Elements of technological prospectives for a Doubly Green Revolution

Results of the CIRAD Scientific Committees' Consultation plant improvement, crop defense, technology, economics-sociology.

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The concept of a Doubly Green Revolution was designed (Conway, 1994) to face new emerging risks in food supply, poverty and the environment as identified by various forecasting studies (Rosegrant, 1995, Alexandratos, 1995, Mitchell, 1993, Griffon, 1994). We must now go beyond the concept of the Green Revolution. Although it has had positive results in terms of production on an exceptional scale, it is now encountering increasing limitations in Asia because of chemical pollution, salinity of irrigated land, levelling off of yields.

Like the Green Revolution, which was both a group of techniques and a strong economic and institutional policy, the Doubly Green Revolution will also have three major components.

The aim of this paper is to identify, and forecast the techniques involved in the Doubly Green Revolution. It has been inspired by discussions at CIRAD [1] Scientific Committee meetings in 1995.

Introductory definitions

The Doubly Green Revolution

To begin with, what is the Doubly Green Revolution? G. Conway et al. described its aims thus, "For the next three decades, it should repeat the success attained by the green revolution on a worldwide scale, in all the diversity of sites concerned. It

1 Scientific Committee of MICAP, the Mission for Plant Improvement, 6 April 1995; Scientific Committee of MIDEC, Mission for Crop Defense, 30 May 1995; meeting of Heads of Mission, 29 June 1995; Scientific Committee of MES, Economics and Sociology Mission, 30 June 1995; Scientific Committee of MITECH, Technologies Mission, 11 July 1995.

must be fair and lasting and must respect the environment. The first green revolution undertook to produce new high-yield varieties. It was only later that questions were asked regarding the benefit which poor people would obtain from them. The new revolution must overturn this logic by starting from the socio-economic demands put forward by poor households, and then seeking to identify research priorities. In substance, it names as its aims:

- food security;
- the creation of income and employment;
- the conservation of natural resources and the environment.

Specifically, this revolution is expected to improve the livelihoods of the rural poor households." (Conway et al., 1994).

With regard to the agricultural techniques, productive systems must show increased physical productivity in a way which is viable from an ecological, technical, economic and social point of view. We will also look at ecological and technical aspects of viability.

The viability of a production ecosystem can be defined as the functioning of all biological cycles in conditions where permanent renewal of its structures and its functions ensures that production potential is maintained and future production is not hindered. Evolutions in the production ecosystem may not be viable due to a deterioration process which may or may not be reversible. The extent of viability of the system's dynamics depends on the whole group of states for which the renewal regime is assured for a given period and for which there is a capacity for resistance to known risks (Griffon, 1995). Ecological viability indicators are therefore, first and foremost, indicators of renewal of the elements that make up the biological cycles which characterise production ecosystems. This concept means that the production system is not isolated from the ecosystem. It means that agronomy and zootechnics are considered as part of the more general operational ecology framework of reasoning.

The ecological environments of the Doubly Green Revolution

The Doubly Green Revolution, like the Green Revolution must have its own geography.

The areas involved in the Green Revolution are mainly areas with high potential, above all the irrigated plains of Asia but also the tropical savannah areas of Central America and Africa. It has been extended to more marginal areas from a production potential point of view, but without success; these areas include lower rainfall and hilly areas.

For the Doubly Green Revolution, geographical priorities are defined by the criteria of poverty amongst populations and environmental risks. Three major types of areas are concerned:

- extensively use
- overuse and hence
- new land areas and forest margins, where populations have a natural tendency to deplete the existing natural productivity capital; this is the case for forest margins in the humid and sub-humid tropic.
- areas where the Green Revolution has never been implemented and where the increase in food demand requires increased productivity. In a large number of cases, the problem will involve a reduction in fallowland.

  This concerns the humid, sub-humid and dry tropic and the Mediterranean areas:
- areas where the Green Revolution or a similar approach has been used, with negative effects on the environment.

  There are also three types of cases involving livestock production:
- Extensive rearing with non-renewal of fodder biomass, particularly in areas like the Sahel and woody-pastoral Mediterranean areas.
- Stock-rearing integrated into agriculture which is being intensified, particularly in sub-humid and dry tropical areas.
- Intensive stock rearing detrimental to the environment, particularly in peri-urban areas.

The geography of areas encouraged to produce and intensify production is determined by transport costs. In the absence of a nationally standardised prices. In areas close to consumption and storage centres, farmers and animal breeders can obtain good prices for selling their products and purchasing inputs. Areas under urban influence where intensification is the most probable, but also where one comes up against the greatest risks. On the other hand, in areas further afield products are sold at low prices and the cost of inputs is high, which motivates farmers exploit the capital of the area's fertility, with the risk of exhausting it (Ninnin, 1994).

