwards, the development of mechanised cultivation was to lead to the selection of bunch-type plants with grouped fructification. The first hybridizations between lines were carried out and resulted in semi-late, bunch-type varieties which very quickly replaced the traditional, running varieties.

In the 50s, the drought which befell the north of the country, and the outbreak of a serious viral disease, known as rosette, made it necessary to reorientate selection towards early, resistant types. Back-crossings were thus used to introduce resistance to rosette in susceptible varieties that otherwise showed good agronomical qualities.

From 1970 the progression of the drought led to adopting short-cycle varieties. Recurrent selection was thus used to produce varieties ranging from the late, dormant types for northern growing areas to types with a semi-long cycle for the south.

More recently, the recession of the oil market and concerns over diversification have led us to reorientate research towards edible groundnuts.

Groundnut today

The world's groundnut production reached 16 million tons in 1992, which represents a growth of 27% since 1980. This production can be divided up as follows: 68% from Asia, 20% from Africa, 2.2% from the United States and 0.5% from South America.

A large part of this production (66%) is used for human consumption—nuts, peanut butter and oil—the rest (34%) is used for animal feedstuffs. Autoconsumption is very high in whatever country the groundnuts may have been produced; exports only account for 13% of production.

In Senegal, depending on the growth area, the current selection work is aimed at finding material adapted to drought conditions, able to produce under whatever the climatic conditions may be, and to maintain productivity.

In order to do this, the selection techniques are evolving towards the use of methods which generate variability in the populations under consideration—intercrossings and recurrent selection—and also towards developing sophisticated screening techniques—physiological tests for adaptation to drought, serological tests for aflatoxin and HPLC chromotography for fatty acid composition.

Selection is being pursued for improving tolerance towards fungal diseases (rust, leaf spot) and contamination by aflatoxin.

Groundnut in the future

According to FAO, the world's oilseed economy should continue to develop and reach the world's demand for 107 million tons of fats and 71 million tons of oilseed meal in the year 2000.

In most southern countries, the groundnut's industrial vocation for oil-production is evolving towards autoconsumption and the edible groundnut market. This situation is generating new needs in terms of nutrition (participation in the protein ration, fatty acid composition) and health (aflatoxin).

The development of irrigation in tropical areas has called for varieties with a high production potential, resistance to disease and conformity to the technological norms of the edible groundnut market. This new orientation in research joins together with the preoccupations of developed countries such as the United States and Israel, and has opened up the way for scientific cooperation between CIRAD and the laboratories concerned.

Several breeding methods are being explored all over the world. Their development should lead towards better quality production and a reduction in the need for pesticides.

Interspecific hybridizations between cultivated varieties and wild groundnuts are being envisaged for oligogenic resistance (diseases and nematodes). This method is associated with genetic markers which enable us to follow the gene flow.

Genetic transformation is being studied for resistance to drought and to *Aspergillus flavus* (with the help of a bacterian vector).

Maize

Maize, *Zea mays,* is a monocotyledon from the family Poaceae. It is a self-pollinated species and its genome is diploid. It is a herbaceous, annual, monoecious plant.

Maize in the past

Maize has been grown for thousands of years in Central America, as can be testified by grains found in Mexico. It is the only cereal for which no wild parent is known for certain.

From its center of origin, cultivation of maize spread to all the other continents, to tropical and temperate regions alike. Its presence in the Mediterranean region, Asia and the gulf of Guinea was mentioned in the 16th century, and in the Sudan region of Africa in the 17th century. In Europe, cultivation of maize was limited to Mediterranean areas. It was only in 1965, with the creation of high-yielding, early hybrids, that it developed towards the north, mainly in France.

Because of the way it reproduces, maize was submitted to mass selection right from the start of domestication. Farmers chose the best cobs for sowing their fields the following season. This method is still the case today for local ecotypes.

However, at the beginning of the 20th century, other methods of selection were developed. These focused on pollination control. After several generations of self-fertilisation leading to the creation of pure lines, the best of these were crossed with each other to produce a hybrid which was then distributed. For tropical maize, hybrid selection was already widely used in Brazil and Mexico, under the influence of the United States, and in South and East Africa in relation to colonisation by the English.

A rust epidemic due to *Puccinia polysora* spread to the gulf of Benin at the beginning of the 1950s following the introduction of American maize in the name of food aid. This was the first known demonstration of a fact that had been hitherto unsuspected: diseases did exist, and were to spread rapidly.

Since 1960, tropical maize breeding has undergone three important stages.

From 1960 to 1975, the hybrid era: this was the intensification period. It was enough to transfer intensive European techniques to Africa in order to resolve the problems of food-producing agriculture. The application of this principle to African maize ended in a complete failure. Landraces offered for extension were adapted to extensive farming and reacted badly to intensification (excessive height, susceptibility to lodging, limited yields) and selection (low genetic variability).

Work thus became orientated towards the only other existing type of variety: that of hybrids. The first hybrids created from lines derived from African landraces were disappointing. Experiments were thus made by associating temperate lines with good breeding value, with local varieties that were well adapted to the environment. This method was applied with success in Senegal, Côte d'Ivoire and Réunion. Intervarietal hybrids were also offered in Benin and Burkina Faso. But despite all their qualities these varieties could not be extended and demand remained small.

From 1975 to 1985, the variety era: intensification was fine, but not for the whole world. For years to come there would still be traditional farmers whose cropping systems are indeed low-producing, but in harmony with the environment, and others who, particularly in areas where cotton-growing was developing, wished to try intensification. Could the same variety be offered to all? The answer was "no", and the necessity to adapt the variety type to the degree of intensification came to light.

Recurrent selection, developed from the 60s onwards in the United States, proved to be interesting in this context. Besides, the notion of composite arrived in Kenya, where hybrids did not give satisfaction to the farmers. Composite made it possible to create new genetic variability. Finally, CIMMYT (Centro Internacional de Mejoramiento de Maís y Trigo) and IITA (International Institute of Tropical Agriculture) emerged on the international scene.

In the 70s, out of these three factors joined together, the vogue for improved varieties was to be born, combining high yield potential (over 9 t/ha), agronomical qualities (about 2 m in height and resistance to lodging) and resistance to all the main diseases. They found their place between landraces and hybrids and were widely distributed throughout all the areas where intensification was developing or wherever a serious problem, such as maize streak virus in West Africa, appeared, for which IITA created resistant varieties.

From 1985 onwards, the return of landraces: improved varieties did not satisfy all the requirements. They were adapted to a relatively intensified agriculture, but, for the traditional peasant farmer, responded badly to his cropping system and criteria for grain quality. He has continued to grow landraces. It has thus become necessary to improve these for tolerance to stress and grain quality. This work is in progress.

Maize today

Maize is the world's most commonly grown cereal with 127 million hectares, 58 million of which are in tropical areas. It can be found from latitude 40° South in America and Africa, to latitude 58° North, in Canada. The ecological and socio-economical conditions for its cultivation are very diverse. In tropical regions it is mainly grown in low altitude areas (68% of total surface area) and medium altitude (26%) in traditional farming systems or average intensification.

