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Title:

ORGANIZATIONAL DETERMINANT OF TECHNOLOGICAL INNOVATION IN FOOD AGRICULTURE AND IMPACTS ON SUSTAINABLE DEVELOPMENT

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Abstract:

The food security challenges faced by populations in sub-Saharan Africa and the fact that extensive production systems are reaching their limits in the food-producing agricultural chain have increased the need to accelerate technological innovation toward the ecological intensification of agricultural production systems. A review of the research conducted on plantain bananas (*Musa Paradisiaca.*) in Cameroon since 1988 revealed how institutional innovation has enabled the hybridization of different research forms—such as fundamental, systems, and action research—and reinforced the organizational innovation required for technical change. We found that impact evaluation underlined the complementarity between the increases in productivity and income in rural areas, as well as the production of human and social capital and the protection of forest resources.

Keywords:

innovation, agricultural technology, institutional, information, knowledge

JEL code: O31, Q16, B52, D83

1. INTRODUCTION

In the agricultural systems of southern countries, the transfer of innovation models promoted by industrialized countries has historically dominated the governance of technical change (Swinnen, 2006). These models underpin the governance of innovation techniques in agriculture following two different lines. The first examines generic research on upstream agricultural production (e.g., biotechnology and mechanics) in the industrial sector, which guides “process” innovation at the producer level. The second examines the downstream conditions for accessing markets that influence “product” innovation. The agricultural producer, often considered as an entrepreneur, is supposed to optimize the opportunities and constraints resulting from the previously sector-based insertion (Pavitt, 1984). The dominant system has not only structured the organization of international agricultural research focusing on the green revolution in Asia, but also that of national agricultural research systems in Africa (Sumberg, 2005; World Bank, 2006). This model is based on a diffusionist and linear approach to technical change between the inventor (researcher) and the user (agricultural producer). It constitutes a technological paradigm that has been successfully transferred to sub-Saharan African agro-industries, which have been focalized by the supply of international markets (Afari-Sefa, 2007).

However, this paradigm has had little impact on food crops production (e.g., plantain, cassava, yams, etc.) in sub-Saharan Africa, where production systems mainly rely on family labor and the conditions for mobilizing the various productive resources—namely work, natural capital (water, land, etc.), and human capital (e.g., knowledge or information)—are highly dependent on institutional and organizational variables (Requier-Desjardins, 1994).

Consequently, the transfer of green revolution principles based on the diffusionist approach during the 1970s/80s failed (Chambers et al., 1994), as demonstrated by the agricultural productivity approach and recent food crises. In sub-Saharan Africa, the available statistics (Fao-Stat) emphasize a decrease or stagnation in food crop productivity According to available data, food security in sub-Saharan Africa will remain uncertain over the next 20 years if no new approach is found or proposed.

Several factors can help to explain the conventional model's global failure in this region including political crises, which disrupt the institutional conditions required for the expansion of agricultural productivity, and state disengagement from the organization of the support services required by agriculture, such as credit, agricultural extension, infrastructure, research, etc. (Nyemeck and Nkamleu, 2006). A transverse explanation is the lack of adaptation of the technical innovations provided by this diffusionist model to the very diverse production conditions (socioeconomic and ecological).

This failure has forced farmers to innovate in order to satisfy the food productivity objectives defined by the issues of food security. In this context, the emergence of the concept of sustainable development examines the capacity of the technical innovations, which have been implemented to ensure the compatibility of the objectives of increasing productivity; protecting natural resources, biodiversity, and forests; and reducing social inequalities (Griffon, 2006). This question guides new research lines for the intensification of production systems. These research lines involve an improved adaptation of complementarities between plants or the ecosystem potential (Crozat et al., 2010) and an understanding of the socioeconomic determinants, which implement biological knowledge within the farmers' technical systems (Chianu et al., 2010).

In the social sciences, the evolutionist referential of technical change (Dosi et al., 2006; Nelson, 2008) shows how the emergence of the innovation system concept helps to understand technical changes, notably in the fields of biotechnology research. The application of this innovation system concept (Carlson et al., 2002) to the analysis of agricultural systems in southern countries (Sumberg et al., 2002; Hall et al., 2003) finally underlines how the fostering of various research orientations and subjects requires the development of interactive frameworks between operators in the innovation process. The exercise focuses on a pathway approach, which "sectorializes" the innovation system in regards to a particular product (Montaigne, 1996). This theoretical referential allows us to specify the concept of technical innovation used here.