Fertility management

Fertility means the productive potential of production ecosystems. This potential is compatible with a given domain of viability and a given regime for the renewal of structures and functions within the production ecosystem. Fertility is the result therefore of the state of viability of the area and its functioning regime. It cannot be explained merely by the stock of nutritive elements contained in the soil, since it is the product of all elements within the production ecosystem.

Different sub-domains for the management of fertility can be identified:

- soil preparation and occupation

- management of crop profile
- management of nutritive minerals
- management of organic matter
- management of competition between plants (ecophysiology)
- management of the pathosystem
- management of the working calendar.

As we shall see, in each of these areas there exists a management concept specific to the Doubly Green Revolution which, taken as a whole, creates a specific agronomical concept.

Agronomy for the Doubly Green Revolution

The Green Revolution seeks to build up a production system which replaces the existing ecosystem thus making part of the original environment artificial. The aim is tight control over the production system by seeking yields which are both the most efficient in terms of the outputs/inputs ratio and the highest possible. This means that, at the interface between the production system and the surrounding ecosystem, the pressure exerted by the latter has to be contained, for example, emissions of weed seeds, local-based parasites, water shortage and flooding. This is "nature substitution" which leads to "confrontation" in search of "containment" (Henry, 1987).

The Doubly Green Revolution seeks, on the contrary, to get the best from existing ecosystems by modifying them progressively, as and when needs arise, and respecting the laws of resources renewal. We no longer seek, to establish a simple production system as a substitute for the ecosystem, but to use the existing ecosystem which we then consider as a production ecosystem. This is a reasoning which no longer seeks to "confront and contain" but to manage nature and its way of functioning intelligently, "conniving" with it so as to "put it to work" (Henry, 1987). This has been done by numerous societies throughout history, because they did not have the means to create artificial ecosystems very rapidly and massively; such endeavours did not always meet with success however[2]. Therefore the idea of managing agricultural production in coherence with ecosystems is not new, but it can be "renewed" by adding a scientific concept.

2 One often cites for the sterilisation of the irrigated land of Mesopotamia and the desertification of areas close to the Nile, at the beginning of history and the difficulty encountered by the Romans in avoiding the desertification of the Maghreb and, more recently, ecological regression in Yucatan Maya.

This concept should have important consequences in environmental management.

Soil occupation

The principle of soil occupation responds to the necessity of combining different crops on surface areas and over time, each with different aims:

- species are required for their direct usage (production) and/or indirect usage (beneficial effect on the environment, e.g. nitrogen-fixing plants). This eliminates the need for managing the weed control problem.
- associations must be synergetic: recycling leached nutrients in lower parts of the root systems of trees, creation of shade with a favourable micro-climate effect, maintenance of a certain level of humidity, etc.
- permanent ground cover helps to limit soil erosion.

Land preparation

The installation of sole crops often requires the overall preparation ofbare land, by burning, clearing or ploughing. The modelling of plant cover, used in association with a crop, on the contrary requires selective treatment.

Soil profile management

Traditionally, tillage aimed at creating a crop profile is undertaken using instruments which:

- create or restore water retention
- facilitate root growth and penetration
- destroy causes of compaction
- plough in organic matter
- reduce weeds.

To limit artificialisation oil tillage is kept to a minimum.

Water and humidity management

In traditional irrigation methods, the principle is to secure a maximum amount of water, using the rainwater only as a supplementary source. In the opposite hypothesis, water from irrigation are meant to complement the climate.

Traditionally, in rainfed agriculture the formation of water reserves is achieved by tillage (ploughing, hoeing to break soil capillarity). Other methods may be used to retain ground humidity: maintenance of plant cover, use of natural or artificial mulches.

Mineral fertiliser management

Priority can be given to the use of mineral fertilisers, but diversifying sources is preferable:

- recycling harvest residue, composting by products, adding composted urban waste and animal manure.
- fixing plants
- use of nitrogen and phosphorus fixing plant (see inset 1), use of new industrial fertiliser and formula: reprocessed organic fertilisers from industrial stock farms, fertilisers released according to temperature and humidity (micro-encapsulation).

INSET 1

Sources of biological nitrogen from the symbiosis of plant and micro-organism.

- Annual nitrogen-fixing leguminous plants using rhizobium: pisum, medicago, sesbania, phaseolus, anichis.
- Leguminous trees: acacia, parkinsonisa (in dry areas) using rhizobium.
- Azole in ricefields using anabaena
- Non-leguminous plants using frankia
- Sugar cane using azospirillum

- inputs in small doses in order to avoid leaching and atmospheric losses (nitrogen).
- recuperation and recycling of nutrients sinking deep into the root system.

