Agriculture et développement

Brazilian frontier agriculture

Special issue

November 1998
ISSN 1249-9951

Special issue – November 1998

Agriculture et développement

Journal published by the département des cultures annuelles (Annual Crops Department) of the Centre de coopération internationale en recherche agronomique pour le développement
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Printing: CIRAD

Agriculture et développement is published quaterly
ISSN 1249-9951

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BRAZILIAN FRONTIER AGRICULTURE

Farming systems are regularly challenged in tropical developing countries because of the rapidly changing socioeconomic conditions and degradation of natural resources, especially declining soil fertility. The sustainability of agricultural systems in these regions, which should be cost-effective, environment-friendly and yield sufficient quantities of staple crops, is dependent on farmers' technical options.

For any given region, applied agricultural research should thus focus on four main areas:
– rural planning and development, to improve farm management;
– creation of cropping systems tailored to actual or potential economic, agronomic and ecological situations;
– soil restoration (when necessary) and preservation of cropland soil fertility, using readily adoptable cropping practices that farmers can afford in an often restrictive and fluctuating economic environment;
– development of decision support systems that take both climatic and economic risks into consideration.

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To meet these objectives, experimental projects should consistently take the diversity of the natural environment and the socioeconomic situation of the targeted area into account. The agronomic strategy presented here, which is called the agricultural innovation-extension method, involves three interdependent open-ended phases: an operational approach to the function of current cropping systems, and the creation and extension of new farm production systems. These three phases are dealt with simultaneously, with farmers and local extension agents actively involved. This strategy was applied on smallholdings in northern Brazil and with mechanized farming systems in humid frontier savanna areas of Brazil. Positive results were obtained under these conditions, thus providing a considerable incentive for farmers.

The main thrusts of this strategy are set out in the first article, entitled *The agricultural innovation-extension method*. The two following articles — *Managing soil fertility with different cropping systems* and *Direct seeding, an organic soil management technique* — present results obtained in Brazil concerning soil and crop management, while highlighting the advantages of mechanized systems based on crop rotation management using direct seeding techniques.

Acknowledgements

We are grateful to all partners who contributed, and are still contributing to facilitate the extension of soil management methods in Brazil:

- Munefume Matsubara, owner of the Fazenda Progresso, who promoted and funded the research;
- colleagues of CNPAF/EMBRAPA at Goiánia, who utilized these techniques;
- the COOPERLUCAS cooperative at Lucas do Rio Verde, which supported research in the *cerrados*;
- the EMPAER-MT research-development team;
- the COMICEL cooperative at Sinop, a research station in the forest zone, and especially the agronomist Jorge Kamitani and the farmers Valder and Jadir Taffarel, Haroldo Garcia and sons;
- the Prefecture of Sinop, and especially the Prefect Antonio Contini for his regular support and unprecedented approach to regional research and development;
- Antero Goncalves C. Duarte (RHODIA AGRO, trustees of CIRAD projects in the Brazilian private sector), John Landers (APDC, Goiás) and Tsuioshi Yamada (POTAFOS) for their active involvement in disseminating the research data.

C. Fovet-Rabot edited this special publication in close collaboration with the author.

Photos: L. Séguy, S. Bouzinac

I. The agricultural innovation-extension method

The overall aim of the agricultural innovation-extension method, which was developed in various regions of Brazil, is to give farmers access to sustainable cropping systems. By this strategy, information can be obtained on interactions between farmers and the environments they utilize. The first goal is to solve problems put forward by farmers or highlighted in initial assessments. There are then longer-term development prospects involving the best soil and rural land management techniques.

The agricultural innovation-extension method involves a bottom-up strategy. Regional farming systems can be analysed through an initial assessment of the situation to determine all types of constraints (Séguy *et al.*, 1991; Séguy & Bouzinac, 1994). The research then involves stakeholders, i.e. farmers, extension agents, research scientists, and planners, with the aim of developing and disseminating new farming systems. The following three phases are tightly interlaced (Figure I-1):

– a quick assessment of the situation;

– setting up long-term experimental units, where farmers are involved, for the purposes of developing open-ended technical data repositories, regularly updated with new data;

– dissemination of technologies on separate topics (varieties, manures, pesticides, cropping techniques, etc.) or operational sequences for specific crops, cropping systems, and corresponding cropping programmes.

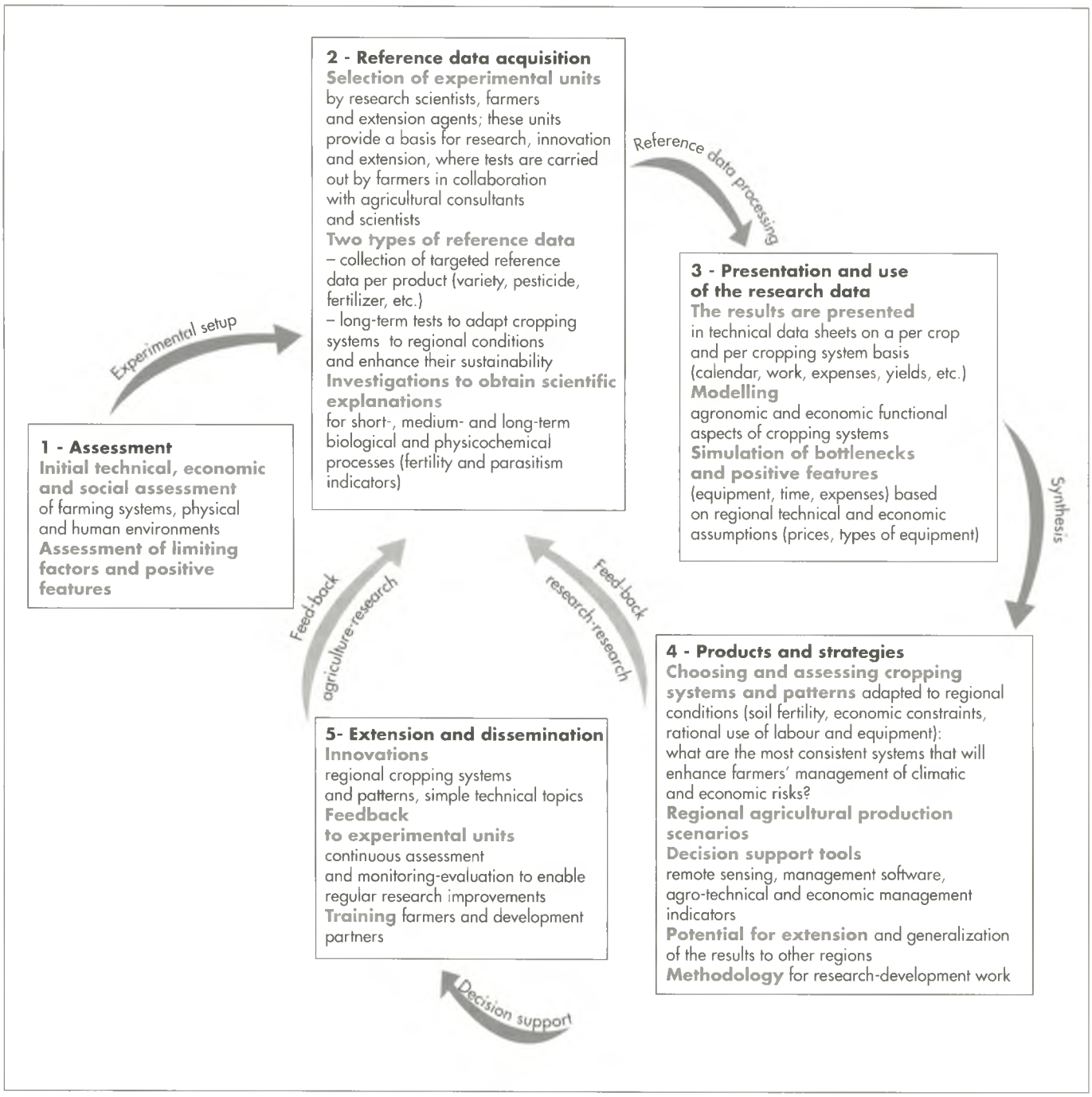

Figure I-1. Development of cropping systems using the agricultural innovation-extension method.

Cropping systems studied at the experimental unit in Fazenda Progresso (Lucas do Rio Verde, Mato Grosso state).

An on-farm research concept

The agricultural innovation-extension method is an agricultural research model based on data derived from on-farm experiments, as reviewed by Triomphe (1989). Since the 1980s, various on-farm research strategies have been developed by multidisciplinary research teams from many countries. The innovation-extension method features three characteristics which are also separately or jointly found in other models. First, the experiments are conducted in the field under controlled conditions, and research objectives are modified as arising problems are solved. Secondly, the research investigates alternatives to traditional cropping practices and systems, with the aim of coming up with short- and long-term improvements. Finally, farmer participation is crucial in terms of the jobs and responsibilities they are assigned, and the risks they accept to face. Farmers' opinions on proposed operational sequences are taken into serious consideration. A quite different cropping system research strategy has been developed by some scientific teams. For instance, according to IRRI (Zandstra, 1979), new cropping systems should be created on the basis of the physical environmental constraints present. In contrast, ORSTOM scientists consider that farmers' strategies have to be taken into serious account when developing cropping systems in Côte d'Ivoire (Filloneau *et al.*, 1983; Filloneau, 1986). This is similar to the thrust of research conducted by INA-PG (Meynard, 1985), which take many constraints into account, e.g. economic, logistic and organizational factors, when assessing crop-yield buildup processes in farming systems. The agricultural innovation-extension method is based on a multiple-step research design to enable continuous overall cropping system development, i.e. the entire farming system as perceived by farmers is taken into consideration rather than focusing on separate technical factors or elements.

The agricultural innovation-extension method has one major advantage, i.e. agricultural aspects are included when setting up cropping systems, in addition to many socioeconomic factors: machine capacity/flexibility, working time, labour, production costs, profit margins, marketing channels, credits, etc. A quick assessment, including socioeconomic studies, is useful for drawing up recommendations and planning how farmers can be involved in interesting ways, as also highlighted in the on-farm research of CIMMYT (1985). The pragmatic analysis involved in the agricultural innovation-extension method eliminates many agriculturally valid cropping systems that would be unsuitable in the regional social, commercial or political environment. The impact of innovations on the regional farming system can be assessed with the aim of modelling successful application conditions. Note, however, that such assessments are not complete as all limiting factors and interactions should theoretically be taken into account (Sanders & Rothe, 1985).

Giving the farming community access to newly developed cropping techniques is a keystone of the agricultural innovation-extension method. This strategy will signal the success of applied research and provide an efficient way for continuously tailoring research methods and targets to actual needs. It is also in line with current agricultural research issues on agrarian research strategies as farmers are essential partners in the research (Sébillotte, 1996).

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COMICEL at Sinop.
CIMMYT: Centro Int
EMAPA: Agropastor
EMATER: Brazilian e
EMBRAPA: Empresa
EMPAER: Research a
IAPAR: Agricultural
INA-PG: Institut nati
IRRI: International R
MAEDA group: top-
ORSTOM: Institut
Prefectures Sinop an
RHODIA AGRO: Br
SULAMERICA AGR
Janeiro.
VARIG AGROPECU
Janeiro.

Implementing the agricultural innovation-extension method

Background and objectives

The agricultural innovation-extension method is a research-implementation strategy based on local farmers' practices noted by research scientists. These practices are reproduced on test plots for permanent control purposes. The most cost-effective and sustainable cropping systems are developed in full collaboration with development agents. They are carried out on a standard user scale (labour time, equipment potential, production costs). Production factors, instead of being tested separately, are analysed in terms of the whole cropping system. Various agricultural scenarios are assessed through the applied research, thus highlighting alternative technical solutions (by dealing with constraints as they arise) and explaining the agricultural and social processes involved. The research results are pooled in a database which serves as an operational forecasting tool: the production potential is tested at several levels using different cropping practices, systems and several cropping plans. This type of project is scheduled over a medium term (3-10 years):

– to compare innovative cropping systems over a long enough period to determine whether they can be successfully implemented under real farming conditions;
– to evaluate and forecast soil changes with various cropping systems;
– to provide access to different sustainable agricultural sequences that have been assessed in terms of farmers' technical constraints and safeguarding rural areas under climatic and economic conditions that could change quickly;
– to develop decision-support tools for users (forecasting models, agricultural assessment, management assistance);
– to help in setting up economic chan-nels for equipment supply or end-product marketing when necessary;
– to provide in-service training for development agents;
– to guide targeted research aimed at enhancing the overall understanding of processes involved in these farming systems.