We define technical innovation as a process that distinguishes an invention (a technique, a type of organization, a hybrid, etc.) that can be developed by a farmer, a researcher, or an organization within the sector. An innovation is embodied by the invention's integration into a productive system. This integration may or may not be supported by non-farmers, such as managers, researchers, etc. (Sibellet, 2006). In fact, it suggests the capacity to "hybridize" both the different sources of the invention's creation (e.g., fundamental research and empirical research) and the different processes required to integrate the invention into a productive system. Consequently, a technical innovation depends to a large extent on institutional and organizational innovation, which structures the coordination between the operators required for its implementation (Aggeri and Hatchuel, 2003). It implies that the researcher's job is no longer limited to producing an invention or knowledge, but that he or she is responsible (directly or indirectly) for ensuring that the three dimensions—technical, organizational, and institutional—giving rise to the innovation are taken into account. This activation mobilizes the concepts of action research and the tools of participatory research.

Another determinant of the innovation process is the need to take the historical or long-term dimension into account, as this ensures coherence between organizing production methods, technological choices, incremental innovations, and collective values. The degree of coherence in the integration of these different dimensions shapes the paradigms that ultimately determine research choices.

In order to test this explanation, we will show how knowledge production concerning these specificities has modified the conditions for the emergence of technical innovations and optimized the focus of agronomic research. It calls on empirical experience and databases produced in the framework of a research program in Central Africa initiated in 1980 (Chataigner, 1988).

The story of agronomic research on plantains leads to the analysis of different institutions' research programs that participated in the production of knowledge that is being used for the ongoing plantain innovation process (Hauser, 2000). We put forward the hypothesis that the mechanism of "hybridizing" the different forms of research implemented at African Banana and Plantain Research Center (CARBAP) since 1989 has played a crucial (but not exclusive) role in ensuring the implementation of scientific knowledge among producers in Cameroon, that is to say, in transforming this knowledge about bananas and plantains in Cameroon, especially in the upscale of technical improvements at the farmer level. The presentation of the methodological framework explains the main research stages that have structured this hybridization (Figure 2) between: fundamental research (botany), systems research (economics), experimental research (agronomy), and participatory research (interdisciplinary).

2. Methodological construction of a chain-based innovation system

2.1. Producing knowledge about the territorial and sector-based determinants of technical changes

Along with cassava and cocoyam, the plantain banana *(Musa Paradisiaca.)* is one of the basic components of the populations' agriculture and diet in the forest zone of sub-Saharan Africa. It is an herbaceous plant with a cycle of 12 to 22 months according to its variety, ecology, and a vegetative multiplication system. While plantains can be produced for four to five years in plantations under industrial production conditions, they can be maintained for decades in well-managed household gardens.

In Cameroon, annual plantain consumption varies between 70 and 90 kg/capita/year (Akyeampong, 1998; Bikoï, 1998), making it one of the most popular consumer products. Formerly produced primarily for private consumption, more than 50% of plantain production is now sold on the market (Bikoï, 1998).

The importance of this product led to studies being conducted to characterize the food chains (e.g., identification of operators and markets, identification and quantification of flows, and identification of the main production areas). In total, four main production zones were identified (Figure 1).

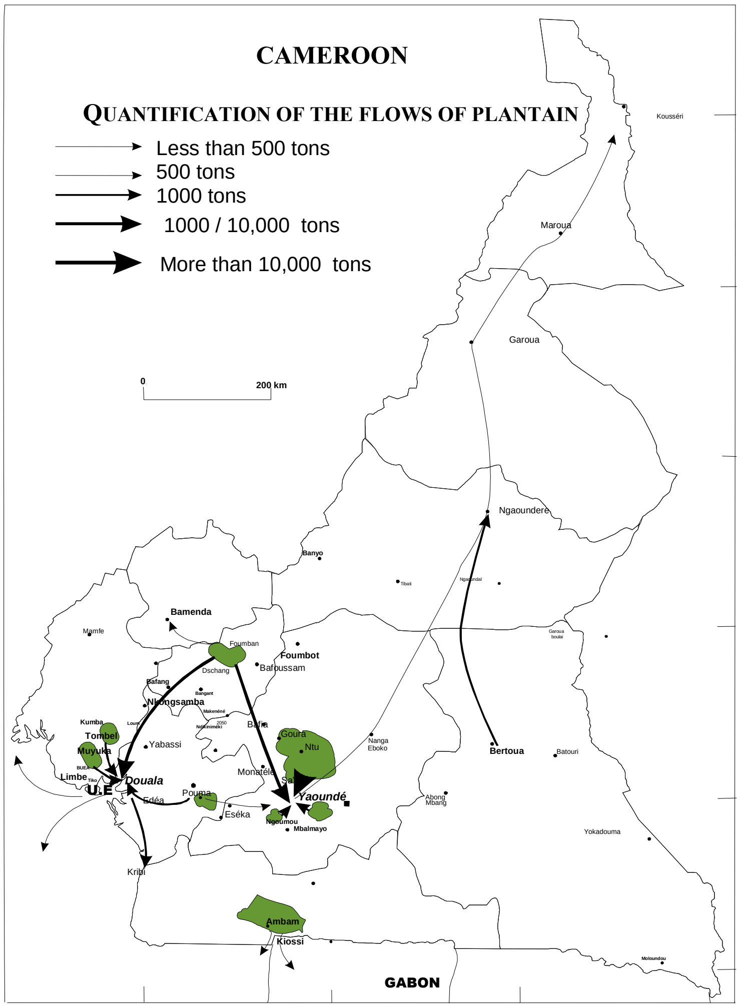

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Figure 1 : Production areas and flow of plantain in main provinces in Cameroon