Management of organic matter

This can be done using the traditional method of complementary inputs, but this is often expensive due to volumes to be transported. One can also progressively reconstitute organic matter by encouraging humidification; humid conditions and favourable temperatures can be obtained using mulches or agro-forestry production ecosystems.

Weed management

The trend in modernised agricultural methods is to use herbicides or mechanical hoeing. Another approach would be to avoid the advent of weeds by competition with other cultivated plants, although herbicides still have their uses.

Management of pathosystem (parasitic biotope and biocenosis)

Modern trends have, over many years, increased the number of chemical treatments used. However, much work has also been done on the search for alternative methods:

- biological methods: use of predators and parasites which are the enemies of pests;
- genetic methods: production of varieties resistant to diseases and pests;
- integrated pest management: a combination of all methods, maximum reduction of biocides (inset 4).

Management of work calendar

The main trend is towards mechanisation in order to carry out crop-related activities in the shortest possible time, and at the most opportune time. Monocultures have, moreover, created peak working times in the calendar which result in the need for mechanisation.

In systems with multi or associated cropping, the working calendar is more spread out and work on crops is less easily mechanised, although research may prove otherwise. This option is coherent with the maintenance of high numbers of farm workers in rural areas.

A concept integrated around the crop system concept

The idea of integrating, on the one hand, soil and fertility management (inset 2), and on the other, integrated pest management leads to a more global concept of integration thanks to the crops system concept and the technical itinerary concept (inset 3) his integrated management of operations can be made coherent with the local ecosystem (inset 4).

Livestock adapted to the Doubly Green Agricultural Revolution

Stock-rearing systems which strive for highly artificial production processes (foodstuffs, animals living conditions) are no longer given priority. Other stock-rearing systems are put forward which are more compatible with production ecosystems and are thereby better integrated. Numerous channels exist already: animals as part of the work-force, manure as a source of organic matter or proteinous foodstuff for fish-farms, animals as income or daily food source with the aim of offering security in the same way as using animals as a form of savings offers security for the owners. New types of low-labour intensity stock-rearing could surely be invented to use the presently wild fauna in the humid tropics (large rodents, tortoises, fish) or in the dry tropics (flightless birds).

INSET 2

Integrated soil management

1. Working the soil without endangering its biomass and structure.

Aim:	to retain as much residue as possible on the soil (mulch)
Means :	to avoid erosion

2. Recycling nutritive elements

Aim:	to avoid the loss of nutritive elements
Means:	appropriate crop rotations and successions crop associations (and agro-forestry) in order to occupy the various levels in the soil through the roots system
	mulches

3. Combating weed-control

Aims:	to reduce the use of pesticides
	to make the working calendar more flexible
Means:	mulches
	crop associations

4. Managing territorial units

Aim:	to integrate interventions within the framework of the local cultivated ecosystem
Means:	ecological works: hedges, erosion control, etc.

From: C. Piéri 1995. Soil fertility management for intensive agriculture in the humid tropics Draft and Integrated soil management for the tropics - IBRD/AGRTN, no.7, Nov. 1994

INSET 3

Crops system and technical itinerary

Crops system: all elements within the system (soil, water, nutrients cultivated plants and weeds, diseases and pests) and relationships between these elements (of the eco-systemic type) at the plot level, which the decision-maker manages using a technical itinerary.

Technical itinerary: all crop operations ordered over time.

A technical itinerary is a succession of crop operations in a given time period (types of tools, technical characteristics of operations).

New directions for plant-improvement genetics[3]

The majority of cultivated tropical plants are traditional, apart from palm oil, rubber trees and Robusta coffee plants which have been grown for approximately a century. Through widespread and age old dissemination crop varieties have become very adaptable. This adaptation has been somewhat eroded but not reversed. Overall, the use of selected varieties still remains an exception, exemplified by palm oil, rubber trees and cotton plants, whilst local varieties dominate most crops like cereals, coffee, cocoa, coconuts.

3 Summary of "Plants from yesterday, today and tomorrow". MICAP File (Knowledge and Improvement of Plants Mission), written by M. JACQUOT, CIRAD, 1995.