Initial assessment

Following a 1-year survey, the aim of the initial assessment is to bring together important elements concerning the ecological, agricultural and socioeconomic environment. This assessment is a continuous process and a prerequisite for all experimental research. It is then useful for monitoring changes in the field and farming systems after the adoption of new cropping systems.

itutions, partners and other contributors referred to in the three articles

tsubara, owner of Fazenda Progresso, is the pilot farmer and regional research promotor. mental in setting up and funding the Lucas do Rio Verde research unit on his estate.

›pération internationale en recherche agronomique pour le développement (France)
and bean research centre of EMBRAPA based in Goiania.
ral-northern Mato Grosso: COOPERLUCAS at Lucas do Rio Verde; COOASOL at Sorriso;

nacional de Mejoramiento de Maíz y Trigo (Mexico).
research institute of Maranhão state, located in São Luis.
tension organization.
Brasileira de Pesquisa Agropecuária (Brazil).
d extension corporation of Mato Grosso state, located in Cuiaba.
search institute of Paraná state.
nal agronomique Paris-Grignon (France).
e Research Institute (Philippines).
nking private cotton producer, located at Ituverava, São Paulo state.
rançais de recherche scientifique pour le développement en coopération (France).
Sorriso.
ilian subsidiary of RHONE POULENC, located in São Paulo.
agropastoral subsidiary of the Brazilian insurance company SULAMERICA, located in Rio de

RIA: agropastoral subsidiary of the Brazilian airline company VARIG, located in Rio de

First year of cropping on newly-cleared deforested land. Sinop prefecture, Mato Grosso state.

Newly-cleared land in western Brazil. The slopes can be very steep, hence erosion control is necessary — here, narrow-based terraces on contours. Southern Goiás state.

Targeted tests to modify traditional cropping systems, Fazenda Progresso.

Colloidal dust raised by the wind. Wind erosion due to the use of disk ploughs in dry soils. This dust destroyed hundreds of hectares of cotton plantlets. Southern Goiás state.

Soybean monocrop. Fazenda Progresso.

Regional information

All regional information that can be obtained from the Ministry of Agriculture and research and development services is potentially useful:
– meteorological data;
– soil maps;
– land-use maps;
– agricultural statistics.

When these data are not available, soil surveys should be carried out at 1/5 000 to 1/10 000 scale for projects concerning a specific area and 1/20 000 to 1/100 000 scale for regional projects. Detailed analyses of agricultural land-use patterns should also be undertaken. The main morphopedological and climatic landscape units have been described.

Agricultural information

Landscape units that differ the most markedly could be described in order to highlight the range of regional variability in soil fertility:
– the most degraded facies with the greatest number of agronomic constraints and development techniques;
– tht most fertile facies, or sometimes even the natural environment before modification by man, to serve as a reference.

Cultural profiles are investigated in these two landscape units under traditional cropping systems. Other factors and their interactions are also studied: state of the soil surface and erosion; weed flora; crop pests and diseases; dry matter production; and the main mineral shortages.

Technical and socioeconomic information

During the cropping season, the research scientists become familiar with farmers' cropping systems through surveys, without any formal quantification or detailed on-farm studies. The farmwork calendar and working conditions are crucial in planning farming activities.

A socioeconomic farm classification is essential, based on the following criteria:
– on-farm consumption and market access (marketing end products, credit, equipment);
– ability to adapt to structural and equipment changes;
– proportion of non-farming activities and interactions with farming activities (farmwork calendar, income);
– description of farming systems (sowing dates, main crops, technical skills).

Leading farmers, i.e. those who influence others in terms of their cropping practices, are also identified.

As a supplement to these surveys, starting the first year of the assessment, it would be advisable to investigate alternative topics of general interest to farmers, e.g. new varieties, herbicides, etc. This additional research is useful at first for gaining the confidence of farmers who will be future partners.

Synthesis of all of these data is useful for subsequently choosing test fields, and facilitating negotiations between farmers and regional research and extension agencies on setting up experimental units. It also provides a basis for presenting the technical setup as well as the material and financial resource needs to sponsors and regional/national farm policymakers. All proposals should be in line with regional development priorities.

The innovation process

Sites to conduct the experiments are first selected. These sites will serve as reference for farmers and researchers for the purposes of creating and disseminating new operational sequences based on sustainable agricultural objectives: short-range objectives to solve simple technical problems (varieties, manure, pesticides, etc.), and long-term objectives to conserve and improve soil fertility inexpensively.

Cropping system modelling

The initial assessment provides a basis for modelling the cropping systems and their components. This involves a matrix in which soil and crop management strategies, available special products and natural conditions are crosslinked to obtain a set of highly varied situations (Figure I-2). The model takes cropping systems, landscape units, and sustainable agricultural objectives into consideration. Cropping systems are assessed on large experimental plots, under conditions that match those found on farms in the region. The technique testing operations are carried out by farmers using their own tools, along with any other special equipment required. The matrix also includes agricultural reference systems, even those that are of no economic interest: potential open-ended systems — complete fertilizer, total crop protection, etc. — and even combinations of harmful factors encountered under the investigated ecological conditions, which could turn out to be unsuitable techniques.

The selected landscape units are representative of the physical environment, including the two toposequences that differ most in terms of soil fertility. The aim is to achieve sustainable land management under extreme conditions, i.e. even under climatic conditions that have a harsh impact on the soil. The following factors are integrated in the model:

– the environment, through the distribution of experimental plots, representative of landscape units, within the toposequence;

– the climate, by setting up multi-annual tests;

– the labour flexibility and potential when implementing the experimental techniques, i.e. the ease of operation.

The cropping system matrix should be flexible: the operational sequences studied and standard controls can vary. Simple technical improvements (e.g. new varieties, fungicides and herbicides) should be gradually introduced without altering the quality of the analysis of technical and economic variables over time.

Statistical and targeted tests, aimed at modifying cropping systems to meet farmers' needs, focus on plant breeding, mineral and organic fertilization, crop protection (pesticides, biological control) and all topics that could help in understanding the limiting factors. Targeted tests are useful for investigating cash-crop systems. The results of these tests are applied in large fields — where problems specific to each cropping system are clearly obvious — for assessment with functioning cropping systems. This methodological package correlates operational cropping systems with the results of targeted tests on small statistical test plots. It is thus designed to achieve improvements on a per-field or per-landscape unit scale, as rotations and cropping plans cover the entire toposequence (top, middle, and the foot of slopes).

1. Cropping system components

tillage technique MTS × rotation R and/or annual crop sequence S × early sowing date DSP / late sowing date DST × plant density DE × variety VA / manure FU / pesticide PE / weeding SA

Soil and crop management techniques — Simple target products

2. Progressive development of cropping systems

(t = traditional; a = improved)

Modelling traditional systems (reference system)

$$MTSt \times Rt \times \begin{Bmatrix} DSP \\ DST \end{Bmatrix} \times DE \times \begin{Bmatrix} VAt \\ FUt \\ PEt \\ SAt \end{Bmatrix}$$

Introduction of improved tillage techniques ($MTSa_1$, $MTSa_2$...)

$$\begin{Bmatrix} MTSt \\ MTSa_1 \\ MTSa_2 \\ \dots \end{Bmatrix} \times Rt \times \begin{Bmatrix} DSP \\ DST \end{Bmatrix} \times DE \times \begin{Bmatrix} VAt \\ FUt \\ PEt \\ SAt \end{Bmatrix}$$

Each tillage technique is crosschecked with new rotations involving annual crop sequences (Ra_1, Ra_1...; S_1, S_2)

$$\begin{Bmatrix} MTSt \\ MTSa_1 \\ MTSa_2 \\ \dots \end{Bmatrix} \times \begin{Bmatrix} Rt \\ Ra_1 \\ Ra_2 \\ \dots \end{Bmatrix} \times \begin{Bmatrix} S_1 \\ S_2 \\ \dots \end{Bmatrix} \times \begin{Bmatrix} DSP \\ DST \end{Bmatrix} \times DE \times \begin{Bmatrix} VAt \\ FUt \\ PEt \\ SAt \end{Bmatrix}$$

Each rotation and crop sequence is crosschecked with:
- two sowing dates (early, late);
- two plant densities (traditional, improved);
- several varieties (traditional, improved).

Manures, pesticides, and weeding techniques are also tested.

$$MTS \times \begin{cases} Ra_1 \times \begin{cases} S_1 \\ S_2 \end{cases} \times \begin{cases} DSP \\ DST \end{cases} \times \begin{cases} DEt \\ DEa \\ \dots \end{cases} \times \begin{cases} VAt \\ VAa \\ \dots \end{cases} \times \begin{cases} FU \\ PE \\ \dots \end{cases} \\ Ra_2 \times \dots \\ Rt \times \dots \end{cases}$$

Figure I-2. Setting up an experimental matrix. The order of limiting factors in traditional farming systems, as determined from the assessment and classified in descending order of importance, is as follows: tillage techniques, rotations, sowing dates, plant populations and simple target products (varieties, fertilizers, etc.). The types of components in the matrix and the extent of their intensification depends on the ranking of problems to be solved and the potential for progress (technologies available or not) (Séguy *et al.*, 1994).

The expression "annual crop sequence" means that several different crops are grown successively in the year: annual crop sequences are thus part of the interannual crop-rotation process.

Operational framework: experimental units

The operational field aspect of the method is represented by the experimental units. Actual on-farm conditions are taken into account on these test farms. They are set up in farmers' fields, and sometimes on land belonging to private companies or cooperatives, covering the morphopedological sequence representative of the whole rural area — which can be affected by erosion, depending on the slope, field length, type of soil, etc. Traditional cropping techniques and new erosion control techniques introduced, which are well adapted to the types of agriculture in the area and its potential, are taken into account for management of these experimental units.

When there is a clear fertility gradient in a landscape unit, some cropping systems are used as controls and should be studied at the top, middle and bottom of the toposequence. A traditional cropping system is selected, along with another system that *a priori* will provide the most improvements as early as the first year of application. In the second year, this improved system could be replaced by the one that shows the most progress. Nevertheless, the initial control cropping system is always maintained.

Representative areas are defined on the basis of the types of tools used, farmers' technical skills, and the pattern of fields within the agricultural area. This should make it possible to obtain reliable "measurements" of technical-economic parameters. For instance, field length is a critical factor for animal-draught and mechanized cultivation. For industrial-scale cash cropping in central-western Brazil, which is heavily mechanized, the minimum length of fields to conduct tillage operations is 300 m, with a minimum width of 15 m, i.e. the smallest basic field is therefore 4 500 m^2. In completely manual cultivation conditions, representative plots can be set up on the basis of the area covered by one person in a day's labour, for the most difficult cultivation chores, e.g. initial weeding subsequent to high weed infestation, and manual harvesting. As a guide, in Maranhão state in northern Brazil, one person can weed or harvest 250 m^2/day on average.

Classifying the matrix components, which involves plot layout and planning in the field, combines different soil and crop management strategies (tillage and crop rotation). For instance, concerning mechanized farming in Brazil's *cerrados*, in Mato Grosso state, the initial assessment revealed that the soil and crop management strategies implemented directly enhanced dry matter production and soil fertility (Séguy *et al.*, 1996). The experimental unit matrix was thus setup as follows:

– crop management strategies, i.e. interannual rotations and annual crop sequences, are assigned to the main plot;
– tillage strategies are assigned to the subplot;
– factors such as varieties, crop pest control treatments, etc., represent the final subdivision.

In this example, the same quantity of mineral fertilizer was applied to the same crop under the different cropping systems, and the pesticide dosages and active ingredients were also identical.

However, some crop sequences require unlimited pesticide treatments to ensure that the impact of weeds or pests will not modify the analysis of effects of soil and crop management strategies — these treatments are taken into account when analysing the technical-economic results.

Technical reference data acquisition and processing

In the experimental units, for each crop and crop sequence with rotations, data on the dynamics of the arable profile are recorded continuously or during special periods. These data concern water-soil-crop interactions and the effects of these interactions on dry matter production and soil fertility changes.

The state of the soil surface under cropping conditions, e.g. roughness, soil capping, and porosity within the top 20 cm, are observed between the first effective precipitation and 30-60 days later. This period is very important in the tropics — when the cropfield is not completely covered, the state of the superficial soil layer determines plant rooting, water infiltration and weed emergence.

In the next layers, parameters characterizing root system growth are observed or measured: porosity, mechanical resistance to penetration, water infiltration rate, root density, root front, variations in chemical and biological properties, and cation dynamics.

Crop development parameters are assessed: crop/weed competition, yield components, dry matter production and mineral removal.