- ⇨ the first zone (accounting for 55% of total production in Cameroon) in the South-West and Littoral provinces supplies Douala (about 2 million inhabitants).
- ⇨ the second zone (24% of total production) in the Center, South, and East provinces supplies Yaoundé (about 1.5 million inhabitants) and northern Cameroon.
- ⇨ the third zone (18% of total production) in the West and North-West provinces supplies the "Great West," but also occasionally Yaoundé and Douala. These main towns have special supply needs, depending on the time of year.

⇨ the fourth recently developed zone near the southern border supplies Gabon, the Congo, and Equatorial Guinea.

Table 1. Agro-ecological characteristics of plantain production zones in Cameroon

Provinces	Agro-Ecological Zone (AEZ)	Altitude (m)	Rainfall (mm)	Temperature (°C)
South-West	AEZ with a monomodal rainfall pattern	0–1000	2000–10000	20–30
Littoral		0–1300	1600–5500	23–32
Center	AEZ with a bimodal rainfall pattern	400–800	1450–2500	22–28
South		350–650	1500–3000	23–32
East		400–900	1350–2000	23–35
West	AEZ with a monomodal rainfall pattern	900–1500	1500–2200	18–26
North-West		750–1800	1500–3500	15–25

Source: adapted from KWA et al., 2002, “Creation and Managing of a banana farm in Cameroon: case of plantain banana,” Technical data sheet, CARBAP, 2002, 28p.

The production zone locations have helped to identify the priority areas for conducting research or identifying limiting factors at the food chain level. Research has revealed a specialization process in certain areas that is characterized by a local increase in the proportion of producers for whom plantain plays a major role in farm activities. Specialization also results in a spatial concentration of production, which in turn facilitates the creation of wholesale markets, thereby making the transport costs for collecting the produce cheaper in comparison to when production is dispersed (Nkendah et al., 2007).

The better localization of production zones supplying the different markets has revealed three main points for agronomic research on governance.

First, it has highlighted the crucial problems related to plantain production, which prioritizes the effect of root and corm pest attacks (i.e., nematodes and black weevil) on production and productivity. These findings have permitted the characterization of farmers' different plantain production strategies through typologies (Temple et al., 2005). This work also helped to identify specific farmers to partake in the participative experimentations in the field (Temple et al., 2006).

A second aspect was that it has characterized the strongest territorial and sector-based heterogeneity of demand for varietal innovation. From a territorial point of view, this heterogeneity is a function of the localized diversity of both the ecosystems and the integrated control strategies implemented by farmers. From a sector-based point of view, this heterogeneity is explained by the differentiated expectations of those involved in the sector, namely wholesalers and consumers. Thus women who purchase plantains can distinguish between 10 different cultivars, as quality depends on the product's origin and degree of maturity—both of which influence the flavor, cooking time, and consistency (Dury et al., 2002).

Finally, it has underlined the fact that the non-availability of planting material reduces work intensification in production systems. In light of the lack of a sufficient quantity of quality plantain material (suckers), farmers collect suckers from old plots that are lying fallow (80% of suckers), thereby transferring significant quantities of contaminated planting material to healthy plots. Production cycles last only four years and produce low yields, with losses amounting to more than 50% of production after the third cycle, resulting in a shift in the production area (Pierrot et al., 2002).

This knowledge has played a major role in guiding research programs (i) in the field of agronomy through the development of sucker multiplication techniques adoptable by farmers and (ii) in genetic improvement by opening a new line of research (Mauricio et al., 2002; Sperling and Cooper, 2003) that focuses on the participative selection of different plantain varieties.

2.2. Generating knowledge about the socioeconomic determinants of technical intensification

In spite of the intensity of urban demand and increased pressure on land resources, the average yield/ha of plantain in some zones did not increase significantly—from 7 to 10 metric ton/ha within a period of 10 years (1980–1990). Therefore, it appears that production systems were still extensive in these areas.

Low yields from plots used for single-crop farming may result from space occupied by felled trees or the lack of suckers. One explanation is the satisfactory labor productivity in this system, which is based on the natural renewal of soil fertility; however, this involves an increase in the use of new land (e.g., forest reserves), spatial dispersion, and high marketing costs. In practice, these extensive systems have started to adapt in two different ways.