INSET 4

Doubly Green Revolution

Technical Principles for Rainfed Agriculture

	Trend "Green Revolution or modernisation"	**Trend "Doubly Green Revolution"**
Soil occupation	Sole crops	Associated crops
Environmental preparation	Obtention of bare land by burning, mechanical clearing, herbicides	Retaining selective plant cover
Management of crop profile	Tillage in order: - to constitute water retention capacity - to facilitate root establishment - to plough in organic matter - to reduce compaction - to form a seed bed - to reduce weeds	Minimum tillage in order to economise energy and work time
Water management	By tillage	By retaining humidity using bush cover and mulch
Fertility management	Mainly mineral additives	Diversification of sources: - recycling residues - animal manure - N and P fixing plants - recycling of nutrients migrating duply e.g. through roots system - effects of mulches and management of soil's micro-fauna - "new fertilisers": urban waste, etc.
Management of weeds	Mainly herbicides Mechanical hoeingcrops	- reduction by competition with associated weeds - herbicides used as a complement
Management of pathosystem	Mainly by biocides	- biological pest management - integrated pest management
Management of productivity	Mechanisation and motorisation to reduce intervention times	- spread of calendar in order to maintain employment - mechanisation by risk reduction
Risk management (climatic, economic)	Specialisation Search for optimum productivity	- diversification - search for an intermediate aim in varied environmental hypotheses
Management of stock-rearing in the production system	Stock-rearing not necessarily integrated into agricultural systems Search for optimum productivity	- stock-rearing integrated into agriculture e.g.: • as a work force • as a source of fertility • as an activity to optimise available working time • as a means of saving

Present selection objectives

Research for maximum yield has until now been the overriding objective. Resistance and tolerance to parasites came as a priority at a later date: coffee plant rust as from 1900, Phytophtora in pineapples in 1914 and citruses in 1920, cercosporosis in banana trees in 1940, etc. Physiological and architectural improvements were researched later on: reduced-height palm trees, dwarf rice and coffee varieties, upland rice, etc. For commercial crops, quality has always been an important criterion: length of fibre for the cotton plant, taste and presentation for citruses and fruit plants.

In order to improve knowledge of intra-and interplant variability and its spatial breakdown, research has developed polymorphism studies using biochemical and molecular markings on numerous species: rice, cane sugar, sorghum, cotton plants, cocoa plants, rubber trees, and so on. This has led to the conservation of genetic resources.

The main improvements for yield potential were obtained by the achievement of hybrid varieties and the mastering of plant multiplication (especially in woody species). Future projects are expected concerning genomic mapping, selection assisted by markers, in-vitro plant multiplication culture, haploidisation and genetic transformation.

The Doubly Green Revolution objective

The objective of the Doubly Green Definition is defined by various criteria: higher yields with lower production costs and respect for the environment in a lasting, viable manner all the while focusing on ecologies and areas where poverty is rife, by working mainly on the crops grown there. Plant breeders should include a multifactorial approach.

The supply of varieties to poor farmers in regions with limited production potential implies the use of hardy, species. In reality, these species are genetically more sophisticated as greater efficiency is required of them in a poor area, and they have to resist stress and abiotic environmental factors over which the farmer has no control. Areas concerned are numerous and varied; likewise plant solutions must be multiple.

Furthermore, research should focus on more numerous species [4]. Research's natural tendency is to work on a small number of species in order to capitalise

4 For example: cereal crops in dry areas, fonio and quinoa in the Andes, tropical fodder crops for a tropical forage, cow-peas, taros, yams, lipped-tubers, plants for new usages: marrows which produce fibres for packaging, polymer-producing potatoes, trees for pastureland and ecological objectives, sand-fixing grasses, etc.

scientific innovations upon each of them. In intensive agriculture and high-production areas where just a few high performance species are present, this approach is undoubtedly efficient. In marginal areas with vast ecological diversities and low-capacity investment power, research could be directed towards other species and in particular towards local farmers' needs. Initially the same botanic family could be retained in order to reduce development time.

Efforts to conserve of genetic diversity are essential when faced with the need for foodcrop diversification and the introduction of useful genetic properties.

Varieties to be offered should have durable stability (e.g. varieties of sorghum whose cycles vary according to water availability) and spatial stability when taking into account the vast heterogeneity in the area and even micro-heterogeneity in small plots of land. They should therefore be able to resist poly-genetical types of aggressions, and have inherent resistance against destructive abiotic factors, in particular, wind and drought (inset 5).

INSET 5

Doubly Green and Genetic Revolution

	Usual objectives	**Doubly Green Revolution Objectives**
Species		Focus on orphan plants Diversify species
Varieties	One or several species given priority	Seek multiple plant solutions Use local varieties
Criteria	Maximum yield in good climatic	Multifactorial approach conditions Yield stability in time and space when climatic conditions vary
Resistance to abiotic stress	No research	Very important objective since essentially beyond farmer's control
Transgenesis	Frequently used	Caution: dissemination occurs in areas where related species grow together
Conservation of resources	Indispensable in the long-term	Rapidly indispensable in order to restrict erosion of adapted variety

Finally, the necessity to continue research to increase food crops yields in high production areas should not be forgotten. The fact that the ever-increasing demand for food is met by these areas reduces pressure on low yield and more fragile areas.