In these units, the framework for targeted tests on cropping systems is clearly defined, with factors classified on a per-system basis. The efficiency and explanation levels should be sufficiently high for the systems to be reproducible and progress steadily. In collaboration with the laboratories, research can thus focus on obtaining detailed explanations that will clarify how the cropping systems function. For instance:
– studies on rhizosphere function, macrofauna dynamics, microfauna, microbial populations and their relations with dry matter production;
– development of analytical tools, for determining biological activity indices, mineral deficiency thresholds, water and nutrient supply dynamics, etc.;
– studies on the biology of weeds and their allelopathic effects.

The technical and economic data are assessed every crop year: cropping calendars, equipment capacity, working time and feasibility for each operation, detailed production costs, cost-effectiveness of each crop sequence and the cropping systems overall.

The essential plant production parameters are determined and checked, and analytical tools able to characterize them are designed on the basis of all reference data collected over a significant time period (3-5 years minimum). This reference data is presented in technical data sheets and classified per crop, crop sequence, and cropping system.

To extrapolate the general trends from the research results, simplified experimental units are set up under different physical environment conditions within the region by scientists and extension agents trained at the main units. These secondary units serve as controls for cropping systems selected at the main unit. In addition, farms located close to the units are monitored to verify the economic results obtained — investments, types of equipment and capacity, technical bottlenecks, margins, etc.

After 5 years of operation for the main units and 2-3 years for the multi-location secondary units, the scientists and farmers develop models of farming systems that could achieve optimal agroeconomic and equipment performance. These models simulate farming operations on the basis of technical and economic assumptions that are formulated and checked on the basis of results from on-farm tests: production costs (inputs), prices paid for products, capital, equipment and manpower. They are also useful for developing decision-making software tools: designing optimal cropping systems relative to market demand.

Preparation of a seedbed with a tine cultivator.

Experimental unit management

Farmers cultivate plots in the experimental units, closely supervised by research scientists. Farmers' know-how is thus fully tapped:
– their complete understanding and control of traditional farming systems, which serve as a constant reference;

Direct seeding on dry millet straw. Sinop prefecture, Mato Grosso state.

Rainfed rice, Fazenda Progresso.

Dry millet before direct seeding. COOPERLUCAS, Mato Grosso state.

A day in the field in Fazenda Progresso.

– their ability to evaluate new crop sequences and systems proposed by scientists but which they implement;
– their farming tools (type, feasibility).

As the assessment progresses, the least interesting systems are gradually phased out at each experimental unit, while promoting interesting systems with the highest user demand.

Extension staff working at the experimental units utilize them as a valuable training and assessment tool. Some extension agents are closely involved with the research scientists and farmers in managing, implementing and monitoring the experimental units. They plan visits for teams of consultants and farmers and training sessions on regional development issues. They also oversee public visits of the units, which is an efficient way of showcasing the innovations: simple equipment and technology, cropping systems, cropping patterns, land management techniques.

Economically, a well managed unit can cover 60-80% of its operating costs through the sale of produce or seed. For instance, in Brazil, the Mato Grosso unit with mechanized cropping systems (Fazenda Progresso, 1986-1992) had about 150 ha of cash crops, with 60 ha on the mechanized AGRIPEC unit in the pre-Amazon region (1989-1992), and 60 ha on the manually cultivated BACABAL unit in Maranhão state. Although less efficient cropping systems are used in 10-20% of the overall area concerned, systems that are more productive and cost-effective than traditional systems are implemented in more than 80% of the area. Experimental units can also be profitable production units.

Note finally that the research services also serve as credit agents, suppliers, and coordinators of commercial subsectors that provide outlets for new products. In some innovation-extension projects (e.g. Maranhão project, northern Brazil), stores have been opened to distribute various farming supplies, such as plant varieties, farming equipment, pesticides and fertilizers. Surveys of these stores indicated farmers' preferences in terms of adopting the proposed technologies and how they were subsequently applied on their farms.

Dissemination of innovations

The techniques are disseminated in many different ways:
– mass audiovisual communication (radio, television, newspapers, specialized press), annual reports and publications from the research institutions, videos, slide-shows and technical data sheets;
– conferences and meetings targeting different audiences (staff of research agencies, universities cooperatives and regional farmers' associations);
– visits of the experimental units scheduled during periods ideal for interesting demonstrations, and organized according to the target audience: research scientists; extension agents, farmers, students and political agricultural development authorities;
– open-house policy of the experimental units, with permanent public access; the units are set up to facilitate this activity (paths, plot signs, presentation of research aims, annual and multiannual results, etc.). These public visits are usually supervised by farmers and technicians working at the units, which is also an effective extension strategy;
– training sessions and courses on activities at the experimental units (supervisors, students, agronomists, etc.).

Farmers often opt for the simplest technological innovation, separately: variety, herbicide, insecticide, tillage technique. The innovations are generally

disseminated in this way to the farming community. Secondly, technological packages (crop-specific operational sequences) and farming/management systems are often disseminated via commercial farms run by recognized leaders of rural companies or cooperatives. The efficiency of this extension process depends on the simultaneous coordination of credit, input supply, and channels for processing and marketing local products — regional agricultural policy.

Surveys are conducted locally and in nearby regions to determine how users understand and adopt the new technologies. The rate of adoption of these innovations can thus be quantified on the basis of small local samples obtained in the vicinity of the experimental units, and on a larger scale for extensive farming regions. The results highlight technical-economic performances relative to those of traditional farming systems. The results obtained on farms and in the experimental units are thus compared. In addition, the surveys take users' opinions into account — extension agents, farmers, regional agricultural policy authorities, farm machinery and input suppliers — as they have an impact on the success of the agricultural innovation-extension process concerning new technologies. The overall results of these analyses are used to develop agricultural management tools: management consultancy, land-use dynamics, and technological progress. Remote sensing is also an important assessment tool.

Agriculture and livestock production, *cerrados* landscape in western Brazil. Mato Grosso state.

Typical landscape with newly-cleared land in western Brazil, Mato Grosso state. Note the preserved gallery forest.

Implementation of the agricultural innovation-extension method in Brazil

From 1978 to 1982, CIRAD conducted research in Brazil, within the framework of a Franco-Brazilian cooperation programme, at the request of EMAPA in Maranhão state, in collaboration with EMATER. The goal was to help settle small transient farmers in the babaçu palm-growing region (Cocais region) and develop irrigated rice cultivation.

Two partnerships were established between 1983 and 1989:
– with CNPAF (Goiás), for the development of rainfed rice cropping systems adapted to the soil and climatic constraints found in central-western regions of Brazil, and for breeding rice cultivars that yield more than traditional varieties;
– with the private sector, i.e. with RHODIA AGRO a Brazilian subsidiary of RHONE POULENC, for breeding commercial maize hybrids, with the aim of supplying markets in the highly developed southern Brazilian states.
As of 1989, three large-scale projects were launched under the aegis of RHODIA AGRO:
– modern mechanized irrigated and rainfed rice cultivation (Piauí state), in partnership with SULAMERICA AGRO, from 1989 to 1993;
– mechanized rainfed cropping systems, involving maize, rainfed rice and soybean, to supply poultry farms set up on newly-cleared land east of the Amazon basin (southwestern Maranhão), in partnership with VARIG AGROPECUARIA, from 1989 to 1992;
– mechanized cropping systems based on soybean, maize and rainfed rice, with some integrating intensive livestock production on newly-cleared land south of the Amazon basin (Mato Grosso state). The main ecological entities are humid savannas *(cerrados)* and tropical forests. The partners are cooperatives of central-northern Mato Grosso, pilot farmers and prefectures. This large-scale project began in 1985 with the support of CNPAF and the French Ministry of Foreign Affairs.

More recently, CIRAD set up a project in 1994, under the aegis of RHODIA AGRO, in partnership with the MAEDA group, i.e. the top private Brazilian cotton producer. The aim is to develop efficient, environment-friendly cropping systems, based on direct-seeded cotton crops (southern Goiás state and northern São Paulo state).

II. Managing soil fertility with cropping systems

Since the late 1970s, agricultural activities have had a destructive impact on the natural environment in humid frontier savanna areas of western Brazil. The new highly mechanized farming techniques implemented have induced rapid soil degradation, thus threatening agricultural sustainability. In Mato Grosso state, new cropping systems have been developed based on the results of research in experimental units using the agricultural innovation-extension method.

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Close to half of all the arable land in Latin America is located in humid savanna zones — *cerrados* and *planos* — on acid soils. This area, i.e. about 243 Mha mainly in Brazil, Colombia and Venezuela, is larger than all of the arable land in sub-Saharan Africa. This environment represents an enormous resource that has not yet been fully tapped. Climatic conditions on humid savannas are conductive to the cultivation of tree crops, annual crops, staple crops and cash crops, in addition to livestock production. One of the main research and development goals is to set up sustainable farming systems in these savanna areas, as a means of preserving the forests, wildlife and plant diversity. Another essential aim is to develop management strategies for improving and sustaining soil fertility.

-1. Brazil: current regions where :ultural innovation-extension method implemented.

Recent development in frontier regions

In Brazil, large-scale enterprises diversifying their investments, agricultural cooperatives and settlement agencies from the southern states (Paraná, Rio Grande do Sul, São Paulo) began developing savanna areas in the wet tropical zone (central-western and western states; Figure II-1) in the late 1970s. This private settlement, with farms ranging from 200 ha to more than 2 000 ha, was initially a land-speculation phenomenon. The Brazilian government actually facilitated this land development so as to tap the profits of the settlement agencies (Lena, 1988), by opening and maintaining roads, granting legal title to property, and introducing a federal credit system (Bank of Brazil, etc.). This mechanized frontier agriculture situation quickly led to industrial-scale soybean monocropping aimed at producing export surpluses, which soon had a detrimental effect on the soil.

Frontier areas in western Brazil are very remotely located in terms of access to export ports and large consumer and processing centres.The fact that there are no agricultural incentive policies has severely penalized frontier farmers, as they are heavily dependent on the road system, which is often unreliable and poorly maintained. The high transport expenses considerably increase freight costs and subsequently production costs, thus reducing farmers' earnings. This income can be 20-50% lower than farmers earn in Paraná and São Paulo states. In this sensitive economic context, soil fertility management must be closely linked with economic risk management objectives. To come up with general solutions to problems arising out of the initial situation, i.e. involving soybean monocultures tilled mainly with offset disc cultivators, farming systems will have to be developed that are diversified, cost-effective and sustainable, with minimal detrimental impact on the soil resource.

Research and development teams of CIRAD and partners began a project in frontier areas in the central-northern region of Mato Grosso state (Brazil), where almost a million hectares of land have been cultivated since the late 1970s. The agricultural innovation-extension strategy was implemented as of 1983 in the savanna zone of this region, and then in the forest zone in preparation for extension into new frontier areas (Picard *et al.*, 1996).

Initial farming system

Migrants coming to frontier areas have introduced traditional cropping systems from southern Brazil:
– land clearing with steel cables;
– windrowing and burning cleared brush;
– rainfed rice is sown during the first 2-3 years of cropping, as acid soils are

not detrimental to this crop, with a ground limestone-magnesium supplement (2.5 t/ha) and lower mineral fertilizer input (40 N-60 P_2O_5-40 K_2O/ha);

– from year 3 or 4, there is a switch to soybean monocultures, with offset disc tillage and lime-magnesium fertilization (1.5-2.5 t/ha, with a further supplement if needed to maintain the exchangeable base saturation index of the soil above 40%);

– or, after the first 2-3 years of rainfed rice cropping, *Brachiaria decumbens* is sown in addition to rice to provide grazings for extensive livestock production (one head of cattle/ha maximum).

In these types of cropping systems, seed soybean yields are about 1 700 kg/ha after 13 years of continuous monocropping.

In the early 1980s, solutions proposed by Brazilian research scientists focused solely on the soil chemistry, i.e. adjusting the acidity while applying several levels of mineral manure under the plant rows, calculated on the basis of critical growth thresholds for soybean (Van Raij, 1991; Souza *et al.*, 1987).

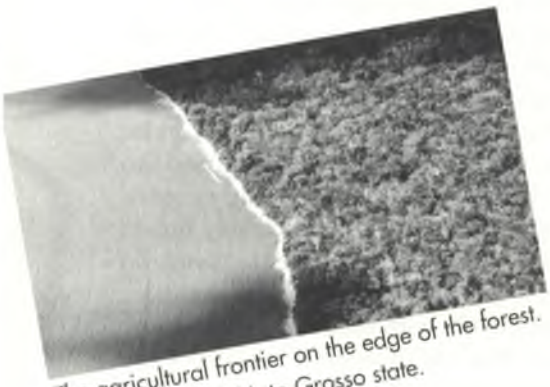
Traditional sowing of rainfed rice after offset tillage. Piauí state.