First and foremost, extensive systems adapt through changes in crop associations including plantain, food (e.g., taro, groundnuts, maize, etc.), or perennial crops (e.g., cocoa, coffee, oil palm) and changes in planting density, crop combinations, and farming techniques (e.g., fallow, ridging, staking, etc.). One economic determinant of these changes is the desire to achieve economies *of range* (the complementarity of different crops) according to several objectives: (i) to ensure food needs (harvest phased with respect to a food calendar), (ii) to make optimal spatial use of land (juxtaposition of several strata of crops in an association), or (iii) optimize work time (the labor needed for clearing and weeding serves several crops). In other situations, these synergies between plants optimize the use of mineral fertilizers (Akinnifesi et al., 2010). We were nevertheless unable to find any references enabling us to assess changes in labor productivity within these systems.

This follows the logic of the progressive labor intensification of production systems based on a better knowledge of ecosystems.

Because of the instability of plantain prices and the lack of stable financial facilities, farmers do not invest for fear of losing their investments, thereby limiting the use of industrial inputs (e.g., pesticides and fertilizers).

The implicit cost of financial resources for family agriculture is high because the use of cash income in a situation of financial uncertainty is subject to the alternative of ensuring human health and education or acquiring pesticides to protect the plants.

Second, extensive systems also adapt through the emergence of a banana monoculture in two contexts: in peri-urban agriculture, thanks to the investment of capital in agriculture from other sectors by people who operate several activities (Gockowski and Ndoumbe, 2004), and in the framework of diversification efforts by agro-industrial banana companies. However, the development of monoculture has resulted in increasing pressure from black sigatoka (*Mycosphaerella fijiensis).* This disease can be controlled by aerial spraying, an operation that is too expensive for family farms and causes environmental pollution that is damaging to human health (Wilson and Otsuki, 2004).

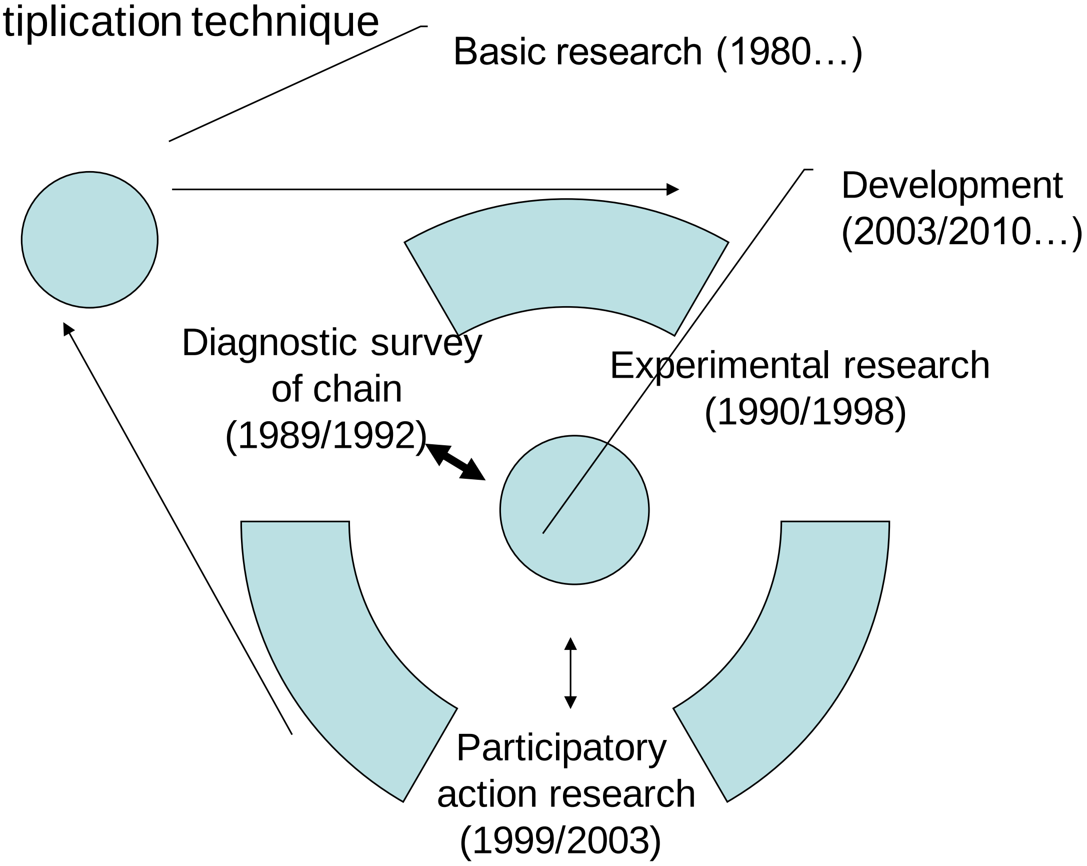
The agricultural intensification model based on the increased use of industrial inputs means that it is difficult for increased production, environmental protection (Nkamleu and Adesima, 2000), and human life to be compatible.