Therefore, genetics should be simultaneously orientated in two different directions: producing varieties which respond better to high-imput intensified farming and varieties which are less demanding and more stable in their environment.

Confirmation of crop production research: integrated pest management [5]

Crop growing systems can be considered as artificial ecosystems when populations of cultivated plants are genetically standardised and thus vulnerable to parasites and pests. Damage which can be considered acceptable in the maintenance of a wild species population, is not acceptable in a commercial harvest. For these reasons intensive farming has used all available means: crop growing systems which restrict the development of related plants and pests, plant resistance, antagonistic or parasitic organisms which act on destructive weeds and plants, and the use of increasingly efficient biological and chemical products. The optimisation of these methods leads to environment-friendly integrated pest management.

Limited scope for research into new products

The use of chemicals has become widespread in most farming practices in order to ensure commercial viability. Scope limitations are: costs, eco-toxicological risks, the absence of products which can be used against bacteria and viruses, and resistance build-up in targeted organisms. Copper sulfate was first used a century ago, organo-chlorides and organo-phosphates were introduced approximately fifty years ago, and since then numerous, more efficient families of products have been created and constituted the number one research objective until 1980. At that time the major objective became the research for molecules with greater respect for the environment. Products corresponding to these objectives now exist, but their cost is often high. This can be offset by seed treatment applications. The cost and necessary duration for the development of a new product is presently estimated at approximately 400-500 MFF on average over 14 years. Because of this, research has focused on a limited number of objectives which correspond to large, present or potential markets for chemical products used in farming. A very small number of pests or tropical parasites are specifically researched (this question to be related with the objectives of the pharmaceutical industry's research programmes). A slightly higher number of the aforesaid subjects will benefit from offshoots of test results on new products concerning organisms which were not initially the research target. Furthermore, the cost of commercial approval and standardisation continuously increases due to constraints brought about by legislation. This imposes serious scope limitations (S. Axiotis, 1995) [6]

5 Summary taken from "Domaine de recherches stratégiques pour la lutte intégrée" (Strategical Research Field for Integrated Pest Management) of the Doubly Green Revolution. Report from the Scientific Committee of the Crop Defense Mission (MIDEC), prefaced by J-L Notteghem.

6 Summary taken from "Domaine de recherches stratégiques pour la lutte intégrée" (Strategical Research for Integrated Combat) of the Doubly Green Revolution. Report from the Scientific Committee of the Crop Defense Mission (MIDEC), prefaced by J-L Notteghem.

Research has for a long time been based entirely on the screening of families of synthetic products. Development of research into molecular aspects of parasitic pathogeny is contributing to new knowledge. This approach which has been widely developed for viruses and bacteria, presently has numerous applications on fungi (Lebrun M.H., 1995) [7] As far as fungi are concerned, results are expected relating to the identification of new fungicide targets and the possibility of using new genes to increase plant resistance.

In 1990, more than 500 species of insects were reported as resistant to insecticides. This type of resistance often leads to the use of higher dosages and more frequent applications. Assessment of resistance levels is a necessary first step in the management of populations of parasites. The growth in mechanisms of resistance now even entails genes and their very functions: studies carried out on Culex pipiens (Pasteur N., 1995) [8]. The example of Culex, pipiens complex mosquitoes raises new study prospects for resistant populations. Mutants rarely exist, but they spread to numerous territories due to migration, encouraged by human activities and selection pressures which favoured the multiplication of resistant populations leading to their expansion around the world. These studies find obvious applications in the management of arthropods, fungi and weeds which are resistant to pesticides. Similar research is useful in the management of resistance to all products used, whether chemical or biological (Bacillus thuringiensis).

The use of genetic resistance

There is tremendous similarity between the studies on the dynamics of populations resistant to pesticides and those of populations of parasites or pests which defy plant resistance. Analysis of populations of phytopathogenes is necessary for designing strategies using resistant varieties. Analysis of the genetic structures of these populations shows frequent links with pathogeny variations (M. Peterschmitt, 1995) [9]:

Variability of pathogeny in phytopathogenic viruses. Analysis and prospects - E. Roumen [10]: Analysis of the European population of M. grisea and the management of resistance genes. Studies carried out on epidemics in present crop growing systems indicate a need to avoid the accumulation of resistant genes in a plant. The latter method can lead to an increase in the frequency of virulent strains and increased persistency whilst methods permitting temporal or spatial associations of resistance genes lead to long-lasting management of effectiveness (C. Pope, 1995 [11] Analysis of populations of phytopathogenic fungi and management of resistance genes).