World production was as high as 460 million tons in 1993-1994. The United States are the highest producers with 161 million tons. The international trade of maize deals with 56 million tons per year.

Breeding of tropical maize is not aimed at finding an ideal variety but a range of varieties. These must be adapted to the different degrees of intensification practised: extensive farming for autoconsumption, semi-intensive farming, intensive commercial farming. They must be capable of producing in very variable environments—stability of the yield often takes pride over productivity. Lastly, they must be appreciated by the user—type and colour of the grain, grinding and storage qualities are essential criteria.

All types of varieties are currently being cultivated according to the farmers needs and the intensification level. The diverse available breeding methods are still being exploited.

Landraces are widely used in traditional, inextensive farming. These constitute the best varieties for yield of less than 2 t/ha.

Varieties resulting from recurrent selection are best suited to average intensive cropping systems, such as those practised in cotton-growing areas, where the required yields are between 2 and 5 t/ha.

Lastly, hybrids are reserved for intensive farming with inputs wherein they may express their full potential much better.

According to CIMMYT, these last two types account for 50% of the surface area cultivated in tropical or subtropical regions, that is to say, 29 million hectares, which, considering the obstacles that hinder the distribution of improved varieties in developing countries, is quite remarkable.

Maize in the future

By outlining, one could say that yield potentials have been created for varieties adapted to the various levels of intensification which exist, except in the case of hybrids. Expression of these potentials in varied environments remains to come. Research is being carried out in view of better use of environmental factors (the efficiency of light and nitrogen, tolerance to drought) or better resistance to stresses (diseases, insects, aluminium toxicity).

Work on the product's quality will be developed to adapt to the user's strong demands, whether they be for human consumption or industrial use.

The use of different biotechnologies should really take off. Molecular markers, which make it possible to study genetic diversity and to utilize markers-assisted selection, are already being used to locate genes for resistance to maize streak virus and insects... Gene transfer (particularly to introduce resistance genes), plant regeneration, and haplomethods are all techniques which are still at the experimental stage.

In the field of seeds, we may say that artificial seeds will soon come into practice. The great unknown remains the transfer, and especially the use, of apomixis in maize, which ORSTOM (French institute of scientific research and development in cooperation) is currently working on within CIMMYT.

These last two innovations will have strong repercussions on the plant breeder's work: he will have to spot the best individual and multiply it identically. There is a real risk of genetic erosion that must not be overlooked. This is why it is becoming increasingly important to pay attention to conservation and systematic exploitation of genetic resources.

Natural pasture and fodder plants

Large grassy areas can be found in tropical areas. It is in these areas, which are naturally rich in fodder plants, that livestock breeding has developed alongside natural herbivores.

Natural pasture and fodder plants in the past

Zonings of tropical fodder resources may be distinguished in two parts: by continental zoning and latitudinal zoning.

Continental zoning is founded on the fodder species encountered. In Africa, most of the tropical grasses eaten by herbivores (*Brachiaria, Panicum, Cenchrus...*) can be found. However, some areas in other continents may also be rich in fodder grasses. This is the case in America with Argentinian pampas and Columbian llanos. Most of the herbaceous fodder legumes (*Stylosanthes, Desmodium...*) come from the American continent. Lastly, Asia (India, Indonesia, New Guinea) has a great variety of forage trees.

Latitudinal zoning is directly influenced by climate. This is particularly obvious in Africa. In equatorial regions, dominated by forests, grasses suitable for grazing cannot develop. There is practically no livestock breeding. On the other hand, to the north and south of this area, perennial or bushy savannahs, favourable to livestock breeding, can be found. The further one goes from the equator, the less it rains. Herbaceous pastures become annual. Agriculture gives way to transhumant livestock breeding.

With the population growth, the influence of Man on fodder resources has been felt more and more. It has become necessary to improve these pastures.

Strategies for introducing fodder plants have been developed. In Australia, going by the definition of pedoclimatic and ecological units, introductions have been made according to a simple principle: a plant living in a given pedoclimatical and ecological environment is highly likely to settle successfully into a similar context. This principle has also been applied in the United States by IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) on various stations.

In the Pacific, however, fodder plants were introduced at the same time as cattle. American *Leucaena* and African *Panicum* thus became subspontaneous there.

This step was then rationalised. CIAT (Centro Internacional de Agricultura Tropical) in Columbia and CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Australia, adopted a scientific approach: plant introduction, seed production, selection.

Natural pasture and fodder plants today

Recently, new production conditions have appeared: a more arid climate and more demanding rearers.

Domestication of fodder plants coming from natural pasture has led to work on a restricted number of plants, bred for a few characteristics. This selection focused firstly on the quantity of dry matter produced (yield), then on product quality (its food value).

However, the fact of working on a restricted number of plants has given rise to phytosanitary problems. If we select a limited number of species or cultivars that are propagated on large surface areas, we multiply the chances of encountering pathogens or pests. The outbreak of anthracnose on *Stylosanthes guianensis* in Côte d'Ivoire and in Senegal (1979, 1981) and on *S. humilis* in Australia and Thailand (1975, 1977) are illustrations of this.

The first reaction to the appearance of these problems was to change species or cultivars by drawing from the considerable reserve constituted by natural pastures in order to find resistant plants.

In parallel, with the mastery of reproduction's genetic mechanism, attempts have been made to create better adapted varieties.

Whatever method is used today, fodder plant breeding depends on preserving all genetic resources, either by forming collections, or by preserving biotopes.

Depending on the farming systems, progress made in pasture management is very variable. In private property systems, where it is possible to protect the pasture by fencing, the pasture is artificial and set with selected seeds. In communal systems such as in Africa, where grass is still relatively abundant, progress is not nearly as great. Seed marketing does not exist. It is now imperative to ensure that small projects are autonomous with regard to their seed requirements.

Natural pasture and fodder plants in the future

Plant breeding is becoming orientated towards plants with good, agronomical and food qualities, whose availability in terms of seeds will no longer be a problem. The priority aim will be resistance to diseases as phytosanitary measures are excluded from pasture for economical reasons.

The ideal grasslands will certainly associate grasses with legumes which are complementary in nutritive terms and make it possible to limit inputs.

The series of plants will be chosen according to wide climatic zones. Indeed, the most remarkable species are established over very large areas. This wide distribution is an indication of good, ecological plasticity.

Improvement in the food value of fodder is achieved by a reduction in the lignin and cellulose rates of grasses. Genetic studies are required in this field.

Improving agronomical quality has also been envisaged. Studies on plant-microorganism symbioses (*Rhizobium* for legumes and mycorrhizas for grasses) should be pursued, as well as more general work on the root system.

Grasslands will be associated with environmental conservation, with reduction in production costs as an imperative: semi-intensive management will certainly be favoured. Finally, one of the main factors of technical blockage, production of quality-controlled seeds, should be removed. Specific studies will have to be made in order to limit the presence of seeds that do not germinate, and are difficult to sow, or dormant.

In conclusion, one may think that, in the future, it will be of prime importance to preserve the biodiversity of natural tropical pastures, before breeding of the best plants from these.