These observed technical changes do not suffice to meet the demand of urban markets. For instance, the department of Lékié, once capable of supplying Yaoundé, can no longer feed its own population. People living in areas subject to serious population pressure are migrating to new locations: towns. Consumer prices, already high, are thus continuing to rise (INS, 2002). These high prices reflect the difficulties in adapting supply systems to urban demand.

The findings discussed above emphasize the need to change the technological focus in intensifying the production function of food crops by modifying the paradigm that polarizes the function of agronomic research (Asenso-okyere et al., 2008).

This modification suggests a shift from an industrial input intensification paradigm, which supports the homogenization of environments, to an ecological one. In this ecological intensification paradigm, industrial inputs are “replaced” by an optimization of ecosystem diversity through improved knowledge. In this context, the conditions for knowledge production through the construction of innovation systems are at the root of the paradigm shift.

Figure 2. Modeling of the innovation procedure on new multiplication technique



The first stage during which two types of research were juxtaposed:

- The search for a diagnostic system (1991) bringing together contributions from economics and agronomy enabled (i) the characterization of socioeconomic conditions that govern plantain production, marketing, and consumption (sector); (ii) the hierarchy of intervention priorities to be established; and finally (iii) the development of a critical review oriented on experimental research, which is sometimes disconnected from empirical reality. Participative investigation methods were used in this phase.

- A study, which was derived from the researchers' empirical observations, based on fundamental research in botany explained the emergence and the development of buds in bananas. This stage, which occurred before 1990, lasted three to five years and led to a better understanding of the failure of the *in-vivo* multiplication techniques practiced up to then, but was not significantly adopted by farmers. It resulted in the development of a technique for multiplying banana planting material from stem bits (Kwa, 2000, 2003). At a complementary level, techniques for integrated control (e.g., trapping weevils, paring suckers, using neem or submersion in hot water, control of black sigatoka by stripping leaves, changing the planting calendar, control of nematodes through crop rotation with plants that don't host nematodes, etc.) were initiated at the research station together with the creation of hybrids resistant to black sigatoka.

The first stage led researchers at the stations (given the environment and number of constraints) to produce technical inventions. The creation of interactions between the two studies was undertaken simultaneously by an observatory that monitored farms and markets. It also disseminated techniques that were implemented within the zone that supplies Douala (South-West and Littoral provinces) by providing specialized training for technicians from the Ministry of Agriculture.

The second stage (1999–2003) saw to the adapting of a set of technical proposals, namely multiplication techniques and integrated control, to the range of different production conditions (and thus constraints) and locations. This adaptation was made possible by the researchers' involvement in the creation of institutional frameworks through contracts with different types of private partnerships (e.g., companies and NGOs) and national and international public partners in the South and West provinces. This system involved negotiations between researchers and development projects, public authorities, and operational partners (e.g., producer groups and NGOs), as well as between researchers from different disciplines (e.g., economists, agronomists, nematologists, phytopathologists, and geneticists) and a network of experimental farmers.

The dynamics of institutional innovation described above defined the interface between the researchers, farmers, and technicians by simultaneously mobilizing:

- the main methodological principles of action research that involve the researcher in creating the conditions that enable technical change to be accomplished.
- participatory research tools (Sanginga et al., 2004), which ensure that proposals resulting from experimental research are validated in real production conditions and involve farmers in the evaluation of the results.

In the South-West and Littoral provinces, the project relied on an observatory that monitored farms and markets. The production of information concerning the markets facilitated an analysis of the structures of marketing costs and value distribution in the different channels. This analysis revealed dysfunctions—such as an increase in the discrepancy between prices in production and consumption zones—that led public authorities to hold national surveys, which resulted in more transparent markets (INS, 2005).

In the Center and South provinces, the scheme was set up around a network of experimental farmers and relay institutions that were responsible for maintaining training plots and demonstration nurseries.

Researchers gave participatory training courses between 2001 and 2003. These brought together more than 80 farmers, 40 of whom were delegates from farmers' groups, representing more than 1000 producers and 90 managers (from the Ministry of Agriculture and NGOs), for 60 days of training. The process was finalized in 2003 through the definition—at the initiative of the researchers—of a national plantain development project, which was adopted and partially implemented by public authorities in the national plantain development project introduced by the Ministry of Agriculture (Tetang et al., 2008).

The third stage (underway since 2003) is a continuation of the second stage in the Littoral, South-West, and, more recently, West provinces. In the Center and South provinces, a monitoring and evaluation survey based on questionnaires was conducted between 2002 and 2004 on a sample of 90 farms and a 2006 participatory survey was organized involving both farmers and managers. In these provinces, International Institute of Tropical Agriculture, which sent its technicians to CARBAP for training in new multiplication techniques, also played a complementary role in disseminating innovation techniques. Monitoring of the scheme enabled (i) the identification of factors that limit the diffusion of techniques, (ii) evaluation in terms of adoption and impact (social, economic, etc.), and (iii) identification of the extent to which the removal of bottlenecks results in new risks and technical needs.