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7 MIDEC conference: M. H. Lebrun: Pathogenic capacity of fungi, molecular analysis of pathogeny genes in M. grisea

8 MIDEC conference: N. Pasteur: Factors controlling the development of resistance to insecticides

9 MIDEC conference: M. Peterschmitt: Phytopathogenic viruses. Analyses and prospects.

10 MIDEC conference: E. Roumen: Analysis of the European population of M. grisea and management of resistance genes

11 MIDEC conference: C. Pope : Analysis of phytopathogenic fungi populations and management of resistance genes

These studies require powerful population analysis tools with high-detection capacities. Immunoenzymatic tests are now applied to a great number of organisms, mainly viruses and bacteria. The generalisation of their use in tropical areas is a current objective. Molecular tools give access to the greater specificity and sensitivity needed to understand the cycles of viral and bacterial diseases. Research to find these tools is under way in numerous laboratories (P. Rott, 1995 [12] : Diagnosis of bacterial diseases, prospects of using molecular methods).

The management of resistance genes can be achieved through improving knowledge concerning these genes. The identification of a new gene and its assessment represents considerable work. Further, methods which give access to in-depth knowledge of them are now being developped. Research is centred on both resistance genes and corresponding virulence genes which are associated in a gene-to-gene relationship. The results of resistance gene cloning have recently met with success, and some ten genes are presently being cloned (M. Dron, 1995[13]: Monogenic resistances to plant diseases). We also expect gene mapping to lead to simplified identification methods for new resistance genes. These studies will help in the development of strategies for use in monogenic resistance. An analysis of links between molecular markers and resistance could facilitate the assessment of the role of genomic segments in partial resistance (QTL) (C. Lanaud, 1995 [14] : Mapping of resistance genes in tropical perennial plants - B. Clerget, 1995 [15]: Corn resistance to tropical viroses). The major objective of these studies is undoubtedly to acquire further knowledge of genetical control over the aforementioned resistances. If the use of the marker method becomes simpler, thereby lowering its price, the usage of QTL in plant improvement could become general practice.

The possibility of genetic transformation of a growing number of species introduces the possibility of creating cultivars with built in resistance genes. This strategy has been most widely developed for viral resistance; now attempts are being made to include resistance against phytopathogenic bacteria and fungi. In the latter case, published results are not conclusive, but the diversity of studies should rapidly lead us to promising research channels. As far as viruses are concerned, following the viral protein envelope approach, one may now observe many experimental methods, are being tested including the use of other viral genes, and animal genes with antibodies against plant viruses. (T. Candresse, 1995 [16]: Strategies to produce transgenic plants resistant to viruses). There are two scope limitations involved here: biological risks, especially the possible increase in recombinant viruses, and the sidestepping of new resistances. Discussions concerning strategies for the use of transgenic resistant plants are vital, and fit in with those on the use of monogenic

12 MIDEC conference: P. Rott: Diagnosis of bacterial diseases, prospects and uses for molecular methods
13 MIDEC conference: M. Dron: Monogenic resistances to plant diseases
14 MIDEC conference: C. Lanraud : Mapping of resistance genes in perennial tropical plants
15 MIDEC conference: B. Clerget: Corn resistance to tropical viroses
16 MIDEC conference: T. Candresse: Strategies to produce transgenic plants resistant to viruses

plant resistances, the analysis of pathogenic and pest populations, and weeds in crops. These are probably the most important fields of research for the years ahead.

Upstream and downstream agricultural techniques

The objectives of the Doubly Green Revolution are not just aimed at the crop-stock farming stage in the food chain. Agricultural supplies are also affected: agricultural machinery, fertiliser production, plant health treatments rural equipment. Similarly the stabilisation, conservation and transformation of products must not be forgotten. These upstream and downstream sectors contribute to increasing the availability of food and diversifying the agricultural supply as well as creating jobs in rural areas and limiting environmental damage.

The mechanisation of agricultural activities

Intercropping systems (including agro-forestry) cannot be mechanised in the same way as mono-crop systems. Work in rows remains the main research channel through which work productivity can be increased, but crop associations probably do not permit the use of high-powered traction machinery. In the same way as machinery exists to work on gradients and narrow roads of land in mountainous farming machines also exist to cater to the ageing farming population (Japan). This leads us to believe that specifically adapted machinery for inter cropping could be developed. Mechanisation would have to include small, easy to handle machines. Since farming interventions are staggered throughout the year high-powered traction machinery (which do the job quickly and are needed for peak time chores should be avoided). The example of manual low-volume sprays for cotton plants illustrates the possibility of mechanising certain selected functions. Hauling remains manual and is acceptable where low volumes are involved. Spraying is electric in order to achieve the correct size of micro-drops. Important research efforts should be made towards transport within the farm as this is often a major obstacle when bringing in inputs and harvests. The mechanisation of seeding under mulch is also a major objective.