Regional agronomic assessments

Regional agronomic assessments were carried out in 1985 by CIRAD, in collaboration with CNPAF-EMBRAPA teams. They focused on the cultural profile of the soil and interactions with cropping techniques and plant growth (rainfed rice, soybean).

Precipitation

The physical environment was found to be a considerable constraint in terms of limiting grain yields. Rainfall levels range from 2 000 to 3 000 mm/year over a 7-month period (October-April), often at intensities of more than 100 mm/h, with a high erosion potential. Underground drainage is high, i.e. above 750 mm/year (Steinmetz *et al.*, 1988), which can induce substantial mineral leaching.



The agricultural frontier on the edge of the forest. Sinop prefecture, Mato Grosso state.

Landscape

The landscape units include plateaux and hills with very long gradual slopes (more than 1 500 m). The slope gradient, which is relatively low in the highest and middle parts in between-stream areas, is 2-4% and quickly increases at the foot of slopes (5-8%). These features are conducive to high erosion.

Soils

Texture

The area is characterized by red-yellow, deep ferralitic soils over an acid arenilitic bed. These soils generally have a clay to clayey-sandy texture, but they are sandy at the foot of slopes. There are three representative types of cultural profiles in humid savanna frontier areas:

– uncultivated soils of savanna areas;

– soils under well established extensive grazings with *B. decumbens*;

– soils under monocropped soybean fields that have been cultivated since the late 1970s.

Physicochemical characteristics and structure

Soils under natural savannas and extensive grazinglands are chemically poor for growing crops: deficient in calcium, magnesium, phosphorus and

Erosion rill formed during one rainy season on a soybean monoculture field using offset tillage.
Lucas do Rio Verde, Mato Grosso state.

Rainfed rice, 4 500 kg/ha of paddy rice.
Fazenda Progresso.

Forest clearing; cleared brush piled in windrows and initial burning.
Sinop prefecture, Mato Grosso state.

potassium, with a high aluminium saturation index (Table II-1). In contrast, these soils are structurally very suitable, with high organic matter levels in the 0-30 cm layer, especially under *B. decumbens* cover. Soils under crops have an adequate chemical composition, but their physical properties are very limiting for rooting. Ferrallitic soils in frontier agriculture areas are always superficially compacted and destructured after 7-8 years of cropping. This occurs as a result of exclusive use of heavy and light offset disc cultivators under excessively moist conditions — when tillage operations are carried out during the 2-month period after the first rains — and in excessively dry soils for the purposes of ploughing-under lime-magnesium fertilizers in the dry season. Under high rainfall conditions, these compacted soils prompt the formation of a reduced asphyxiating layer, i.e. crops can only root within the top 10-20 cm soil layer. As this horizon has a low water-mineral retention potential, crops are vulnerable to harsh climatic events, e.g. drought and periodic asphyxia. Surface compacting also causes rapid catastrophic erosion, even when erosion-control structures such as broad-base terraces have been built (Resck, 1981).

Weed infestation, pest and disease problems

Discing operations clearly facilitate weed germination and propagation, thus immediately leading to high weed competition with crops. Overall, the "monocrop x offset" system accelerates the spread of weeds, nematodes (*Meloidogyne* spp.) and the spread of fungi such as *Rhizoctonia solani*, despite the fact that pesticide active ingredients are currently more targeted and efficient.

Economic situation

Analysis of regional technical-economic farming conditions highlighted a correlation between soybean monoculture fluctuations and the economic situation, i.e. variations in world soybean prices, in addition to high transportation costs (as the road system is almost always in poor condition) and the fact that farmers are often paid low prices locally for their produce.

Conclusion

The initial regional assessment (completed late 1985) revealed that agricultural production techniques for frontier areas are very risky. Only a minor part of the huge soil-climate potential is utilized, and farmers run a considerable economic risk, especially since no real incentive farming policies have been put forward to date. In addition, farmers in this high-risk economic situation are striving to obtain short-term returns — they thus demand research innovations that could bring immediate profits.

Table II-1. Characteristics of red-yellow ferralitic soils in frontier agriculture areas according to their uses.

Location	Horizon (cm)	pH water	OM (%)	P* (ppm)	K (ppm)	Ca + Mg	Al	CEC
						..... (meq/100 ml)		
Savanna	0-10	5.0	3.0	0.5	27	0.4	2.1	7.2
	10-20	5.3	2.3	0.4	25	0.6	1.2	6.4
	20-30	5.3	2.3	0.3	20	0.6	1.0	7.1
Extensive grazings	0-10	4.8	3.6	2.0	25	0.9	0.9	8.7
	10-20	4.7	3.4	1.0	22	1.0	1.0	9.4
	20-30	4.7	3.3	1.0	22	1.0	1.0	9.6
Under crops, after 11 years of continuous cultivation	0-10	5.9	2.2	6.2	63	3.9	0.1	7.4
	10-20	4.9	1.8	2.1	27	1.1	0.6	6.2
	20-30	4.8	1.8	1.8	24	0.6	0.9	6.1

P*: Mehlich method.

Research and development: the Fazenda Progresso project

In 1986, a research station was set up at Fazenda Progresso, the first farm established in this zone (1976), at the request of the owner Mr. Munefume Matsubara, with three objectives: develop more cost-effective and sustainable cropping systems in the region, disseminate these systems, and train regional agronomists on new techniques selected by extension agents. The innovation-extension research phase lasted 6 years (1986-1992).

Experimental design: setting up the matrix

Some cropping systems were modelled on the basis of constraints detected in the initial analysis (Figure II-2). A cropping system matrix was set up in the experimental unit at Fazenda Progresso. In 1986, the size of this unit was 45 ha, gradually increasing to 180 ha in 1992 to be able to develop increasingly efficient cropping systems on a continuous basis. Data collected over several years could be extrapolated to obtain solutions concerning plant growth and development, yield build-up, etc., relative to soil conditions.

Simplified experimental units were progressively set up on other farms by agronomists trained at the main unit. This was useful for checking the technical-economic results obtained for the most interesting cropping systems.

Storage silos, Fazenda Progresso.

The matrix set up at the main experimental unit was designed to meet very short-term and longer-term objectives. The very short-term objectives include decompacting soil, reducing pest-disease and weed pressure, introducing rotation crops that are preferably as cost-effective as soybean. Longer-term goals involve low-cost soil-fertility management to enhance agricultural sustainability. In this matrix, the main components of the cropping system are tillage strategies, combined with interannual rotations with diversified annual crop sequences. The matrix includes:

– the main traditional cropping system used as a permanent agro-economic reference;
– rotational cropping systems involving one annual crop;
– cropping systems with one annual crop alternated with a two-crop sequence the following year;
– rotational cropping systems with an annual two-crop sequence.

This experimental matrix accomodates different uses of biomass, the soil-climate potential and equipment capacity.

Data collection

Over the years, the experimental unit has been useful for assessing the cumulated effects of cropping systems on the physicochemical and biological characteristics of soils, along with evaluating the capacity and ease-of-handling of farming equipment and highlighting the most interesting cropping systems.

On a yearly basis, agricultural data are collected on the cultural profile, dry matter production and soil fertility for all operational sequences and crops. Variations in chemical and biological soil characteristics are investigated, along with conditions that promote root growth and correlations with the soil structure (porosity, mechanical resistance to penetration, water infiltration rate). In addition, weed-crop competition, yield components, mineral export and between-year variations are measured. Technical and economic data are also analysed: cropping calendars, equipment capacity, operational feasibility, production costs, gross and net margins.

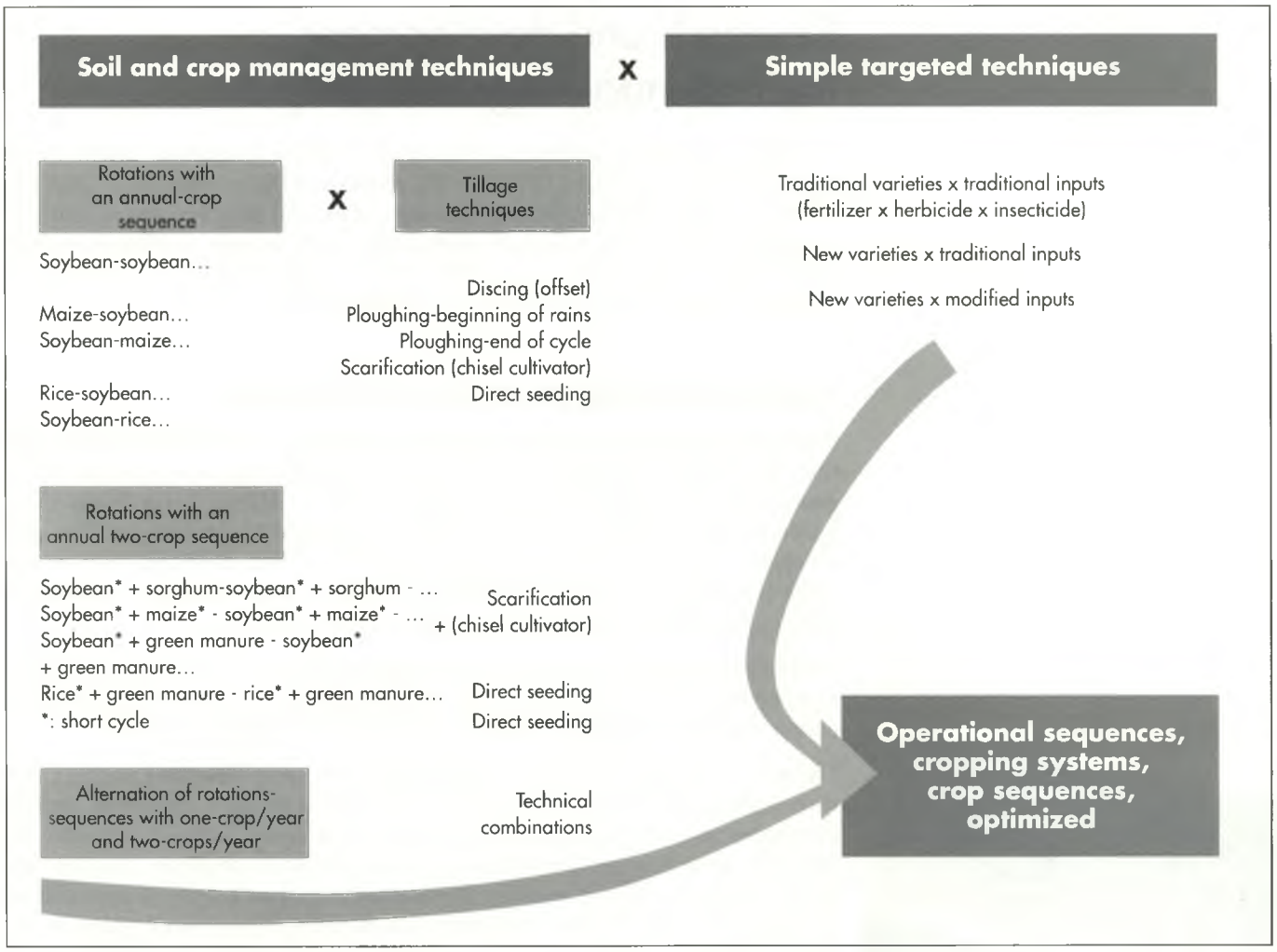


Figure II-2. An exemple of a cropping system matrix in a humid *cerrados* area of central-western Brazil.

Research progress

As of the second year of the study, the most cost-effective cropping systems were selected in order to meet immediate needs. Mineral fertilization tests were carried out: types, fertilizer application dosages and rates, technical-economic impact under frontier farming conditions. Other targeted tests, specific to each cropping system, were conducted to improve the efficiency of these systems and classify the effects of each factor investigated: varieties, pesticides, etc.

During 6 years of followup studies, we determined the best cropping systems from a technical, economic and ecological viewpoint. Conditions required to reproduce these systems were characterized, while determining pertinent cultural profile parameters that best explained yield build-up phenomena (assessment tools).

The agricultural results: an innovative farming system

Agriculturally, soil and crop management strategies (types of tillage and rotations) seem to be essential factors for improving dry matter production and yield sustainability. In terms of assessing explanatory agricultural processes, crop rooting was shown to be critical for obtaining good production results. Finally, soil acidity and other mineral shortages (especially phosphorus and zinc) have to be adjusted at the outset in order to improve soil fertility.