The approach presented here results from a progressive institutional construction initiated some 20 years ago by calling on a theoretical evolutionist referential and a constructivist posture. From a methodological point of view, it is similar to approaches mobilized in other activity-based sectors. These works underline the need to create knowledge through collective action by the various operators involved in innovation (Bocquet et al., 2007; Hamdouch et al., 2008).

3. Results: Impacts on productivity and sustainable development

The evaluation of the impacts of the aforementioned innovations on sustainable development implies the use of socioeconomic and environmental indicators (Elske and Braum, 2002). It raises the methodological problem not only of access to reliable data, but also of establishing causal relationships between externalities linked with the production of knowledge and results that are partially induced by such externalities. These difficulties necessitate the crossing of different sources of information.

The first indicator selected concerns the changes in plantain productivity, which was previously unstable or falling, but has seen upward movement since 1991.

Graph 1

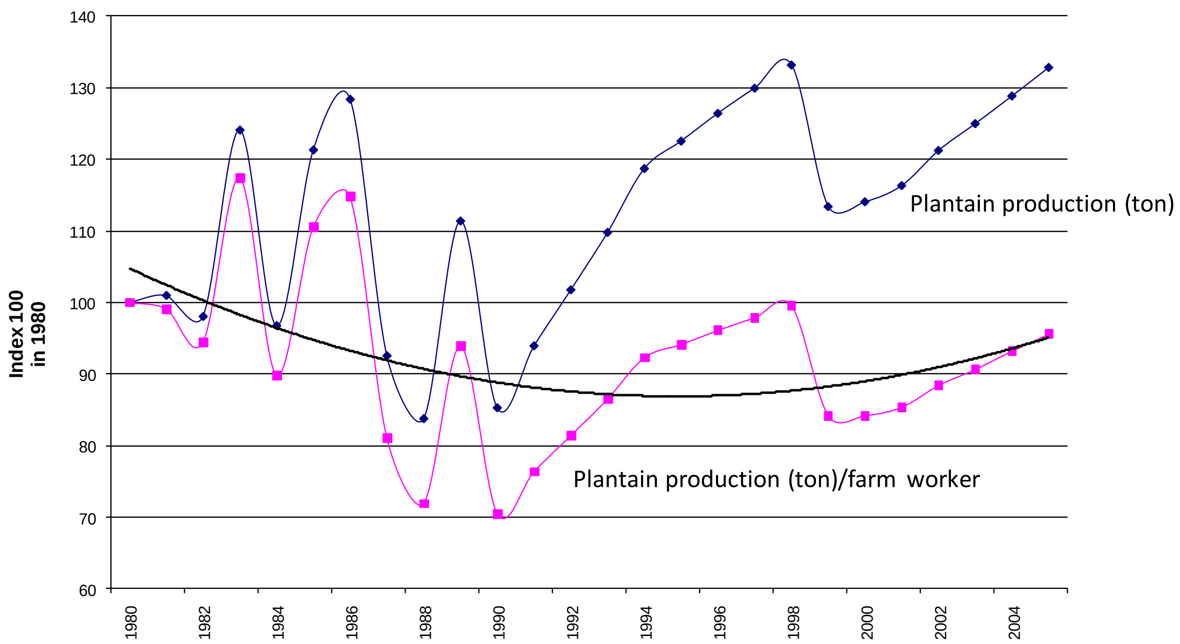


Figure 1. Plantain Production in Camerooon since 1980. Source: FAO Stat

Several different hypotheses may explain this phenomenon. The first supposes that farmers have increased the area of land used for plantains without changing their farming techniques. However, data on the amount of land used for plantain production between 1980 and 2004 (Fao-Stat) does not support this hypothesis. The second questions the validity of the data used; however, we do not have the statistical means to test this hypothesis. The third leads us to suppose that the process of innovation and the support provided by research that began in 1988 have influenced the observed reversal of the trend. We propose to test this hypothesis by analyzing the adoption of technical changes in an area of experimental action (the zone that supplies the city of Yaoundé). Afterward, we will attempt to characterize the relationship between the increase in productivity and its impact on sustainable development, of which the fight against poverty is one component.

3.1. Impacts on the rate of adoption and dissemination of innovations

The evaluation of impacts on the rate of adoption and on the dissemination of technical innovations in the Center and South provinces revealed the considerable success met by new techniques in the multiplication of planting material. A survey conducted on a sample of 90 experimental farms shows that the rate of adoption (57%) is high (i.e., the percentage of farmers who make significant use of the technique), but the rate of diffusion is even higher. Each year one farmer who masters the technique trains more than 14 others. Techniques for integrated control of nematodes and weevils have also been widely adopted, although their rate of diffusion is considerably lower (Temple et al., 2006).