Upstream Agriculture

The Doubly Green Revolution could change the nature of demand towards other agricultural supply sectors: fertilisers, land developement companies.

As far as fertilisers are concerned, the need for organic matter should increase. In addition to internal on-farm resources, other sources should be explored. This is the case in Japan where research is underway to produce low weight organic fertilisers. Animal manure from large industrial stock-breeders could be dehydrated using hydraulic pressure, liquid slurry could be transformed into solid fertiliser and the remaining liquid de-polluted ("transfilter" process) for irrigation and methane gas could be produced for energy. Considerable commercialisation networks for these offshoots exist already in Europe (Truong Binh 1944). Compost made from urban waste emanating from large tropical towns also constitutes a tremendous source of fertiliser.

As far as nitrogenous mineral fertilisers are concerned, there is presently no industrial alternative which would give low-cost local production. For phosphates, solubilisation using sulphuric acid phosphates with low water solubility constitutes an important breakthrough Africa.

Innovations in packaging pesticides so as to restrict skin-contact are extremely welcome: self-spreading granules in self-dissolving sachets for paddy-fields, "jumbo" size granules, drop-by drop-insecticides.

Rural development companies (dams, irrigated plots, anti-erosion works) are generally in charge of entire operations. New systems are presently emerging. Local populations are becoming involved in manual labour combined with machinery (sub-soilers, bulldozers, trucks) for work that cannot be done dealt with manually. The work of local populations is an investment subsidised with food-aid.

Reducing post-harvest losses

Losses are often estimated to be as high as 10% of the harvest. This can be due to bad harvesting and poor biological stabilisation of the product. Other causes are attacks from diseases and pests during storage, poor transformation, commercialisation, and at times consumer handling.

Local knowledge concerning storage has been ignored too often in the past. This valuable information should be heeded as it is based on years of experience.

On this basis, research could be undertaken in different fields to improve:

- drying and stabilisation of cereals and oil-proteinous grain in humid tropical conditions,
- the protection of perishable food stocks,
- the conservation of products obtained by grinding grain,
- drying, dehydration and conservation of fruit.

The transformation of products by small companies

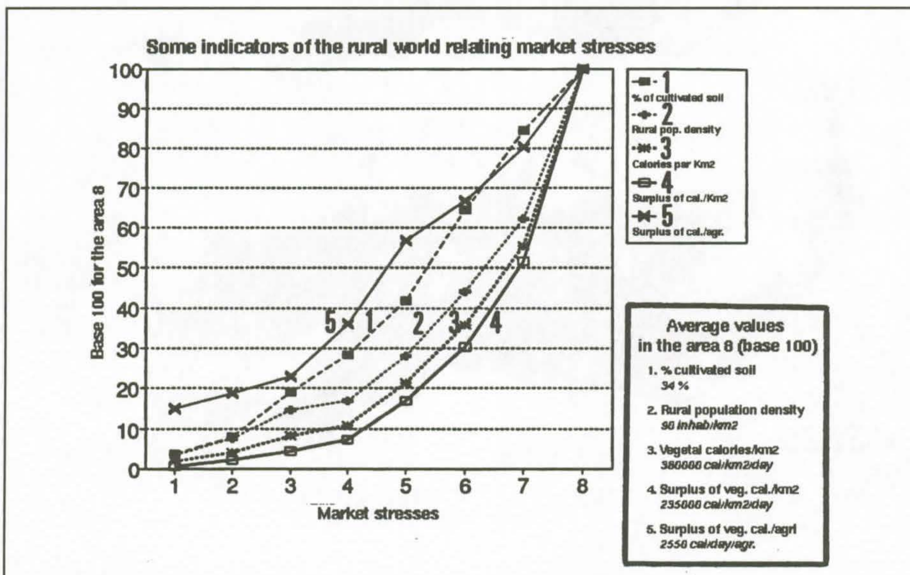
In poor and landlocked areas, developing the local economy by diversifying transformation activities contributes to job security. These small transformation units serve the local market and include grain mills and oil presses which also produce cake and animal feed, etc.

In the future new techniques could be offered to local companies: dehydration-impregnation by osmotic immersion, canning, edible or biologically degradable packaging, bread making with manioc starch, new fermented foods for sauces.

New agricultural productions for industry: energy, fuel, timber.