Tillage and crop rotations

The soil structure was found to be markedly improved in cropping systems with deep tillage and crop rotations: disappearance of the physical unconformity in the cultural profile, with base and organic matter redistribution in deep horizons, thus inducing very high root growth.

Crop rotations: beneficial for soybean

Substantial yield increases relative to traditional cropping systems can be obtained with the best combinations, i.e. tillage techniques x interannual rotations and annual crop sequences (Figure II-3).

Indeed, significant yield improvements were obtained with soybean in rotations with rice or maize, combined with deep tillage or direct seeding on crop-residue mulch: there was a yield gain of around 80%, i.e. soil productivity had increased twofold even though mineral fertilization was the same in all cases. The mean soybean yield over the 6-year period was higher than 3 000 kg/ha, while that of the monocropped control with offset tillage was 1 670 kg/ha.

A day in the field. Nova Mutum prefecture, Mato Grosso state.

Rainfed rice: technical combinations

Deep tillage was found to markedly increase rainfed rice yields in rotations with soybean, as compared to offset discing or direct seeding on crop-residue mulch (Figure II-3). The mean yield after deep tillage (5-year period) was 3 093 kg/ha, as compared to 1 835 kg/ha with offset discing and 1 655 kg/ha with direct seeding. In addition, combining this cropping system with basal thermophosphate fertilization (1.5-2 t/ha every 3 years) substantially reduced the impact of rice blast, and reproducible yields of higher than 4 000 kg/ha were obtained.

Other benefits of crop rotations

In all cases, the most interesting cropping systems, i.e. legume-cereal rotations, markedly improved disease, pest and weed control. Moreover, systems in which one annual crop (rice or soybean) was alternated with a two-crop sequence the following year (soybean + sorghum, or rice + sorghum) turned out to be more agronomically, technically and economically interesting than the reference systems (monocultures and offset discing).

Deep-tillage risks

It should be pointed out that, despite the fact that rotations or crop sequences combined with deep tillage markedly enhanced soil fertility and was the most efficient technique for limiting soil compaction and nuisance problems, continuous deep tillage with mouldboard ploughs considerably accelerates organic-matter mineralization.

Deep tillage can also lead to rapid soil degradation, to the extent that high mineral inputs could be required to maintain high sustainable crop yields over the medium and long term. Moreover, tillage does not reduce the risk of erosion. Techniques should therefore soon be developed to facilitate direct seeding on permanent plant cover. These are actually the only techniques that markedly improve soybean, maize and sorghum yield performance — although the improvement process is more gradual than with deep tillage. This strategy also provides complete erosion control and increases the productive area via the introduction of crop sequences. The complementarity between livestock-production activities — traditionally carried out extensively and independently of cropping activities — and grain production could provide many technical and economic solutions to the problem of developing sustainable agricultural systems in frontier areas.

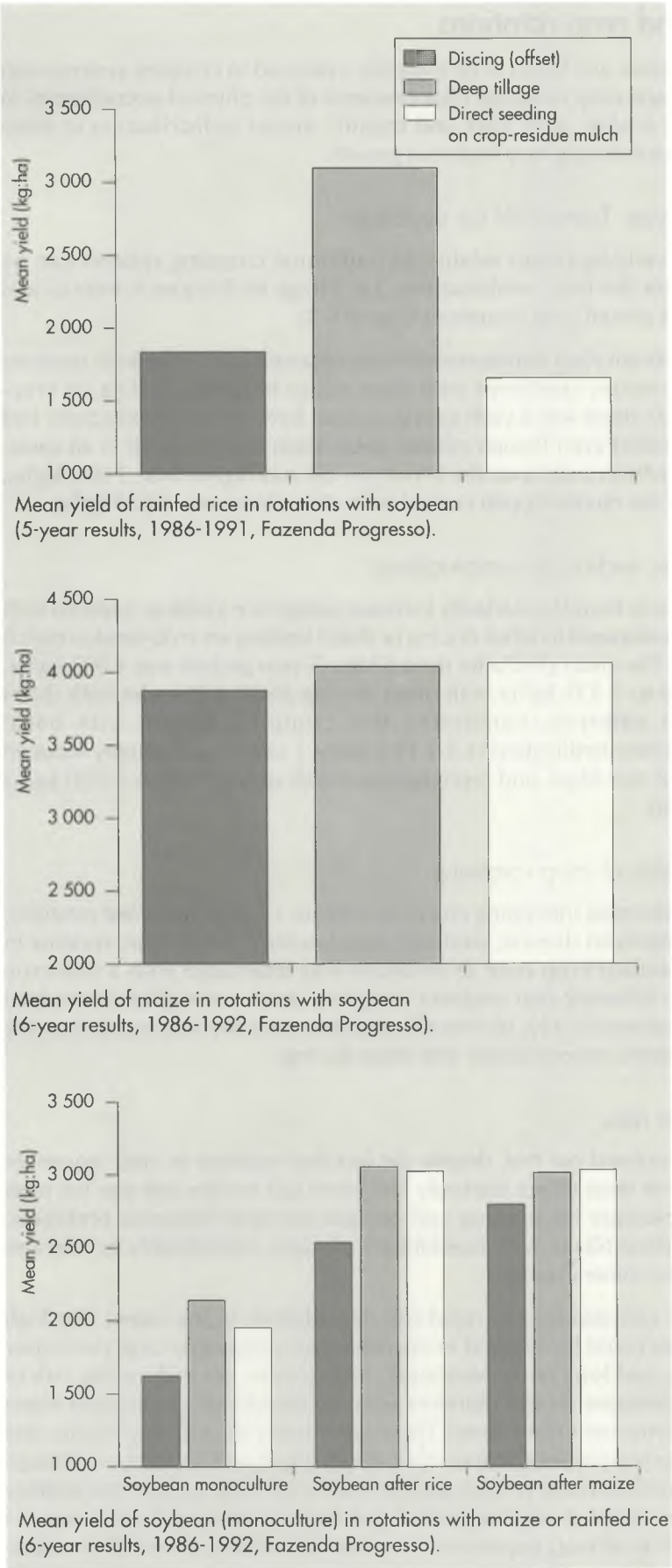


Figure II-3. Mean yields of the main crops according to the type of tillage.

Chemical parameters

Chemical parameters were measured in 1985 and 1992 in the same improved cropping systems. The results were higher than the established deficiency thresholds (Tables II-2 & II-3) (Van Raij, 1991; Lopes, 1984; Souza *et al.*, 1987).

Organic matter reduction

Organic matter was the only component that was sharply reduced in cropping systems involving deep tillage with mouldboard ploughs, regardless of the type of single annual-crop rotation (soybean-rice, maize-soybean), or with offset disc cultivators (monocultures) — ranging from a mean 2.5% organic matter at the outset to less than 1% after 6 years of continuous cropping in the 0-30 cm cultural horizon. These results are not encouraging for long-term soil-fertility management. Systems involving direct seeding on permanent plant cover help maintain initial organic matter levels, or even increase levels in the surface layer.

Maintenance dressings

For the above-described cropping systems, maintenance dressings with nitrogen, phosphorus and potassium fertilizers, applied within the planting rows, are sufficient to obtain yields of about 3 000 kg/ha for soybean, 2 500-3 000 kg/ha for rainfed rice and 4 500 kg/ha for maize:

- 8 N-80 P_2O_5-80 K_2O with soybean;
- 35-40 N-70 P_2O_5-70 K_2O with rainfed rice;
- 60-80 N-70 P_2O_5-70 K_2O with maize.

Fertilizer needs

Annual fertilization should be supplemented with lime-magnesium dressings when the base soil saturation index is less than 40% for soybean, i.e. the most demanding crop in the rotations (rice is the most tolerant of acid soils).

Table II-2. Chemical analyses of the cultural profile after corrective fertilization (Fazenda Progresso, 1986-1992).

Cropping system	Horizon (cm)	pH $CaCl_2$	pH water	OM (%)	Ca	Mg	Al	K	CEC*	V (%)	P** (ppm)
					..... (meq/100 ml)						
Soybean monoculture with offset (control)	0-10	4.9	5.5	1.0	2.9	1.1	0.1	0.21	8.4	50.1	8.3
	10-20	5.0	5.6	1.0	2.0	0.8	0.1	0.12	6.3	46.2	2.6
	20-30	5.2	5.6	1.0	0.5	0.3	0.4	0.09	4.3	20.7	5.3
Soybean monoculture with deep tillage	0-10	4.5	5.1	1.1	2.7	0.9	0.1	0.17	9	42.0	2.6
	10-20	4.4	5.0	0.9	2.7	1.0	0.1	0.08	10.2	37.1	5.3
	20-30	4.5	5.1	0.7	2.5	0.8	0.1	0.10	9.8	34.7	5.3
Soybean-maize rotation with deep tillage	0-10	5.1	5.7	1.5	1.9	0.5	0.1	0.15	5.3	47.6	3.0
	10-20	5.5	6.1	1.3	2.1	0.7	0.1	0.16	4.5	64.2	7.6
	20-30	5.2	5.8	2.0	1.2	0.9	0.1	0.12	4.8	58.5	7.6
Rotation system alternating one crop with a two-crop sequence and direct seeding	0-10	4.7	5.3	2.4	2.0	0.9	0.1	0.21	7.8	39.8	6.5
	10-20	5.1	5.7	2.2	2.8	2.0	0.1	0.17	6.8	58.6	10.0
	20-30	5.2	5.8	2.0	1.2	0.9	0.1	0.12	4.8	58.5	7.6
Soybean-rice with deep tillage	0-10	4.6	5.2	1.7	2.5	1.0	0.1	0.24	8.3	49.6	9.6
	10-20	3.6	5.2	3.4	2.5	1.0	0.1	0.14	8.3	43.7	2.3
	20-30	5.0	5.6	1.3	2.5	0.7	0.1	0.10	6.1	53.9	7.8
Soybean-maize system. 5 years with direct seeding on *Calopogonium*	0-10	4.3	4.9	2.0	3.4	0.8	0.1	0.20	10.2	43.2	9.5
	10-20	3.6	5.2	3.4	2.5	1.0	0.1	0.14	8.3	43.7	2.3
	20-30	4.9	5.5	3.8	0.8	0.4	0.1	0.12	7.1	18.6	1.2

*CEC: ammonium acetate method.
P**: Mehlich method.

Table II-3. Recommended range for chemical factors with improved cropping systems, in the 0-30 cm soil horizon, for the highest yield objectives (Séguy, 1993).

pH $CaCl_2$	pH water	OM (%)	Ca	Mg	Al	K	CEC	P (ppm)
			..... (meq/100 ml)					
5.0-5.4	5.6-6.0	1.7-3.0	2.0-3.5	0.8-1.3	< 0.2	0.15-0.24	6.5-10	5-10

Harvesting rainfed rice, Fazenda Progresso.

Overall strategy

When implementing tillage and rotation techniques that utilize biological factors, problems of soil acidity and shortages of phosphorus, potassium and zinc can be solved with relatively low fertilizer inputs in comparison to the high crop yields obtained. Fertilizer applications can be carried out in two ways:
– progressively, using ground dolmitic limestone(1) and annual mineral maintenance dressings using slightly higher levels of trace elements than required to meet crop needs, applied under the planting row;
– when the fields are cropped, with a fertilizer containing ground limestone (2.5 t/ha), thermophosphate[2] (1.5-2 t/ha), gypsum (600 kg/ha) and potassium chloride (160 kg/ha).

This extent of corrective fertilization resulted in the highest sustained productivity with the best systems: more than 4 000 kg/ha of rainfed rice and soybean, sequentially followed by 1 200-2 000 kg/ha of sorghum and millet. Repeated applications are required, but without lime-magnesium input, on a 3-year basis to meet the needs of 5-6 successive crops.

Crop rooting: the main assessment factor

Irrespective of the crop, tests on the cultural profile highlighted a close correlation between quick, strong deep rooting and high yields. In the best yielding systems (i.e. rotations with soybean, deep tillage, corrective thermophosphate fertilization and early sowing), rainfed rice roots were found to always grow to depths of more than 1.20 m during flowering, while soybean roots grew to 60-80 cm depth at the same stage.

(1) To maintain the saturation index of the clay-humus complex at 40% or slightly higher.
(2) Thermophosphate composition:
total P_2O_5 17.5%; citric acid P_2O_5 16%;
Ca 20%; Mg 9%; B 0.1%;
Zn 0.55%; Mn 0.12%; Mo 0.006%; Cu 0.05%.

Maize growing on *Calopogonium* cover, Fazenda Progresso.

Monitoring crop rooting until flowering is a simple, very reliable and inexpensive assessment tool. Investigations involve digging observation ditches, or injecting herbicides to check the extension of the root front (Séguy *et al.*, 1992a, b).