Box 1. Impacts on the experimental area (Center and South provinces)

In 2001, in the framework of the experimental scheme, 150 nurseries were created in collaboration with farmers who used shoots in natural conditions over an experimental area of 70 hectares. In 2004, the national development project for plantain that was created as a result of the scheme (in the area concerned) distributed 800,000 plantlets or the equivalent of planting an average of 750 ha/year.

3.2. Impacts on ecological intensification

The adoption of new multiplication techniques for planting material results in major changes in the management of banana plantations on family farms. It enables farmers to select varieties before planting. It also means that the planting calendar can be adapted to the needs of the variety concerned and to existing soil and climate conditions. The result is an increase in planting density. On the farmers' land monitored by means of survey, planting density more than doubled, increasing from an average of 300 to 700 banana plants per plot.

The need to supply nurseries with healthy suckers has lead 65% of the farmers to establish plots for multiplication close to their homes that are also used to experiment with integrated pest control and organic fertilization. This technique, which enables varietal homogeneity to be controlled, has led to the creation of special plots dedicated to the varieties most in demand among urban consumers. Table 2 illustrates this development and shows that two varieties—"Essong" and "Elat"—are most frequently selected and thus represent 75% of nursery production. Hybrids that are resistant to black sigatoka, provided by researchers for testing, (Crbp39) (included in the category "other") have only been multiplied to a limited extent and consequently have rarely been adopted.

Table 2. Variety multiplied by new technology

Variety	Number	%
Essong	42,335	53.8
Elat	19,845	25.2
Divers	7870	10
Assugbegle	5410	6.9
Otouga	3000	3.8

Other TOTAL	190 78,650	0.24 1.00
Sample of 10 nurseries. 2005 survey by authors		

The dissemination of new techniques creates a risk of varietal homogeneity in the plots. Before the dissemination of this new multiplication technique, there was an average of 12 varieties of plantain per plot (in the Center province). The adoption of this technique by a sample of farms, monitored by means of survey, demonstrated a fall in the average number of varieties per plot to six. A generalized version of this observation would be reflected in a fall in biodiversity in terms of varieties and possibly a risk of increased pressure on plant health (Black Sigatoka)).

On the basis of the sample we surveyed, the new techniques have increased the yield by between 10 and 30% due to reduced losses caused by parasites (healthy planting material), increased weight of the bunches, increased density, and improved farming management thanks to the homogeneity of the plots. Experimental results of the observations we made showed an increase in the quantity of work of between 10 and 20%. The increase in yield, which results from ecological intensification, reflects an increase in the intensity of work and an increase in labor productivity without the use of chemical inputs.

This intensification leads to a disconnection between the current increase in the supply of plantain and the continued and increased farming of new land. It should be recalled that cultivating forest areas currently left fallow in the long term generally implies burning trees with negative consequences for the greenhouse effect. This results in positive externalities concerning the protection of forest reserves, biodiversity, and the greenhouse effect that cannot be discussed in the framework of this paper.

3.3. Impact on the increase in incomes in rural areas

The widely dispersed plantain production mainly takes place on family farms (around 500,000 farms in Cameroon). The increase in labor productivity (without the use of inputs) increases income from diversification on small farms by means of two main mechanisms: (i), a mechanical effect caused by the increase in the volume of products sold linked to the increase in physical productivity and (ii), the change in marketing conditions. The homogenization of varieties and ripeness and the spatial concentration of production (at the individual farm level and for the entire supply zone) reduce the costs of marketing and the transaction. The increased yield of varieties that are homogenous in terms of ripeness enables sales to be grouped, resulting in considerable savings on transport costs as well as allowing producers to draw up sales contracts with buyers (thus a reduction in transaction costs).

The farmers pool their sales, thereby enabling them to increase their ability to negotiate wholesale prices. They have also acquired "a reputation for quality" and are on the road to becoming "professionals."

One quality indicator that is important for wholesalers in the banana sector is the homogeneity of ripeness and of varieties, which reduces losses resulting from logistical issues. The "bayams sellam" prefer to buy products produced using "seedlings resulting from stem fragments" and this has resulted in an increase in the price paid to the producers, which has not yet been evaluated. In rural areas, income from plantain production is generally used to satisfy basic needs and, in certain situations, finance investments in other crops (e.g., cocoa or coffee). It contributes to the fight against poverty in rural areas and reduces the migration of the rural populations toward the towns. While the observed link between the homogenization of varieties, the reduction in transport costs, the increase in farm incomes and the fall in migration towards urban centers was observed in farms that are members of the Interprofessional Plantain Banana Network; however, it has not yet been subject to a precise quantitative impact assessment. These measures involve specific methodologies and survey mechanisms, which are programmed within the work in progress.

Two other contributions to the fight against poverty should be underlined. The first is linked to the professional behavior of a certain number of nurserymen who combine their plantain nursery work with other crops, such as fruit trees, palm trees, or cocoa. At another level, the plantain supply is better suited to the logistics of supplying towns (homogeneous and regular quantities, sufficient supplies), which consequently increases the competitiveness of the plantain in respect to imported food products, such as cereals.