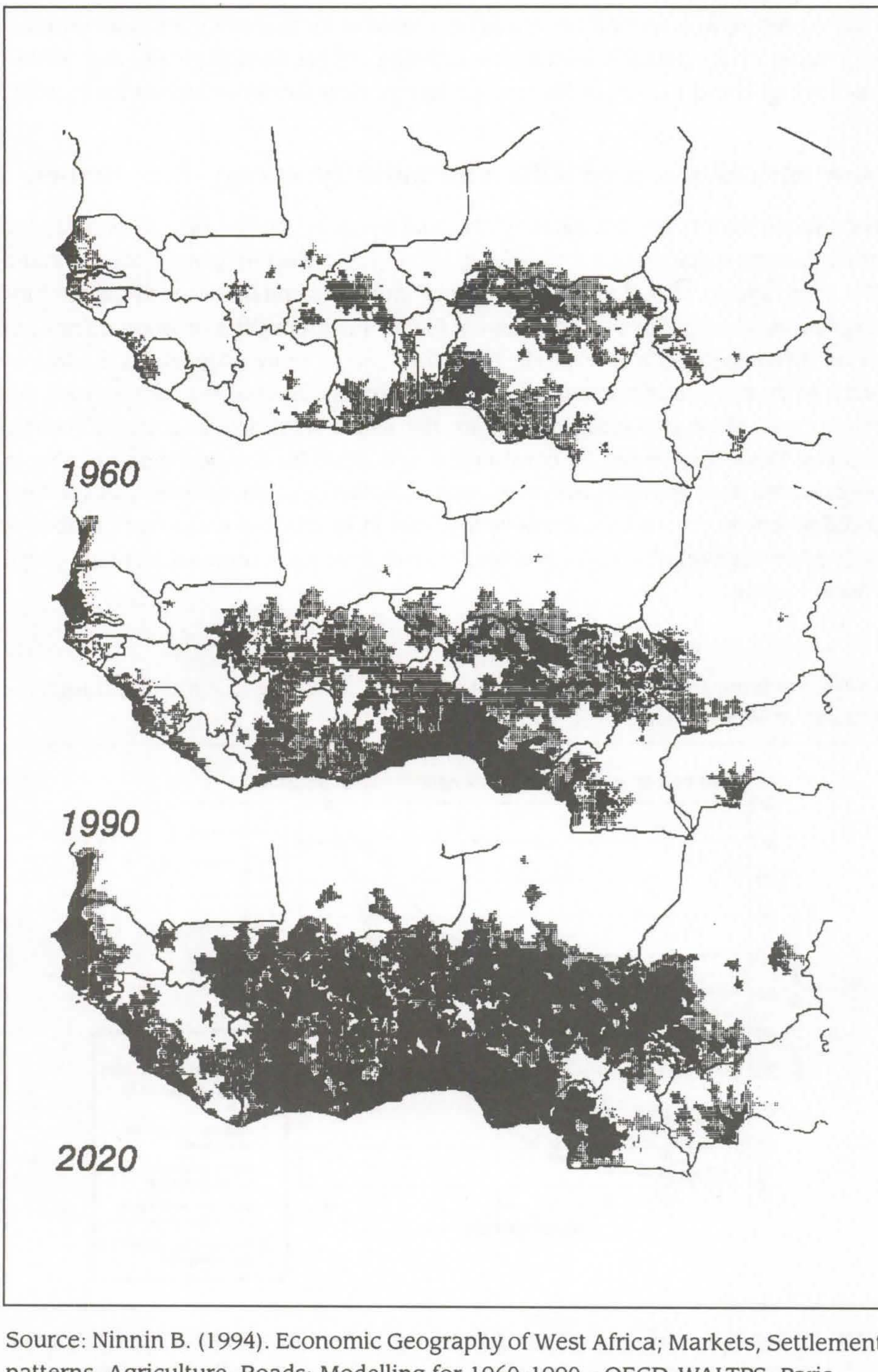
Food requirements are not the only essential needs which increase as populations grow. Energy requirements for cooking, lighting and electricity are also important. The same applies to fuel for transport, small industries and for producing electricity. Biomass production for the extraction of fuel or the production of wood do not necessarily compete with food production. They can be in synergy within the framework of cropping systems (agro-forestry, oil-proteinous seed production with different uses). These non food products are also useful in the diversification of income sources. Producing timber for construction and wood for fuel become profitable in areas where trees are rare. The production of biofuel (alcohol, ethanol, gas, oil, fuel) could be envisaged as an alternative to diesel in landlocked areas (remote towns, poor infrastructure) or in areas situated far away from main commercial roads (small Pacific islands).

Graph showing the influence of the proximity of towns upon agricultural intensification in West Africa.



Source: Ninnin B. (1994). Economic Geography of West Africa ; Markets, Settlement patterns, Agriculture, Roads: Modelling for 1960-1990 - OECD-WALTPS, Paris.

Map showing the influence of the proximity of towns upon the motivation to produce in West Africa (Market tension).



Source: Ninnin B. (1994). Economic Geography of West Africa; Markets, Settlement patterns, Agriculture, Roads: Modelling for 1960-1990 - OECD-WALTPS, Paris.

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