With rainfed rice, which was shown to be the most demanding crop in terms of physical soil characteristics, moisture infiltration rates were positively correlated with crop yield and root density within the 20-30 cm soil layer (Figure II-4a). Crop yields were negatively correlated with soil bulk density, the number of weeds, and mechanical resistance to penetration.

With soybean, crop yields were positively correlated with root density at deep soil layers (Figure II-4b).

Optimal equipment use

Farm machinery is used to optimal capacity with cropping systems involving rotations with one annual crop (rice or soybean), with a direct-seeded two-crop sequence the following year. At Fazenda Progresso, tillage time increased from 80-90 days with soybean monocultures to 135 days with improved cropping patterns. Similarly, harvest times increased from 80 to 135 days. The area cropped annually increased by 50-60% without clearing any new land since two-crop sequences were used every other year.

For equipment supplies, six companies began manufacturing mouldboard ploughs in 1986, i.e. Ikeda, Sans, Baldan, Lavrale, Tatu and Maschetto. Three years later (1989), more than 367 000 ha had been tilled in central-western Brazil.

Ferralitic soils of western Brazil

Ferralitic soils, according to the French classification, account for about 63% of all soils in wet tropical regions (Robert, 1992). Before cultivation, these acid soils have the following characteristics:
– they generally have high organic matter content and are well structured;
– they are deficient in calcium, magnesium, phosphorus, potassium and often zinc (as in Brazil);
– they have a high aluminium saturation index, which is toxic for most crops.

Direct seeding of rice on millet + *Calopogonium* straw. SULAMERICA project, Piauí state.

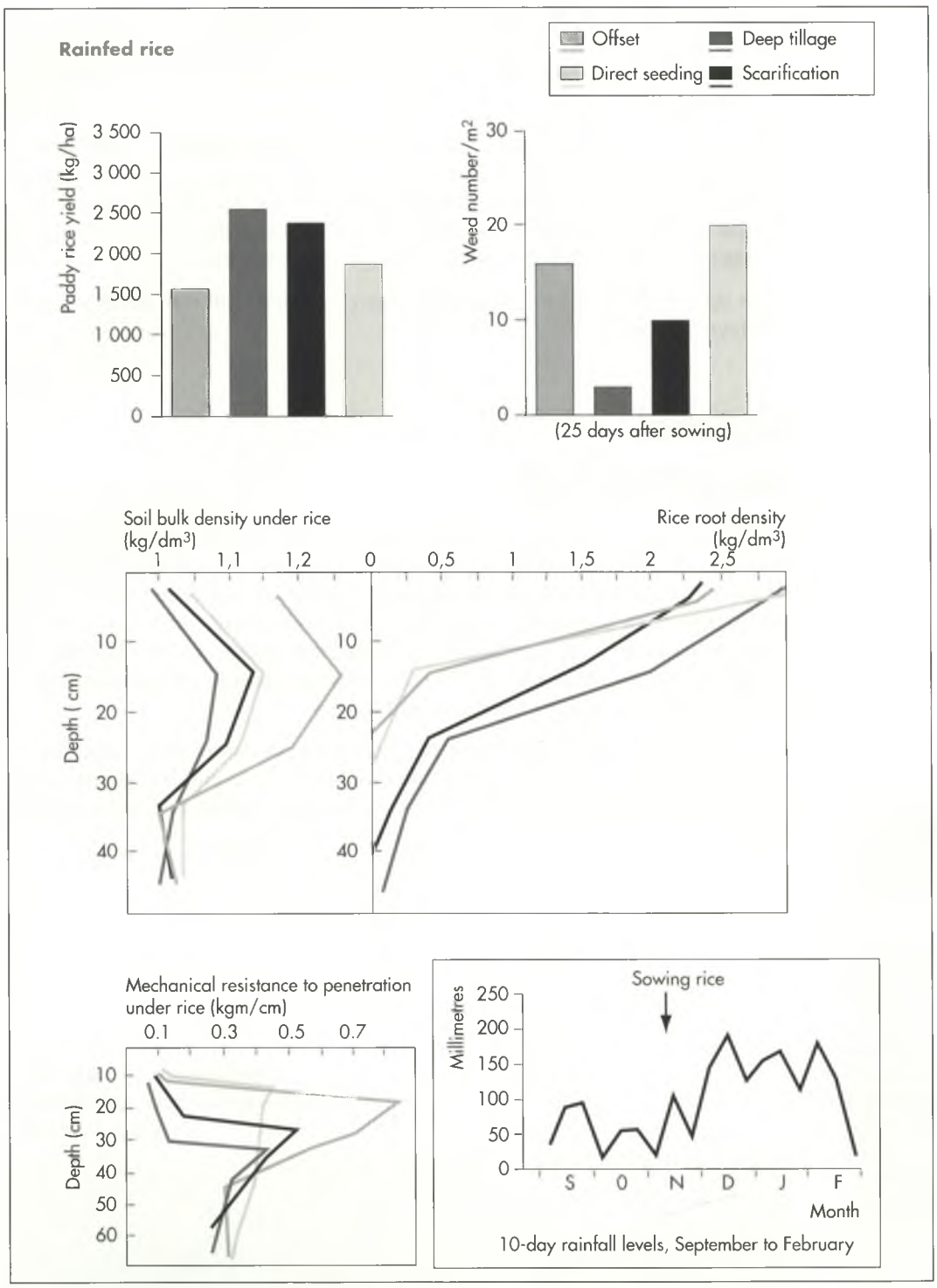


Figure II-4a. Rainfed rice in a rice-soybean rotation: relations between various cropping factors and yield, according to the type of tillage (1990-1991, Fazenda Progresso).

Fazenda Progresso.

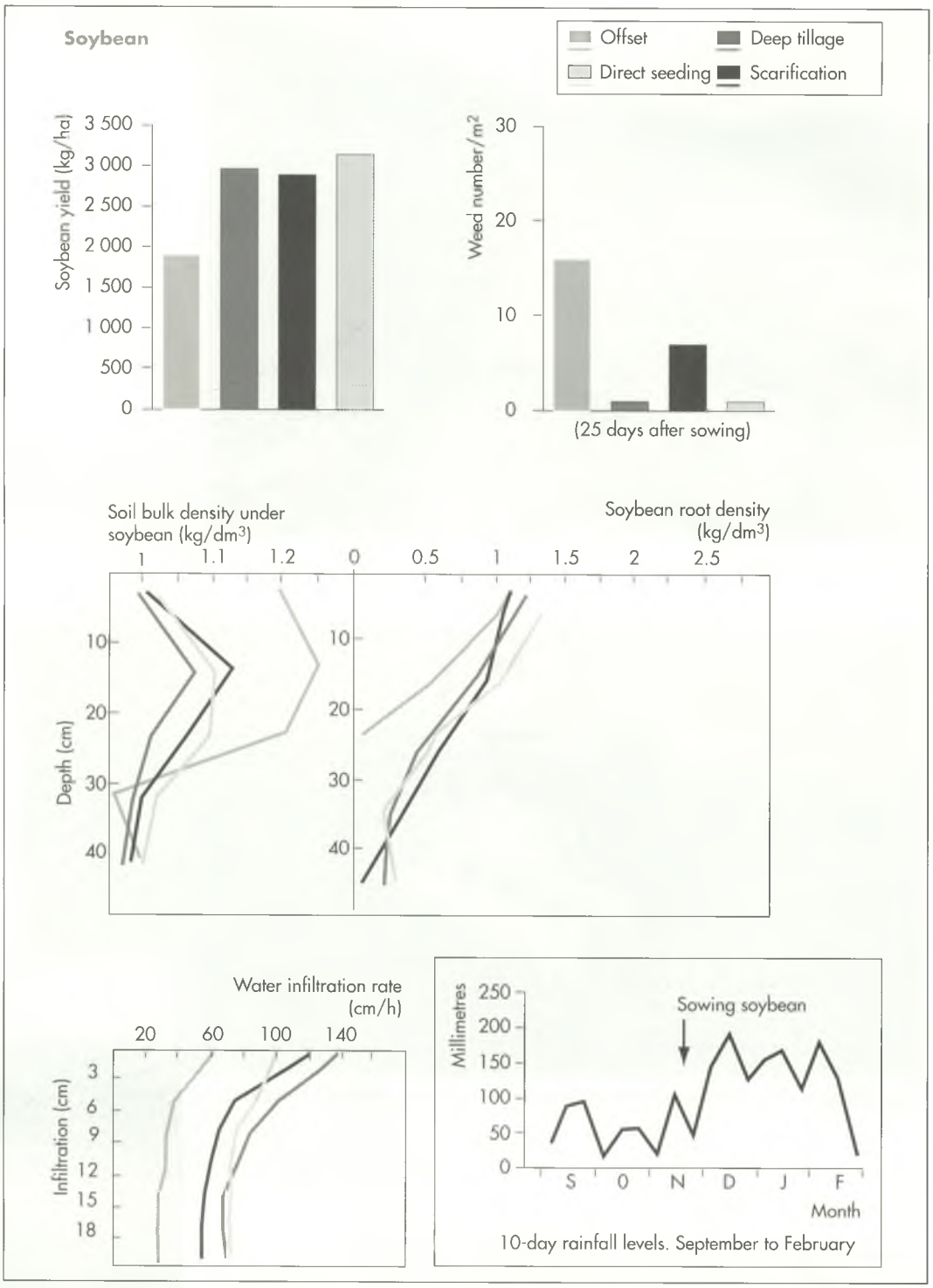


Figure II-4b. Soybean in a rice-soybean rotation: relations between various cropping factors and yield, according to the type of tillage (1990-1991, Fazenda Progresso).

Rainfed rice. Fazenda Kamitani, Mato Grosso state.

High erosion in a traditional offset discing system (left); protected soil with direct seeding (right). SULAMERICA project, Piauí state.

Deep tillage with a moultboard plough after trash mulching, Fazenda Progresso.

Erosion in field of young soybean, traditionally monocropped with offset tillage, Mato Grosso state.

Direct seeding of soybean, Primavera region, Mato Grosso state.

Economic results

General fluctuations

Economic conditions were very unstable in Brazil from 1986 to 1992, and a series of economic plans were implemented. This permanent crisis situation was aggravated by the geographical location of the agricultural frontiers. In 1994, for instance, more than 2 800 kg/ha of soybeans had to be harvested to cover production costs, whereas only 2 100 kg/ha was required in the southern states, close to ports and consumer areas. The marked variations in production costs are presented in Figure II-5 for the two main products of the region: soybean, increasing from 300 000 ha in 1989 to 457 000 ha in 1993-1994, and rainfed rice, increasing from 68 000 ha in 1989 to 86 000 in 1993-1994.

Attractive gross margins

The economic performances of the main cropping systems (Table II-4; Figure II-6) indicated that rice and soybean monocultures were the least productive systems, and financial losses were always incurred. High gross margins were obtained with systems involving rotations and crop sequences. This situation is of considerable interest, especially in light of the fact that the smallest farms in the region are 200 ha. These cropping systems could be combined to improve annual crop sequences, thus enhancing economic risk management (Table II-4).

Guaranteed prices upset economic assessments

Note that these results were calculated on the basis of minimum guaranteed prices set by the government — they are difficult to extrapolate as preset prices are not necessarily respected locally. When the quality of harvested grain is poor, for instance, the crop is not marketed, or it is sold at prices that are much lower than the minimum guaranteed price. In addition to diversifying crops, the overall aim should be to improve product quality and process products locally. This would provide an incentive for farmers, as they could obtain guaranteed prices for their crops, and also decrease road-transport costs.

Catastrophic runoff on compacted soil.

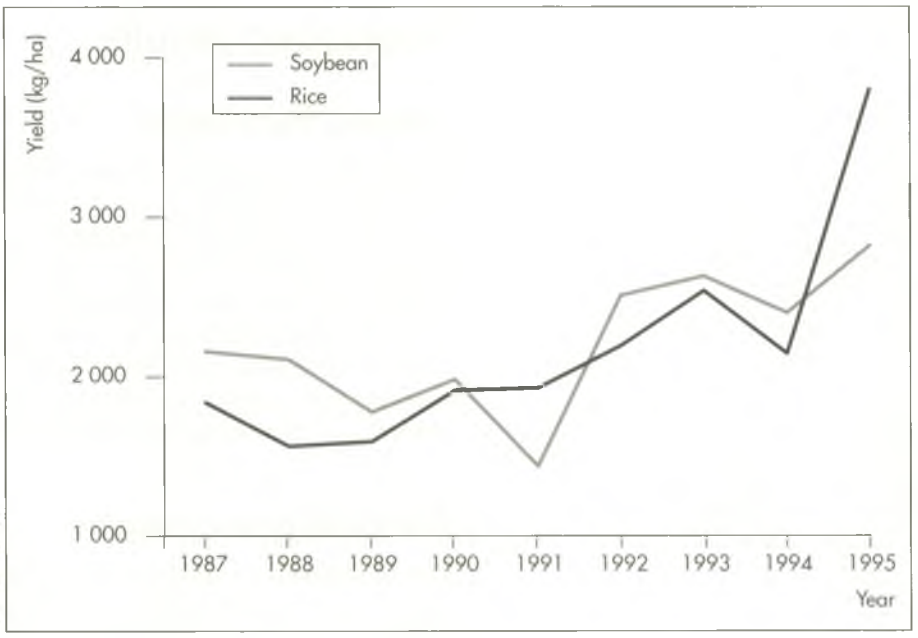


Figure II-5. Economic pattern: minimum soybean and rainfed rice yields covered production costs (1987-1995).