Oil palm

The cultivated oil palm, *Elaeis guineensis,* is a monocotyledon from the family Arecaceae. It is a monoecious palm whose stem may reach up to 25 m long. It is cross-pollinated and only reproduces by seed. In plantations it has an economic lifespan of 25 years.

The main product is palm oil which is contained in the fruits' mesocarp. The palm-kernel oil contained in the fruit's kernel is considered as a by-product. Today, it is the oilseed which gives the highest production of oil per hectare as it commonly gives up to 6 t/ha under the right growing conditions.

Oil palm in the past

The oil palm originates from humid, tropical Africa, in the area bordering on the gulf of Guinea to be more precise. It could be found growing wild in primitive vegetation associations in galeries, alongside the great rivers of West and Central Africa.

Its first important migration from its original growth area took place from the 16th century onwards, towards South America and the region of Bahia, where it settled naturally. Even today it forms subspontaneous populations in this region.

In the 19th century, a few individuals were introduced into Asia in an Indonesian botanical garden. These gave birth to the first plantations at the beginning of the 20th century. Until then, the oil palm had only been exploited for gathering.

In 1922, experimental plantations were set up in Zaire with material collected in the Congo basin, where spontaneous populations were abundant. Research began to develop in several countries of Africa and the Far East whilst planters began perfecting rational exploitation techniques.

In 1942, genetic regulation of the fruit's shell thickness was demonstrated. Three types of oil palm were recognised: *dura,* characterised by its thick shell, *tenera,* with a thin shell and *pisifera,* without any shell at all and a high sterility rate among females. The discovery of *tenera*'s hybrid nature was quickly exploited as this type was the most productive.

During the 50s, a new step in oil palm breeding was made when the superiority of interorigin crosses, as compared to intraorigin crosses, was demonstrated. The experiment was carried out under the initiative of IRHO (Institute of research on oils and oilseeds which has since been integrated into CIRAD's tree crops department) in Africa and Asia, using plant material from different countries (Zaire, Côte d'Ivoire, Benin, Malaysia).

Yields from improved material gave the oil palm high economic interest, which would explain the spectacular development in cultivation of it from the 60s onwards. As from 1959, IRHO decided to adopt a reciprocal recurrent selection scheme for the oil palm. This aimed at creating hybrids between unrelated ecotypes with complementary characteristics and focused on the mastery of artificial fecundation techniques. Each cycle lasts twenty to twenty-five years and requires large experimental surface areas. An informal network of research centres which shared the work and results was soon established.

The main criterion for selection has always been palm oil productivity, but various other criteria have been taken into account, especially resistance to *Fusarium* wilt which is rife in Africa. A vast programme was set up in the 60s to identify sources of tolerance. The speed of upward growth became an important factor due to its effect on costs and length of exploitation. Studies began on variations in the oil's fatty-acid composition as well as that of polyunsaturated fats which were an important element in its market value. Trials have been carried out to establish behaviour variations under drought conditions.

At the beginning of the 80s, the progress made in yields, by exploiting the superiority of interorigin crosses and one cycle of reciprocal recurrent selection, was around 20 to 25%. Sources of tolerance to *Fusarium* wilt were identified and the production of material that tolerated high risk areas became well established. The upward growth rate of plant material was also greatly reduced.

Oil palm today

The oil palm is grown in all humid, tropical areas. Plantations cover a surface area of 4.5 million hectares, 2.1 of which are in Malaysia and 1.1 in Indonesia. These plantations are mainly industrial but plantations ranging from a few hectares to several hundred hectares have developed in all palm oil producing countries.

The world's palm oil production is around 14 million tons, about 9 million of which are for export. Production of palm-kernel oil is about 1.8 million tons. The oil palm alone provides 23% of the world's production of edible oils.

Since 1980, exploitation of the second selection cycle has begun. In the mid 1990s, progress made on productivity from 1960 was 35 to 40%. Now, the size of palms has been reduced by 15 to 20%. The level of tolerance to *Fusarium* wilt of material distributed for areas at risk has got high enough to avoid a serious attack of the disease. The unsaturated fatty acid content of oil from certain varieties has also progressed considerably.

Due to the complexity of techniques used to obtain improved, certified seeds, production of these is only carried out by research stations. They may be stored for three years and are distributed in the form of seeds for germination, either pre-germinated or germinated.

Industrial plantations are almost always established with improved material.

One of the major events in the history of oil palm breeding came at the beginning of the 80s when IRHO, assisted by ORSTOM (French institute of scientific research and development in cooperation) perfected the technique of micropropagation by somatic embryogenesis. The stakes were high as exploitation of individual variability made it possible to gain a whole selection cycle for a characteristic such as yield, and much more for other characteristics. In the mid 1980s, a laboratory network was installed in Africa and Asia; 500 clones were created, 2500 hectares were planted with clonal material.

Production results now coincide with the expected estimated progress but an anomaly in floral morphogenesis has affected certain clones. Although the percentage of normal palms is 95%, clonal material cannot be distributed yet.

Oil palm in the future

The third cycle of the oil palm's reciprocal recurrent selection scheme is beginning to be established. Great progress is expected for all characteristics as the best parents from several programmes are being grouped together and combined, and population variability at the start of this cycle is higher than that of the previous one. Theoretical annual productivity is far from being achieved as it is estimated at 12 t/ha of oil under the right growing conditions, and only 6 t/ha are produced at present.

Productivity will remain a high priority. But other criteria such as adaptation to mechanised harvesting and environmental stresses (soil, climate, diseases...) will become more important. Generally speaking, the same will be true for characteristics that make it possible to reduce exploitation costs and increase palm oil's market value.

To comply with these challenges, *E. guineensis'* variability is not sufficient and it has become necessary to appeal to a neighbouring species which originates from South America, *E. oleifera.* In fact, this species has interesting characteristics such as reduced growth, oil rich in unsaturated fatty acids and good tolerance to bud rot. Furthermore, certain ecotypes of this palm are tolerant to *Fusarium* wilt. Interspecific hybridization undertaken at the beginning of the 70s ended up with a highly sterile hybrid. A programme to restore fertility by back-crosses is now going on. The first back-crosses of the second generation have been planted and could perhaps be exploited by cloning worthwhile individuals.

Finally, one of the most important things at stake is micropropagation by means of somatic embryogenesis. Preparations are being made for the setting up of control tests for material produced in the laboratory, so that this technique may be applied to the production of marketable plant material. The micropropagation procedure itself has evolved so as to produce large quantities at smaller costs, not for vitroplants now, but for artificial seeds.

Pineapple

The pineapple, *Ananas comosus,* is a perennial herbaceous monocotyledon from the family Bromeliaceae. It is generally self-sterile and diploid. It is propagated vegetatively through ratoons, suckers, or the crown. The adult plant forms a rosette about 1.20 m high.

Different morphological types of cultivated pineapples may be distinguished. The most important are: Smooth Cayenne, Red Spanish, Queen, Pernambuco, Mordilona-Perolera. However, plantations intended for export or the international canned food market are almost exclusively established with clones of the Smooth Cayenne variety.