3.4. Contribution to social capital: institutional to organizational innovation

The process currently in progress is improving the ability of farmers to understand ecosystems, the relations between plants and disease, and the management of banana plantations (e.g., scheduling sales). The creation of this shared human capital enables farmers to improve their capacity to analyze the technical transformations that are taking place by combining their experience with knowledge produced through research. The reinforcement of their understanding of plantain accelerates their capacity to specialize: the majority of nurserymen have become large-scale producers of plantain. This alters the ways in which farmers are involved in marketing by introducing contracts. An improved cognitive capacity of the farmers also affects their ability to negotiate with researchers and management structures, such as NGOs.

Specific know-how results in collective recognition of the nurserymen who are then called on by other farmers to organize training sessions for new converts, as one farmer said: “Being a nurseryman has given me an identity and increased my social recognition and prestige.”

This has resulted in the creation of social capital, which, when mobilized by the farmers, has institutionalized horizontal coordination and given rise to socio-technical networks via legally identified organizations:

- The Interprofessional Plantain Banana Network, which brings together about 50 farmers/nurserymen and managers, was set up in 2002 with the following objectives:
    - to collect and circulate information (e.g., technical information, sales opportunities, etc.) between nurserymen and encourage the exchange of ideas.
    - to collaborate on specific and mutually advantageous activities.
    - to create a structure to tap the sources of subsidies (public and private).
- Association of Producers of Plantain Bananas Lékié (established in 2001), which institutionalized a network of experienced planters for the purpose of producing plantlets.

The existence of these “summit” organizations has led to the creation of about ten other producer groups (Common Initiative Group) that focus their activities on multiplying planting material and disseminate either the techniques themselves or the knowledge required for their implementation via two means:

- by organizing participatory training courses for non-members: in exchange for the transfer of know-how, the participants provide the inputs needed for the seedbed (sawdust, etc.) and suckers to multiply that will belong to the seedbed owner.
- by distributing “seedlings resulting from stem fragments” free of charge to encourage farmers to see for themselves the difference in yield with the new planting material, resulting in the “creation of new converts.”

This scheme has produced organizational innovation dynamics that are a key element in the mechanism behind the rapid dissemination of knowledge and technical proposals produced through research since 2002. Control of the homogeneity of the harvest calendar in respect to the stage of ripeness, which is linked to the ability of farmers to multiply suckers, also changes the terms of agreements with sellers. Beyond the horizontal forms of coordination mentioned above, this has resulted in new forms of vertical coordination in marketing contracts that have not previously been described in this context. In this study, we did not examine the relation between technical innovation and improved valorization within the sales chains.

Different externalities can also be mentioned. As far as positive externalities are concerned, the increase in the demand for water to irrigate the nurseries has led nurserymen to invest in digging wells that not only benefit other horticultural activities, but also fulfill family needs. In regard to negative externalities, the fact that the nurseries are located close to homes has resulted in serious termite infestations in certain areas, as the sawdust used in nurseries attracts termites.

Concerning the questions posed in the introduction, it is difficult to say whether the development of "organizational producers" is a condition for activating innovation processes through the implementation of scientific knowledge produced through research or whether it is created by the involvement of researchers alongside the producers.

4. CONCLUSION

The questions arising in connection with the adaptation of the supply of agricultural food products to the urban market demand and the limited natural resources, which determine the performance of extensive production systems in sub-Saharan food-producing agriculture, have led to strategies for ecological intensification that require a change in classical research orientations. The historical review of a 1988 scheme for plantain bananas launched in Cameroon has revealed how different forms of research (e.g., fundamental, diagnostic, action, and participatory) can be hybridized by relying on interactions between different disciplines. Monitoring and evaluation have revealed significant impacts in terms of productivity, the protection of natural resources, and an increase in the income level of family farms in rural areas. It is difficult to measure these impacts exactly, as they result from externalities induced by institutional and organizational innovation systems that accompanied the implementation of technical innovations. The process described here is part of the intensification of work and ecological approaches toward food-producing systems that increase productivity. The innovations that activate a gradual intensification—making use of knowledge about socioeconomic conditions and multiplication processes—also mobilize productivity reserves in the field of food agriculture without using the conventional models of the industrialization of production. Nevertheless, while it appears possible in light of our results to increase the productivity of food agriculture without damaging natural resources by increasing income, we cannot determine whether or not this increase in productivity is sufficient in regards to the objectives of food security. Nor do our results analyze the consequences on the reduction of social inequalities.

The shift in the technological paradigm for agronomic research toward a better ecological intensification of potential production systems is possible. It underpins the governance of new knowledge production involving users of research results prior to defining research orientations. It must also be recalled, in respect to the experiences experimentations presented in this paper, that the impact of research evaluation should include the lag between the time of invention and that of innovation.

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