Figure II-6. Economic performances of the best cropping systems compared to soybean and rice monocultures (1988-1990 results, Fazenda Progresso).

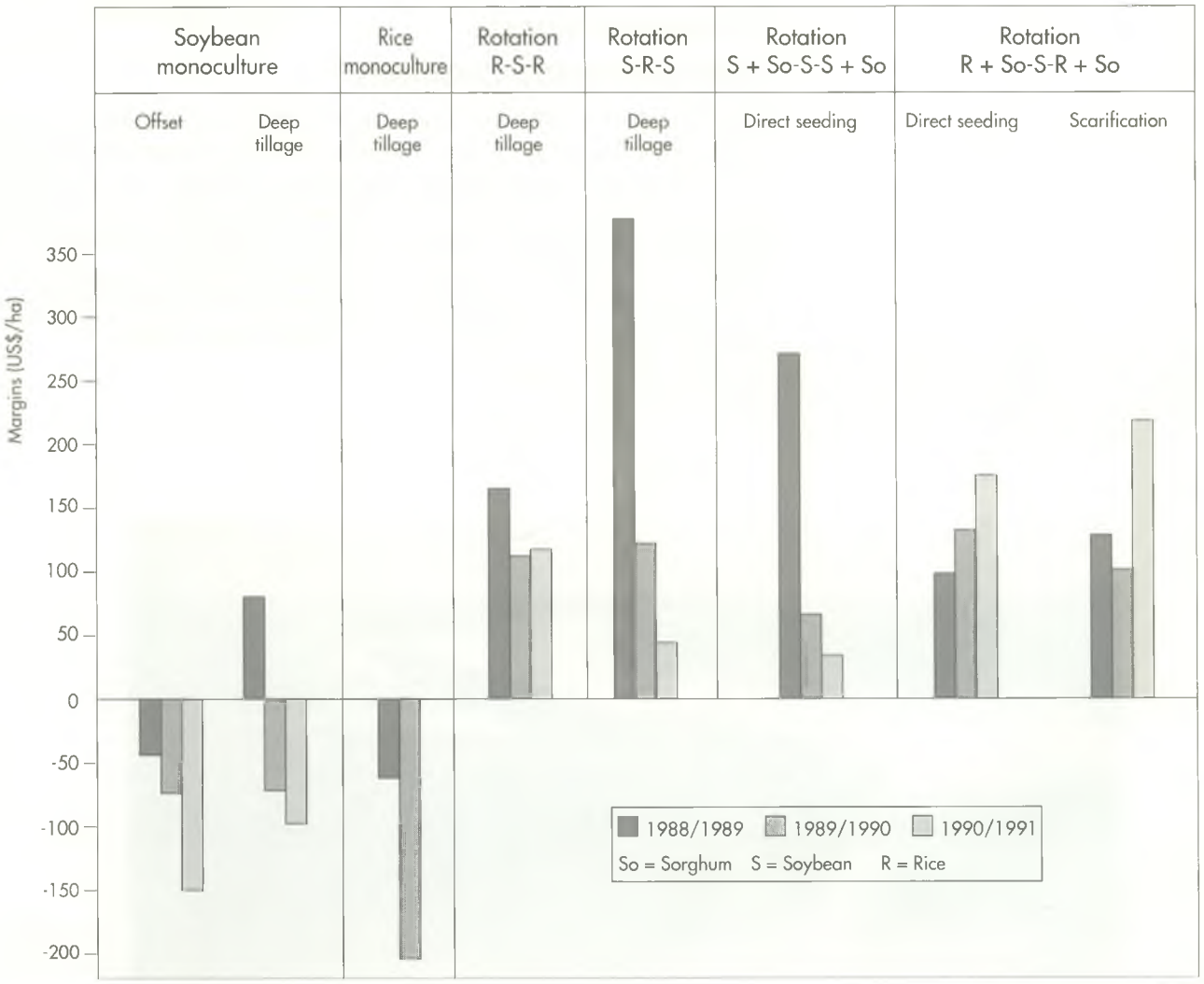


Table II-4. Agro-economic performances of different cropping systems. Mean for three crop seasons, 1987-1988, 1988-1989, 1989-1990 (Fazenda Progresso, Lucas do Rio Verde, Mato Grosso).

Cropping system	Main crop (kg/ha)	% relative to control	Crop sequence (kg/ha)	Production cost	Gross margin	Net margin
				(US$/ha)		
1. Control, soybean monoculture, offset, NPK	soybean: 1 436	100	-	318	-77	-141
2. Rotation, annual sequence rice-soybean-rice, tillage, NPK	rice: 3 245	-	-	301	+ 110	+ 50
	soybean: 3 048	194	-	350	+ 260	+ 190
	rice: 2 090	-	-	364	-17	-90
3-year mean	-	-	-	**338**	**+ 118**	**+ 50**
3. Rotation, annual sequence rice-soybean-rice, tillage*	rice: 3 770	-	-	343	+ 138	+ 78
	soybean: 3 396	216	-	395	+ 284	+ 205
1.5 t/ha thermophosphate	rice: 2 900		-	390	+ 91	+ 13
3-year mean	-	-	-	**376**	**+ 171**	**+ 99**
4. Rotation, soybean + sorghum-rice-soybean + sorghum, tillage*, NPK	soybean: 2 785	197	sorghum: 648	313	+ 166	+ 103
	rice: 2 480	-	-	315	+ 93	+ 30
	soybean: 3 080	233	sorghum:1 620	340	+ 171	+ 103
3-year mean	- -	-		**323**	**+ 143**	**+ 79**
5. Rotation, soybean + sorghum-rice-soybean + sorghum, tillage*, 1.5 t/ha thermophosphate	soybean: 3 080	217	sorghum:1 711	381	+ 225	+ 149
	rice: 2 980	-	-	361	+ 130	+ 58
	soybean: 3 580	271	sorghum:2 830	444	+ 211	+ 123
3-year mean	-	-	-	**395**	**+ 189**	**+ 110**
6.Rotation, rice-soybean + sorghum-rice, tillage*, 2 t/ha thermophosphate	rice: 4 317	-	-	382	+ 164	+ 88
	soybean: 3 450	219	sorghum:2 022	514	+ 368	+ 265
	rice: 3 360			426	+ 131	+ 46
3-year mean	-	-	-	**441**	**+ 221**	**+ 133**
7. Rotation, soybean-maize-soybean, continuous direct seeding on crop-residue mulch + *Calopogonium*, NPK	soybean: 2 940	-	- -	308	+ 146	+ 95
	maize: 5 200	-	- -	355	+ 269	+ 210
	soybean: 3 260	-	- -	338	+ 152	+ 96
3-year mean	-	-	- -	**334**	**+ 189**	**+ 134**
8. Rotation soybean-maize-soybean, continuous direct seeding on crop-residue mulch + *Calopogonium*, 1,5 t/ha thermophosphate	soybean: 3 486	-	- -	370	+ 170	+ 108
	maize: 6 400	-	- -	381	+ 377	+ 314
	soybean: 3 940	-	- -	376	+ 213	+ 150
3-year mean	-	--	- -	**376**	**+ 253**	**+ 191**

NPK on soybean = 0-84-87; on rice = 60 to 80-75-75 + trace elements applied along the planting row. Thermophosphate is supplemented with N and K equivalent to NPK fertilization. It is applied for 3 years and decreased (over 5-6 crops).
*: in these systems, tillage is done before sowing the main crop (soybean, rice); the follow-up crop is always direct seeded on crop-residue mulch from the main crop, without fertilization.

Cerrados, grazings and soybean crops, Mato Grosso state.

Research data dissemination

Surveys carried out in 1989 and 1990 evaluated the extensive application of these research results in central-western states of Brazil (Tables II-5 & II-6). The mean performances of cropping systems within this area and their classifications were in line with those recorded on the experimental unit in Fazenda Progresso. This indicated that techniques developed at the unit were applicable throughout the region. The agricultural innovation-extension method is thus a valuable methodological tool for improving the efficiency of large highly-mechanized farms, under the soil-climate and economic conditions of central-western Brazil.

Table II-5.Results for cropping systems adopted by farmers for the 1989-1990 crop season in the regions of Sorriso, Agua Boa (Mato Grosso state) Paracatu (Minas Gerais state), Maracaju (Mato Grosso do Sul state): 42 664 ha, 116 farmers, mean for several tested varieties (Séguy *et al.*, 1990*a*, *b*).

System	Soybean (32 531 ha)		Rainfed rice (7 121 ha)		Maize (3 012 ha)	
	area (%)	yield (kg/ha)	area (%)	yield (kg/ha)	area (%)	yield (kg/ha)
1. Deep tillage with trash mulching	46.5	2 492	14.6	2 122	81	4 656
2. Offset ploughing after clearing	7.4	1 562	67.0	1 566	-	-
3. Deep tillage, legume-cereal rotation	19.0	2 881	10.8	2 306	-	-
4. Monoculture and offset ploughing	27.1	1 994	7.6	1 494	3	3 360
5. Offset ploughing with trash mulching	-	-	-	-	16	3 507

- : sample not represented

Table II-6. Results for cropping systems adopted by farmers for the 1990-1991 crop season in the regions of Sorriso, Agua Boa (Mato Grosso state) Paracatu (Minas Gerais state), Maracaju (Mato Grosso do Sul state): 17 123 ha, 57 farmers, mean for several tested varieties (Séguy *et al.*, 1991).

System	Soybean (13 904 ha)		Rainfed rice (1 678 ha)	
	area (%)	yield (kg/ha)	area (%)	yield (kg/ha)
1. Monoculture and offset ploughing	40	1 410	28	1 050
2. Offset ploughing after clearing	1.5	1 110	37	1 470
3. Monoculture and deep tillage	52	1 875	-	-
4. Rotations and offset ploughing	1.5	2 480	17	1 905
5. Rotations and deep tillage	5	2 560	18	2 890

- : sample not represented

Conclusion: a qualified success

By using deep tillage techniques along with rotations and crop sequences, frontier farmers are able to improve the fertility of soils degraded by continuous soybean monocultures and disc ploughing, while increasing and stabilizing their farming income. However, under the soil-climate conditions of the region, regular deep tillage markedly accelerates organic-matter mineralization, i.e. a humus loss of more than 50% was noted over a 6-year period. This detrimental effect could jeopardize possibilities of establishing sustainable, efficient and cost-effective agricultural systems in this region. These techniques should only be used temporarily to correct the physicochemical characteristics of degraded soils. Alternative cropping strategies are thus required. For soil management purposes, using direct seeding in fields with mulch or vegetation cover, under the same natural and social conditions, could be quite beneficial: total erosion control, preserving organic matter resources, enabling farmers to earn equivalent or higher income than they would with systems involving deep tillage. This agrobiological soil management strategy is presented in the next article.

Rainfed rice, Fazenda Progresso.

III. Direct seeding, an organic soil management technique

Sustainable and cost-effective management of soil resources in tropical countries cannot be achieved by simply transferring tillage techniques from temperate countries. New sustainable cropping system management strategies have been designed and developed by CIRAD, in collaboration with its research and development partners in Brazil, for acid soils of the hot humid tropical zone. The systems developed function like forest ecosystems and involve direct seeding over permanent grass or mulch cover. They are based on interannual crop rotations involving annual sequences with various crops. These systems can be adopted for the purposes of seed or livestock production, or a combination of these two activities. They can be used in hot humid savanna or lowland tropical forest ecosystems with mechanized cropping. For the same ecosystems, these cropping systems can be tailored to meet the needs of manual, animal draught or partially mechanized peasant farming by introducing different cover crops.