Pineapple in the past

In the wild, species of the genus *Ananas* are found together in clumps scattered throughout the forests and clearings of the Amazonian region. The centre of diversification and domestication of the genus is located in the Amazonian basin, between the south of Venezuela and the north of Brazil. However, various species were grown throughout the whole of tropical America long before the arrival of the first Spanish navigators in the 15th century. The Indians used some of them for their fruit *(A. comosus* and *A. bracteatus)* and others for their fibre *(A. lucidus* and *A. ananassoides).*

In the 16th century, due to the opening of the main maritime routes, the pineapple spread rapidly over the whole of the tropics. It reached Africa, Madagascar, then Asia. Less than two centuries after the discovery of America, its cultivation could be testified in several countries such as Guinea, Madagascar, India, the Philippines, Indonesia and China.

The beginning of the 20th century marked a turning in the development of pineapple cultivation with the mastery of industrial canning techniques making it possible to export production. The pineapple then began to expand rapidly to Hawaii, Asia (Malaysia, the Philippines, Indonesia, Thailand), then to West and Central Africa. Industrial type plantations continued to develop in these areas.

In parallel to this boom in the canned goods industry, the export of fresh fruit from the Carribean region to North America began to develop. But it was not until 1950, with the mastery on intercontinental refrigerated transport, that the production of fresh fruit for export really began to take off. West Africa began to produce for the European market, Taiwan and the Philippines for the Japanese market and Hawaii for North America.

The international market is dominated by the Smooth Cayenne variety whose fruit is ideal for preserving in slices and for exporting fresh. Other varieties, such as Queen or Perolera, have great importance within certain local markets.

Due to its reproduction system, the pineapple has always been mass selected since it first became domesticated. This type of selection is still practised and most of the varieties cultivated today result from it. However, this mass selection of clones has some drawbacks. The characteristics of resistance to pathogens and parasites are most difficult to observe. Consequently, it is possible to select plants that turn out to be susceptible to a disease that was practically unknown or considered as secondary.

In 1914, the first hybridization programmes of the Smooth Cayenne with other varieties or species from the genus *Ananas* were begun in Hawaii. These programmes aimed to improve the Smooth Cayenne for resistance to diseases (*Phytophthora,* wilt, nematodes, black spot), quality of fruit (vitamin content, acidity, shape), and productivity. This work continued up until the 80s. However, as the Smooth Cayenne was perfectly adapted to the local ecological conditions, no hybrid ever managed to outclass it.

In 1940, IFAC (Institute of colonial fruits and citrus which is currently CIRAD's fruit and horticultural productions department) improved clones from populations of Smooth Cayenne cultivated in Guinea for the production of fresh fruit for export to Europe, a market which began to grow in the 60s. The main characteristics improved were productivity, resistance to diseases, leaves without spines and fruit quality. The Smooth Cayenne is, however, considered as "sophisticated" in the sense that it requires great investments in fertiliser, pesticide and manpower. In most of the countries where it is grown, and especially those with very few technological resources, hardier varieties would be better adapted.

In this context, IRFA (Institute of research on fruits and citrus, which later became CIRAD's fruit and horticultural productions department), began in 1978 a breeding programme for the Smooth Cayenne using controlled hybridization with the Perolera variety in Côte d'Ivoire. This programme was aimed at obtaining varieties that were better adapted to the growth conditions in West Africa so that their productivity and, more importantly, their quality would be improved.

Hybridization programmes are now suffering from the narrow genetic basis upon which they are founded. Genetic material has been collected since 1979 in the species' diversification area, particularly in Brazil, the country that holds almost all the wild forms of the genus *Ananas.* This was intensified later on in collaboration with the fruit and horticultural productions department of CIRAD.

Pineapple today

The pineapple is grown over all humid, tropical areas between latitudes 30° N and 33° S. It is most often found on well-drained soils (sandy, gravelly, slightly volcanic soils), in areas close to maritime outlets for exportation.

Cropping systems are very diverse: ranging from large production units of several thousand hectares to smallholder plantations of less than one hectare. The trend, however, is towards crop intensification, which, in the long run, is likely to cause problems of pollution due to the intensive use of pesticides or fertilisers.

The world's pineapple production is of around 11 million tons per year. Southeast Asia alone produces more than half of it and the American continent just over a quarter, with Africa and Oceania producing the remaining quarter.

Only one type of pineapple, the Smooth Cayenne, largely dominates the world market. However, for some large producing countries, the national market depends on other varieties: Perola, Perolera and Spanish, in Latin America, Queen, in Asia...

Pineapple breeding is still based on classical breeding methods: clonal selection and hybridization.

However, over the last few years the criteria have evolved. Resistance to diseases is still an important objective: *Fusarium* wilt in Brazil, black spot, wilt and nematodes in all growing areas. But diversification of the products proposed to the consumer has become a new preoccupation for fresh pineapple.

Breeding programmes, started in the mid 1980s, all seek to exploit genetic variability by using mainly cultivars that are different from the Smooth Cayenne, such as Spanish and Queen in Malaysia, the Philippines or in Thailand, and also wild forms and species resulting from collecting.

Accessions collected in Brazil from 1985 to 1994 in collaboration with CIRAD are currently being propagated and evaluated in Martinique. The germplasm that was collected constitutes a potential basis for future breeding programmes, not only for its resistance to different parasites but also for variety diversification.

In Martinique, CIRAD is conducting an important phase of selection for hybrids. Some of these may settle on the European market for fresh pineapple or in the local industry for canned fruit.

In spite of the relatively big efforts by several research teams, hybrids still remain little used in plantations. They are absent in Africa where plantations have been set up using only improved clones. However their use may become more widespread over the next ten years.

Lastly, the techniques of in-vitro culture, which have now been fully mastered, are still little used due to their high cost. For the moment these are limited to international exchanges of healthy plant material but may be used to develop new varieties of much greater value.

Pineapple in the future

The pineapple market is progressing, particularly with regard to fresh fruit trade. In order to respond to this increase, it is becoming necessary to find varieties that are better adapted to the different production contexts as well as the different markets, and to diversify the kind of fruits being marketed.

The future of pineapple breeding largely depends on safeguarding and exploiting the biodiversity of the genus *Ananas.* Therefore, collecting, constituting germplasm collections and evaluating genetic resources must remain a priority. Important programmes carried out by CIRAD are already under way.

The use of biotechnologies, particularly gene transfer, is being envisaged by several research teams. This may allow us to create varieties that are resistant to parasites and predators more rapidly.

Rice

Cultivated rice is a monocotyledon, annual grass from the family Poaceae. It is a semi-aquatic plant in the sense that it tolerates conditions of aquatic cultivation but does not depend entirely on this. It is a diploid, self-pollinated plant.

Cultivated rice belongs to two different species: *Oryza sativa* which originates from Asia and is found all over the world, and *Oryza glaberrima* which originates from Africa and is only found on that continent.

Within the *O. sativa* species, two main genetic groups may be distinguished: *indica* and *japonica.* Other groups such as *aus* in India, and *basmati* in Pakistan, may also be mentioned. These are morphologically close to the *indica* type.

The *indica* group, which originates from the southwestern Himalayas, is distinguished by strong tillering, narrow leaves and long, thin grains. Varieties within this group are adapted to aquatic farming in low altitude, tropical areas.

The *japonica* group which originates from the eastern Himalayas, contains three morphological types.

The temperate type, *japonica* in the strict sense of the word, has medium tillering, fine leaves and grains that are round and short. It corresponds to varieties for aquatic cultivation in subtropical and temperate areas.

The tropical type, *javanica,* can be distinguished by its reduced tillering, wide leaves and long, broad grains. Varieties from this type can be found in upland farming systems in tropical regions, but also in aquatic farming in the United States.

The third type, somewhere between the two previous ones, contains aquatic farming varieties found in high altitude, tropical regions.

Rice in the past

Rice is one of the oldest food crops ever grown. Domestication, which goes back to several thousand years ago, was begun for *O. sativa* in Asia from annual forms of *O. rufipogon,* and in Africa for *O. glaberrima,* from the annual species *O. breviligulata,* related to *O. rufipogon.*

From these centres of domestication, *O. sativa* quickly spread towards China where there were accounts of farming it reported in about 3000 B.C. It then spread through the whole of Asia. Its introduction into other parts of the world was more recent as this took place during the last thousand years due to the opening of the main maritime routes.

As for *O. glaberrima,* this remained on the African continent where it was gradually replaced by *O. sativa*.

During the course of *O. sativa*'s dissemination throughout the continents, and in spite of natural crosses, the two morphological types *indica* and *japonica* were conserved. However, with traditional agriculture, enrichment of forms was observed by selecting particular characteristics such as grain colour and earliness.

Rice-growing developed under conditions in which weeds were controlled, and soils were fertile: in lowlands for aquatic cultivation, after burning for shifting upland cropping.

With aquatic cultivation, irrigated or slightly flooded rice-growing predominated. Rice-growing in mangrove swamps or after high flooding (floating rice) and even at very high altitude, all had their own importance. From an agronomical viewpoint, the main improvements were water control, transplanting, fertilisation and, more recently, mechanisation and phytosanitary treatment. Adopting these improvements largely depended on the kind of aquatic cultivation practised.

In the upland system, shifting cultivation evolved very little. However, other pioneer systems were being developed: intercropping in young plantations and opening up of pasture lands, with or without mechanisation. The settling of rice-growing by integrating it into rotations, and the use of fertiliser and herbicide made intensification possible.

In parallel with these agronomic improvements, new varieties adapted to the evolution of cultural practices were created. Intensification of farming began in temperate regions in the beginning of the 20th century and, in tropical areas, in the 1950s. This caused a need for high-yielding varieties with reduced height.

For tropical *japonica* for aquatic cultivation developed in the United States, hybridization with temperate *japonica* was used for creating new varieties from 1930 onwards. The varieties obtained were grown from 1942 onwards and progressively replaced old varieties resulting from selections.

The same was true for temperate *japonica* that were grown in Asia (North China, Korea, Japan) and the Mediterranean regions in the 50s. High-yielding varieties thus became available. These were of average height (1 m).

Continued improvement of these varieties for temperate areas made it possible for them to achieve yields of over 10 t/ha.

The situation was very different for rice grown in tropical areas.

Until the 50s, the varieties of *indica* that were grown in flooded or irrigated systems, were of the traditional type, or came from crosses between traditional varieties. They were photosensitive and quite tall (1.4 m). Their grain yield was limited to 5 t/ha.

Tropical *japonica* varieties, grown in upland systems, were also of the traditional type and rather tall (1.5 m). They were fairly indifferent to photoperiod and had durable, polygenic resistance to rice blast, a major fungal disease. Their grain yield was no more than 3 t/ha.

For tropical *indica* rice, an important breeding programme was undertaken in the 50s by FAO. It aimed at combining this rice's adaptation capacity with the productivity of temperate *japonica* rice. But, apart from a few rare cases, intermediary forms were not found from the crosses carried out. Only a few varieties from this programme, such as Mashuri, remain today.

It was in 1965 that IRRI (International Rice Research Institute) created the first semi-dwarf *indica* varieties (0.8 m), which were not photosensitive and gave high yields. This programme used a natural semi-dwarf *indica* mutant as a genitor. The yield potential for these varieties was close to 8 t/ha. Their continued improvement (earliness, resistance to disease and insects, grain quality) led to a potential yield of 10 t/ha. These varieties were at the heart of the green revolution in many tropical countries of Asia.

For upland tropical *japonica* rice, little research was done before the 60s except in the Belgian Congo and Brazil, where new, early varieties were offered. However, the plant's morphological type remained unchanged.

It was not until the 70s that the first varieties of upland *japonica* with an average height (1.10 m) appeared. These were obtained either from crosses between tropical and subtropical upland *japonica* rice or by means of induced mutagenesis on upland *japonica*. These varieties, improved and distributed by IRAT (Institute of tropical agronomical research and food crops which has now become part of CIRAD's annual crops department), had better grain response to nitrogen. They produced up to 5 t/ha and maintained the characteristics of resistance (drought, rice blast) of traditional varieties.

One may think that an important step in the evolution of cultivated rice was made in 1975: varieties adapted to intensive rice-growing thus became available to most rice-growing areas and for all cropping systems.

Rice today

Rice is grown under very diverse ecological conditions; from the equator up to latitude 50° N and at altitudes of from 0 to 2000 m. Rice cropping systems are still very varied.

Rice-growing surface areas cover about 150 million hectares for an annual production of 530 million tons of paddy rice, which represents 320 million tons of milled rice. Asia alone provides 90% of this production.

New restrictions in intensive rice-growing (particularly attacks from parasites) and the market (the demand for long, flavoured grains) are at the origin of new orientations in variety breeding. The aim is still to increase productivity—the demand never ceases to increase with population growth—but resistance to biotic and abiotic stresses and product quality are being taken into account more and more.

Specific needs are appearing. This is why work is being orientated towards diversification of variety types, according to the level of intensification practised, the physical growing environment, especially altitude, and the availability of water resources (economical management of water in the case of aquatic varieties).

In this context, one may mention the first varieties of upland rice adapted to altitudes of over 1000 m. These were created in 1990 by CIRAD and were the result of crosses between upland *japonica* rice, and high altitude *japonica*. They are now grown at up to 1500 m altitude in Madagascar with yields of 5 t/ha, whereas before, under these conditions, they were no higher than 1 t/ha.

The majority of varieties improved remain pure lines. Hybridizations are generally carried out within genetic groups, but more and more bridging varieties are being used to make intergroup crosses. Thanks to better appraisal of the distance between potential genitors, by genetic markers, crosses can be better orientated today.

Haplomethods are used routinely for obtaining pure lines rapidly, and mutagenesis continues to be practised. These two techniques are used with the *japonica* genotype. But other breeding techniques are being exploited today. Recurrent selection for multicharacteristics or precise characteristics (resistance to rice blast or submersion) is beginning to come into practice. Work on genetic transformation is now going on for resistance to herbicides or insects.

Also, following the success of a Chinese experiment, selection work on rice hybrids is being done in many countries including India, the United States, Japan and Brazil. In this latter country, research is being carried out in collaboration with CIRAD.

Nowadays, hybrid rice covers one third of all rice-growing surface areas in China with yields that are 20% to 30% better than for other varieties.

Adopting improved varieties depends firstly on the economical context. The existence of a market favours the use of more productive varieties that are likely to provide a marketable surplus, or varieties whose grain quality responds to the demands of new markets. Access to more elaborate cropping techniques, as is the case in irrigated or pioneer areas, also helps to develop improved varieties that are better adapted to these farming systems.

However, when improvements correspond to one of the farmer's real needs (better grain quality, earliness...), new varieties are easily adopted.

The rice-growing landscape is very diverse today. This situation results, not only from the importance of rice in human nutrition, but also from the species' genetic potential. The latter holds plenty of exploitable wealth.

Rice in the future

The demand for rice is going to increase in years to come to satisfy the needs of a fast-growing population: production of paddy rice should reach 625 million tons at the beginning of the 21st century, representing an increase of 100 million tons in ten years.

To respond to this demand, two complementary ways have been suggested.

The first consists of raising output per hectare of irrigated rice cultivation, which already provides most of the world's production. IRRI is currently working on a new ideotype for a plant with moderate tillering but all fertile tillers, and with well-loaded panicles from crosses between *indica* and tropical *japonica*. The main aim is to reach a potential yield of 15 t/ha.

The other way, being developed by CIRAD among others, aims to favour the diversification of farming systems, particularly by developing upland rice cropping. Agronomists have noticed, in fact, that current progress in upland rice is comparable to that made by wheat, some decades earlier.

Rice breeding needs more systematic exploitation of the available genetic variability and by perfecting the plant breeders' methods and tools.

Analysis of the species' genetic organisation is already enabling us to make more rational, more systematic explorations of intra and intergroup combinations. Genome mapping is under way and will lead to the use of markers-assisted selection and cloning of important genes (whose product is hitherto unknown), such as genes for resistance to *Magnaporthe grisea* and *Xanthomonas* sp., by means of chromosome walking.

The use of genetic transformation should quickly bring results for crop protection against insects, viruses and fungi. In the long-run, it will make it possible to manipulate more complex characteristics such as resistance to abiotic stresses and plant architecture.

But important progress is also expected from the multidisciplinary approach to plant science and grain use.

Studies on pathology, entomology and rice physiology will enable us to better understand and, therefore, control the plant's behaviour when faced with biotic or abiotic stresses (temperature, water regime, soil salinity or acidity...).

Work on rice technology will lead to a diversification of products resulting from industrial transformation.

Rubber

Rubber comes from a tree of the family Euphorbiaceae. The genus *Hevea* contains nine ligneous species which produce latex, but only the species *H. brasiliensis* is exploited nowadays. This monoecious tree, with its long cycle, is considered as being preferentially cross-pollinated. It would seem to be an allotetraploid with a behaviour pattern which is very close to that of diploids.

Rubber in the past

Hevea in the wild, is a tall, deciduous forest tree, 25 to 30 m high, with a circumference of 1 to 2 m.

It is most often found on well-drained soils but also on lowlands undergoing annual flooding. It lives in small, sparse groups of a few trees per hectare, closely mingled with other forest species.

In its original growth area, the Amazonian basin, the whole of this genus alone covers over 6 million square kilometres; *H. brasiliensis'* distribution area is limited to south of the Amazon river.

Production of rubber from trees had been known since the time of Christopher Columbus. At that period, its use was confined to the manufacture of a few native items. It was not until the 18th century that this tree was identified by botanists.

In the 19th century, chemists managed to tame the product, industry found a demand for it and native trees began to be exploited in the forest. Brazil practically had the monopoly of it and Manaus became the capital of rubber.

When industry began mass-producing tyres, the demand grew, harvests from native trees no longer sufficed and rubber trees left the South American continent to be cultivated on artificial plantations in southern Asia (India, Sri Lanka), southeast Asia (Malaysia, Indonesia and, later, Vietnam...) and finally Central and West Africa.

Due to sanitary problems, Latin America was not able to develop this type of plantation. *Hevea* left its original continent to undergo a considerable boom in other tropical regions of the globe.

The history of the plant's breeding may be resumed by a few notable stages.

In 1900, plantation economy became important. Seeds were sown without being improved. Annual yields were low, around 0.4 t/ha, and increase in production was the result of extending the area and perfecting agricultural techniques.

In 1925, plant breeders eliminated the unproductive trees and improved the homogeneity of plantations whose productivity rose to 1.2 t/ha.

In 1930, two means of selection were being followed up simultaneously: selection in progenies from the best trees which led to seedling-type plantations whose annual productivity stagnated at 1.75 t/ha; and vegetative propagation by grafting, with the creation of clones derived from "plus" trees by means of mass selection, with annual yields of around 2 t/ha.

In 1950, propagation of *Hevea* by means of cloning became essential. Breeding for new clones was carried out from the progenies of better clones crossed together, which not only made it possible for producers to achieve annual yields of up to 2.5 t/ha, but also to introduce characteristics that were favourable to maintaining populations, such as resistance to certain diseases, wind...

The *Hevea* of the past has already made considerable progress since the start of its domestication: productivity has been multiplied fivefold, clones are so homogeneous that plantations have reached output levels that would certainly never have been dreamt of half a century before. However, very few efforts have been made to improve the technological qualities of rubber so far.

Rubber today

The main rubber-producing areas are still located in humid, tropical regions. Attempts have been made, sometimes with great success, to extend cultivation to areas considered as marginal—particularly to areas with low average temperatures such as China, or average altitude regions, 500 to 800 m high.

Asian countries alone produce over 90% of all natural rubber, the leaders being Thailand, Indonesia and Malaysia. Africa accounts for 6% of world production whereas the Latin American continent only produces 2%, still due to the sanitary problems already mentioned, namely, a terrible disease of the leaves caused by a fungus, *Microcyclus ulei.*

World production is around 5 million tons per year; 1 kg of rubber is sold at an average of 1 US dollar. The planted surface area is a sure 7 million hectares and an estimated 20 million people are involved in rubber production and transport. Post-war competition between natural and synthetic rubber has been very fierce and their respective shares are about one third compared with two thirds. Natural rubber, however, has certain technological qualities to which synthetic rubber could never economically claim.

One should note that a research institute for rubber has been set up in each of the five main production countries, to which France may be added, thanks to CIRAD. Five of these are conducting important breeding programmes on *Hevea.*

The plant breeder's tools are still those used in classical genetics. These are quantitative genetics and biometry for parent choice and sorting through progenies. Experiments in the field still account for the greater part of activities, although work in the laboratory, on molecular biology or physiology, for example, are generating an increase in knowledge that will be quite useful to the genetician on site.

Propagation of this plant is still done by means of grafting and the quality of clones available has progressed yet again: present clones have annual production potentials of over 3 t/ha. The age when trees enter into production has changed from 7 years to 5 years, which represents considerable economic progress. Homogeneity of plantations is still being improved. Plant breeders dispose of a portfolio of relatively varied clones. They may thus adapt their variety choices to the pressures of the environment (diseases of the aerial parts, damage caused by wind...) and even respond to the agronomists' demands to ensure clonal adjustment to the tapping methods used.

Technological quality of rubber is beginning to be considered, but only in the sense that plant material producing unfavorable characteristics is eliminated, rather than true improvement in the real sense of the term.

Clones resulting from current selections are, above all, adapted to industrial plantation conditions, whose average annual production may be over 2 t/ha over several thousand hectares. These companies are relatively receptive to the introduction of new clones; they often participate actively in the process of evaluation and selection.

Smallholders also use mainly improved clones. If they do not, this is only because they are under particular socio-economical conditions which are not really compatible with the current economical evolution. Their annual production is very varied; from 0.5 to 2 t/ha, but often less than one ton, which proves that modern plant material is not being correctly used. It is therefore difficult to say whether this material is badly adapted or whether the planter is not doing the necessary.

Rubber in the future

Because of the rise in costs of labour, and its rarification in some of the larger production countries, the trend for large cultivated surfaces will slacken off over the next ten years—so, in Malaysia, rubber-producing surface areas have dropped from 1.8 to 1.2 million hectares over the last five years.

Increase in productivity is therefore as high on the agenda as possible. In order to achieve it, we must aim for intensification of the tree's production or better population conditions.

Expansion of the area cultivated is also to be envisaged, either by selecting clones that are specifically adapted to new agroclimatic conditions (cold, drought, altitude) or by selecting clones that are resistant to this terrible disease which abounds in the Latin American continent, which would make it possible to exploit new, very vast regions, in Amazonia.

Considering the poor exploitation of the production potential from modern clones by the smallholders, and also considering that these planters account for 85% of the world's rubber production, the plant breeder's efforts should be concentrated on bringing out new varieties for this agricultural sector.

Improvement in technological qualities of rubber will have to be integrated into the process of creating varieties in a more direct way, in order to respond to pressures coming from synthetic rubber, which is always ready to substitute natural rubber if the market conditions allow it.

Finally, wood from *Hevea* is being used more and more often. How can we conciliate, in the same plant, relatively contradictory aims such as biomass production and production of a secondary metabolite? The answer may lie with fast-growing material which is renewed very quickly.

Increasing the tree's production may be envisaged from different aspects, often implying new methods in a classical procedure for creating varieties which must be maintained in the long-run. We may envisage obtaining these by means of in-vitro culture of a whole clonal tree on its own roots and no longer a grafted tree, which would do away with the problem of poor rootstock-graft relationships; genetic transformation, which makes it possible to envisage a direct effect on the genes intervening in rubber-production, or regulating these; the most rational exploitation of genetic resources possible, in order to obtain really new clones, aiming at complementarity or heterosis.

Improving the condition of tree populations means selecting clones on secondary characteristics of very high importance, such as resistance to diseases and morphology of aerial parts. Selection assisted by molecular markers should constitute a new tool to be added to the genetician's toolkit. In this sense, our team is working on establishing its gene map. Cloning of the tree's root parts, which was impossible up until now, has almost become a reality thanks to in-vitro culture. Selection of roots which are resistant to *Fomes* has been envisaged. The use of costly, fungicidal products, which are dangerous to the environment, could thus be abandoned.

Responding to the needs of smallholders means introducing several disciplines which have been relatively independent so far, such as genetics and socio-economy, into breeding processes; it means taking a second look at a programme which has proved itself in a certain context, but which should surely be forced to evolve with the idea of greater integration.

Sorghum

Sorghum, *Sorghum bicolor,* is a monocotyledon originating from Africa. It is widespread over the whole of the tropical area, and overflows into temperate areas. It is a herbaceous, annual, diploid plant from the family Poaceae. It is preferentially self-pollinated.

Sorghum in the past

Domestication of sorghum is very old and seems to have taken place in two stages. Firstly, a primitive sorghum of the *bicolor* type is said to have been domesticated on the fringes of the Sahara. Then, other races were improved independently in various regions of Africa.

From these centres of diversification, sorghum crossed the sea to Asia. Next, it reached Europe, then North America at the end of the 19th century and, finally, South America.

The numerous tropical varieties are classified into five main races according to the panicle and ear characteristics, and the region where they are grown.

Bicolor are the sorghums with the most primitive characteristics. They are found in Asia but also all over Africa. They have a loose panicle and the grain is small.

Guinea are typical sorghums from West Africa. They are generally tall, photosensitive and have loose panicles.

Durra can be found mainly in East Africa, the Middle East and India. They have very compact panicles.

Caudatum are mainly grown in Central and East Africa. Their panicle varies in shape. They are generally at the origin of sorghums grown in temperate areas.

Kafir are spread throughout southern Africa. They are small-sized sorghums and their panicle is compact and cylindrical.

Sorghum is grown during the rainy season, but may also be grown during the dry season, for cultivation in flood-recession systems. This is the case for *muskwari* in Cameroon. They may be cultivated with irrigation, but this practice is rare in tropical environments.

In Africa the first selections consisted of simply collecting landraces, then assessing them. The best landraces were offered to farmers, and often well accepted, as they were close to their usual varieties. But their improvement, by means of mass selection, or crosses between varieties of the same race followed by pedigree selection, only gave rise to slight progress.

In view of intensifying cultivation, three different ways were explored.

Other races of sorghum were introduced into West Africa where the *guinea* had reduced yield potential. The *caudatum,* which were not photosensitive though more productive, were introduced on a large scale. However, the productive varieties thus proposed were badly adopted by farmers because of their susceptibility to grain mould and their mediocre aptitude for traditional cooking transformations.

The creation of hybrids made it possible to use heterosis to its best advantage and thus offer varieties with high yield potentials. This variety type which is common in temperate environments and in mechanised farms of Latin America, is little used in Africa where sorghum cultivation is rarely intensive.

Crosses followed by pedigree selection became widely used, whether this be for trying to combine the qualities of the two parents or to transfer certain characteristics from one variety to another. Although the transfer of dwarf genes was a success and made it possible to obtain reduced height *guinea* varieties, the progenies of crosses between *guinea* and *caudatum* did not give the results expected, particularly with regard to grain quality, which is a primordial characteristic for human consumption.

Sorghum today

Sorghum is cultivated over about 50 million hectares in the world, with production of 53 million tons in 1993-1994. Africa and India grow about 30 million hectares but only produce about 24 million tons with an average yield of about 0.8 t/ha, whereas it is 4 t/ha in the United States, the world's highest producer.

In America and China, resorting to hybrids is systematic and sorghum is used for animal feedstuffs. However, the African and Indian farmers mainly grow traditional varieties intended for human consumption. This situation is due, partly to the extensive cultivation techniques that are practised, which do not justify resorting to improved varieties, and partly to the fact that the improved varieties have many serious defects. Grain quality rarely corresponds to the consumer's demands (which is not so true for the manufacture of sorghum beer, which is one important outlet for this crop) and furthermore, sources of resistance to pathogenic agents are rare (especially with regard to mould on grains).

Sorghum in the future

The creation of hybrids for intensive farming will continue without us being able to imagine a revolution.

For farmers in Africa and Asia, we may say that sorghum will remain a cereal which is widely consumed by Man and cultivated extensively or not very intensively. The failure of current improved varieties has made the plant breeders become aware of the importance that should be attributed to grain quality—the technical and genetic criteria for this quality are getting better and better established—, photosensitivity—interesting character for flexibility in cultivation calendars and sanitary quality of grains—, and tolerance to biological stresses (stem borer, panicle bugs, grain mould, *Striga*).

Tropical sorghum will be improved, not so much for high yield potential, but to obtain regular, stable production, with average yields, adapted to the cropping systems. With reduced height—2.5 to 3 m would seem reasonable—sorghum will no doubt be photosensitive or show great tolerance to grain mould. It will be resistant to insects and *Striga.* Grain quality will live up to the consumers' expectations and that of industry.

No revolution, then, but varieties that respond to the producer's needs as well as those of the users, much better.

Sugar cane

Sugar cane is a herbaceous, perennial monocotyledon from the family Poaceae. Several species are cultivated: *Saccharum officinarum, S. barberi* and *S. sinense,* with the latter two being natural, interspecific hybrids.

The *Saccharum* spp. canes that are cultivated today, are recent interspecific hybrids between *S. officinarum* and the wild species *S. spontaneum.* These are complex aneuploids with high polyploidy and are propagated vegetatively.

Sugar cane in the past

Saccharum officinarum originates from southeast Asia. Its domestication in Papua New Guinea goes back as far as over 2500 years B.C. From this center of domestication, *S. officinarum* migrated towards the islands of the Pacific, India and China. *S. barberi* and *S. sinense* appeared three thousand years ago, in India and China respectively. They were the result of introgressions between imported *S. officinarum* clones and local allied species, such as *S. spontaneum.*

The spread of sugar cane cultivation from India towards the west took place somewhere in the middle of the first thousand years A.D. Its introduction into America in the 16th century was carried out using only a few clones, probably from *S. barberi* or one of its hybrids with *S. officinarum.*

In the middle of the 18th century, European explorers brought back clones of *S. officinarum* from the South Pacific. Cultivation of these developed rapidly in South and Central America. These clones were known as "noble" because of their richness in sugar. One of these clones, Bourbon, was cultivated all over the world until the middle of the 19th century. The sugar cane industry thus underwent serious development.

The cultivated clones all seemed to be sterile. In 1885, seeds were obtained in Barbados and Java for the first time. From the discovery of this possibility of sexual reproduction, programmes for varietal creation were set up. At the beginning of the 20th century, there were six research stations on sugar cane in the world.

Plant breeders were interested, firstly, in crossings between noble clones of *S. officinarum.* These programmes met with certain success and were responsible for remarkable progress in sugar production.

In parallel with these intraspecific hybridization programmes, work was being carried out on interspecific hybridization between noble clones from *S. officinarum,* which are rich in sugar, and clones of allied species that are vigorous and resistant to disease. The hybrid obtained was then back-crossed with a noble clone in order to recover a cultivable phenotype after several cycles of back-crossing. For sugar cane, this improvement method was known as "nobilisation".

In Java, this is how hybrids, resistant to Sereh disease which was rife on the island at that time, were created by crossing with a clone from *S. barberi* that had been imported from India. These hybrids were rather unproductive, however, and susceptible to mosaic which made them unuseable in Java. However, certain progenies of this cross were grown on a large scale basis in other regions and used as genitors, especially in India.

In the 1920s, in Java, the interest in interspecific crosses from a spontaneous hybrid between an *S. officinarum* clone and a local *S. spontaneum* clone was demonstrated. Among the progenies of this nobilised hybrid, an exceptional clone, known as POJ 2878, was obtained. It was rich in sugar and resistant to mosaic and Sereh disease. Cultivation of this clone spread very quickly, first in Java, where it covered 90% of cane fields in the 30s, then throughout the whole world. This clone was widely used as a genitor in most research stations.

In India, breeding also became orientated towards the creation of interspecific hybrids by nobilisation. The first hybrids were obtained using a Bourbon clone and a local clone from *S. spontaneum*. Then, the use of hybrids of *S. officinarum* and *S. barberi* produced in Java led to the development of trispecific hybrids, by crossing with local hybrids of *S. spontaneum* and *S. officinarum*. Up until the 70s, creation of varieties depended solely on these first hybrids obtained in Java and India. Commercial varieties were created according to a classical pattern of clonal selection among the progenies of crosses between commercial clones. Modern hybrids resulting from this selection, have enabled to double sugar cane yields.

This breeding method soon reached its limits, however. In the 1960s, the narrow genetic basis on which it was founded no longer made it possible to make obvious progress.

In order to rectify this situation, work on nobilisation has begun again in many research stations.

Wild material belonging to the genera *Erianthus* and *Miscanthus* is also being used to create intergeneric hybrids and broaden the genetic basis of cultivated clones.

Sugar cane today

Sugar cane is grown throughout all the tropical and subtropical regions. Climatic factors have a dominating effect on production: water and heat for growth, drought or cold for maturing. However, in naturally unfavourable areas, sugar cane may still be grown with good care and irrigation.

World production of sugar cane is as much as 73 million tons. The highest productions come from India, Brazil and China.

Farming systems are very varied: ranging from large sugar complexes over 10,000 hectares to small fields of 2 to 3 hectares.

The main breeding criteria today are still sugar productivity for cane resulting from cuttings, but also for ratoons. These ratoon-cane fields may be harvested over ten times in certain regions. Resistance to disease and adaptation to particular cultivation conditions (frost, cyclones, drought...) are also being sought.

Breeding remains founded on classical methods of clonal selection with the creation of hybrids between commercial clones. These current varieties have genomes with 100 to

130 chromosomes, 90% of which come from *S. officinarum* and 10% from *S. spontaneum*. But research is being orientated more and more towards enlarging their genetic base, which is the only possible way to make progress. Different ways are now also being explored.

Research on somaclonal variation by tissue culture, begun in 1977, has not come to any conclusion. However, this has enabled to set up sanitation measures and to accelerate micropropagation in several areas (Guadeloupe, Louisiana, Hawaii, Indonesia).

Work on the introgression of wild species has offered interesting perspectives. It particularly aims at introducing resistance to disease into commercial clones.

Sugar cane plantations are now being established with modern clones. Their yields vary between 20 to 300 t/ha depending on climatic conditions and cultivation techniques.

Sugar cane in the future

New molecular tools at the plant breeder's disposal will, in the years to come, lead to faster, more efficient selection.

Perfecting the use of genetic markers will enable us to understand the genomic structure and function for commercial varieties of the *Saccharum* species. Genome mapping is under way for this at CIRAD. It hinges on, among other things, the synteny which exists between sugar cane genomes and those of maize and sorghum. Identification of molecular markers associated with certain agronomical characteristics will lead to markers-assisted selection. The possibility of spotting the genomes of different species involved in introgression programmes will allow us to increase the efficiency of such programmes.

Lastly, genetic transformation, which has been successfully practised in several countries on an experimental scale, is opening up new horizons for this plant which has a particularly complex genome.

Collection Notes et Documents

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