Organic matter has many basic functions in the cultural profile: a source of nutrients (Nye, 1961; Sanchez, 1976), formation of the clay-humus complex which helps maintain the soil structure and moisture storage (Lal & Greenland, 1979), erosion control by improving the soil structure and surface mulching.

Organic matter is produced continuously under forest cover or dense shrubby crops, thus stabilizing the ecosystem and making it very biologically active. Most nutrients are recycled at the interface between living and dead organic matter, thus retaining them in the ecosystem. This accounts for the stability of these ecosystems, even with the poorest soils (Nye, 1961).

Amazon forest, AGRIPEC project, Mato Grosso state.

This nutrient cycle is disrupted by forest clearing and cropping, which results in organic matter mineralization. Subsequently, the tillage technique, the use or absence of rotations, and high plant residue recycling are critical factors affecting decomposition rates and for determining whether organic matter is maintained in the soil or lost.

The no-till cultivation strategy was developed by observing dense forest or shrub systems, with the overall goal of reproducing natural phenomena. However, the strategy only began being used in mechanized farming after the non-selective herbicide paraquat was marketed, and after the first seed drills (manufactured by Allis Chalmers) appeared that could be used in no-till conditions.

In Brazil (Figure III-1), mechanized direct seeding techniques were first used in the 1970s, in Paraná state and subtropical highland zones[1]. Projects undertaken by the ABC Foundation, Paraná state cooperatives and the research projects of IAPAR were outstanding in this respect [2]. Currently, more than 3.5 million ha are being cultivated using direct seeding techniques in the southern states. In these regions, a suitable soil cover can be almost permanently sustained using crop-residue mulch as the climatic conditions, including a cold season, are favourable.

In contrast, crop-residue mulch on the soil surface breaks down very rapidly under the very hot humid conditions that prevail in agricultural frontier areas of western Brazil. Even when mulch with high cellulose and lignin contents is used, e.g. rice and maize, soil coverage is only 50% complete 8 weeks after the beginning of the rainy season (Table III-1). Alternative systems should therefore be developed to protect the soil year-round, i.e. under crops and during the dry season. The high levels of biomass produced in direct seeding systems with permanent plant cover would make it possible to progressively maintain soil organic matter levels, while efficiently controlling erosion.

(1). A few farmers in Paraná state (Brazil) are the main promotors of direct seeding — H. Bartz, M.H. Pereira, F. Djikstra, etc. — and agronomists of the ABC Foundation, including H. Peeten, J.N. Pavei and J. Moraes de Sa.

(2). J.Z. Mazuchowki and R. Derpsh, 1978; Castro Filho *et al.*, 1980; J.A. Machado & A.C.R. Brum, 1981; A. Mondardo & R.M. Biscaia, 1981; O. Muzilli, 1981; F.S. Almeida, 1983; H. Lorenzi, 1984; R. Derpsch *et al.*, 1984; K. Igue, 1984.

The direct seeding strategy

In direct seeding systems, sowing is carried out with special machinery over untilled soil — only a small furrow or seed slot is made, just deep and wide enough to ensure that the seed will be sufficiently covered and in full contact with the soil. The fields are weeded, usually with herbicides, prior and subsequent to sowing.

This no-till seeding technique can be used in temperate and subtropical zones with a cold season. Under such conditions, a slowly decomposing crop-residue mulch layer can be permanently sustained. Conversely, in lowland hot humid tropical zones, crop residue on the soil surface decomposes very quickly after rains — there is a very high organic matter mineralization rate (more than 4-5%) — which means that the mulch layer does not protect the soil surface for a long enough period of time to be efficient. Moreover, in these conditions, the mulch layer is not very useful for controlling erosion or weeds through competition (e.g. shade, rooting, spatial and nutrient effects) and allelopathic effects. New soil and crop management systems adapted to hot humid climatic conditions thus had to be developed to obtain a sustainable efficient and permanent mulch and plant layer. Since 1989, CIRAD has been designing and developing no-till cropping systems that meet these objectives.

Soil cover after 3 years of direct seeding with crop sequences, Fazenda Progresso.

Direct seeding maize in *Bracharia* cover. Forest zone, Sinop prefecture, Mato Grosso state.

Direct seeded soybean in millet mulch. Cooperlucas, Lucas do Rio Verde, Mato Grosso state.

Table III-1. Variations in soil cover and loss of crop-residue dry matter.

Type of residue	Number of days after the first rains	Weight of dry matter on the ground (kg/ha)	Soil cover index (%)
Maize	30	7 500	82
	60	4 300	54
	90	2 500	30
	120	1 400	22
Rice	30	6 200	85
	60	3 100	46
	90	2 200	38
	120	1 700	26
Soybean	30	1 700	35
	60	540	16
	90	240	≈ 0
	120	≈ 0	≈ 0

Tannin-free high-protein sorghum. Mato Grosso state.

Direct seeding of *Bracharia* in annual crop sequences with soybean, at the beginning of the dry season. COOPERLUCAS, Mato Grosso state.

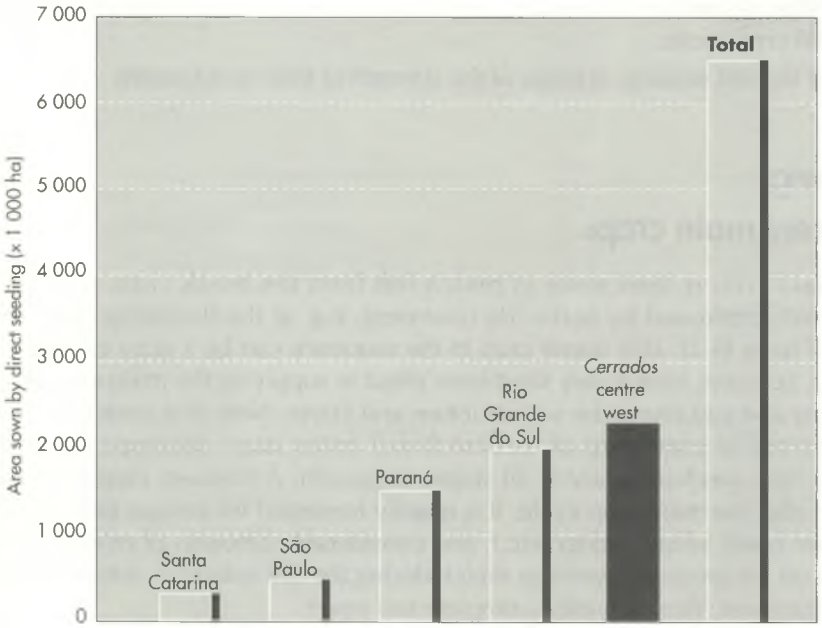


Figure III-1. Estimate of the area sown by direct seeding in the most productive regions of Brazil in 1996-1997 (from Borges, 1996).

Direct seeding techniques for hot humid tropical zones

The overall aim is to cost-effectively produce as much biomass as possible before and/or following each cash crop, thus avoiding the need for mechanized tillage.

Biomass-producing plants

This biomass is produced by a starter crop sown at the beginning of the crop sequence and/or a final so-called follower crop that is grown after the main crop (Figure III-2). These crops, which are direct seeded prior and subsequent to the main cash crop, can produce high biomass under relatively poor climatic conditions, e.g. millet and sorghum. Sowing these biomass-producing plants should be at least as cost-effective as the soil management techniques that are being replaced. By this approach, there is no tillage and the crops are always sown by direct seeding.

Direct seeding of soybean, Mato Grosso state.

Multiple purpose plants

Biomass-producing plants should meet the following needs:

– control erosion in both the rainy season and dry season;

– cushion the effects of varying temperature and humidity;

– supply the main crop with mineral nutrients through mineralization of the biomass produced;

– draw nutrients to the surface that have been leached deep into the soil;

– control weeds that compete most directly with the main crops;

– enable cost-effective pest management.

These plants, which are grown before or after the direct-seeded main crop, act as biological pumps for minerals. Their efficiency can be assessed in two ways:

– on the soil surface, by determining the volume and quantity of biomass that is recyclable, renewable at low cost, and that can be quickly mineralized during the main crop cycle;

– under the soil surface, in terms of the strength of their root systems.

Planting different main crops

The main crop is then sown in mulch left from the break crop, which is previously destroyed by herbicide treatment, e.g. at the flowering stage for millet (Figure III-2). This starter crop in the sequence can be a grass or legume species. Legumes have a very short-term effect in supplying the main crop with nutrients and sustaining the soil structure and cover. Note that under the hot humid tropical conditions of western Brazil millet straw decomposes more readily than sorghum straw at all stages of growth. A follower crop is direct seeded after the main crop cycle. It is usually harvested for various production purposes (seed, silage, fodder, etc.), and considerable amounts of crop residue are left on the ground to serve as mulch during the dry season — when it does not decompose, thus providing complete soil cover.

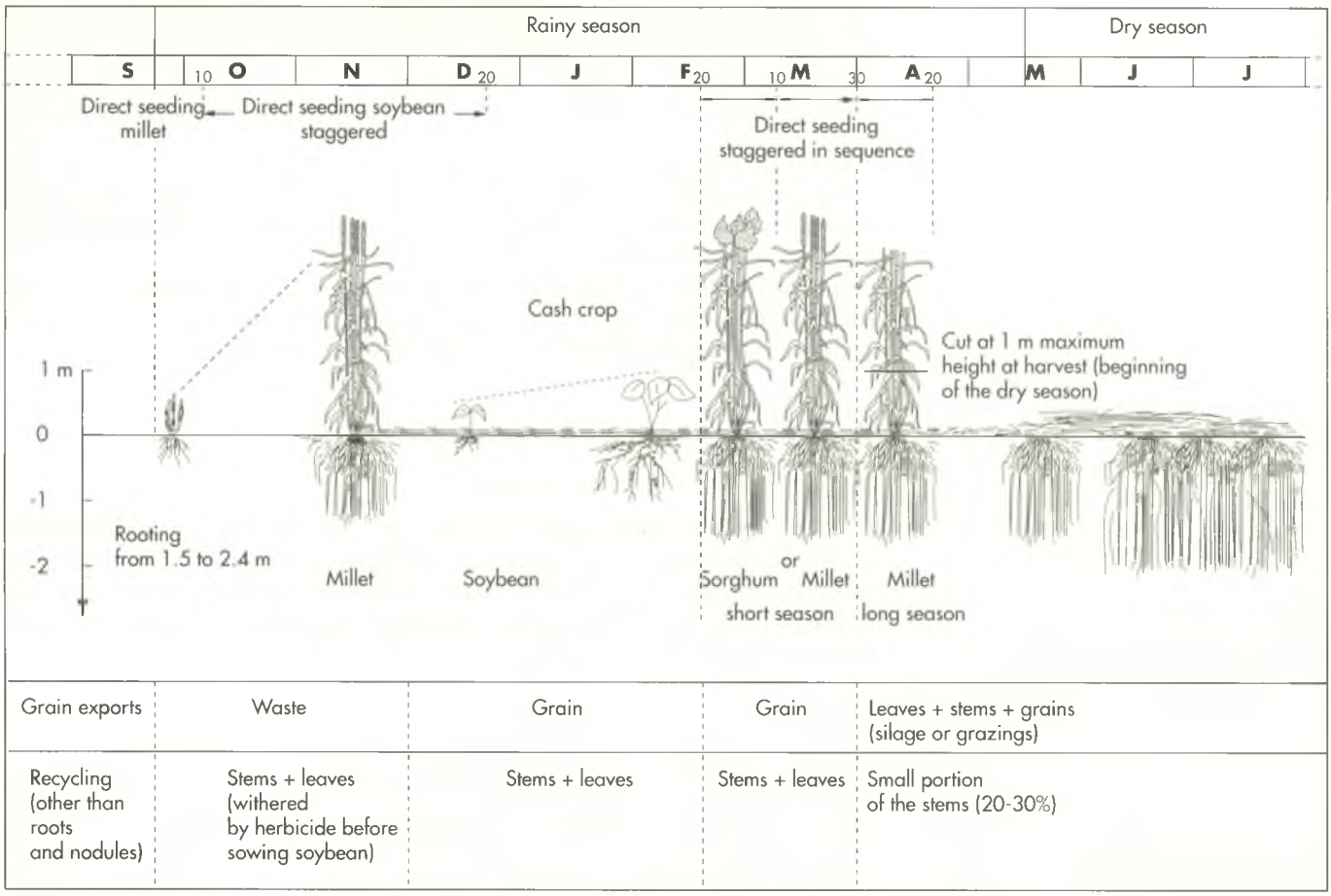


Figure III-2. Cropping system with direct seeding, using cereal crops as "biological pumps" for the benefit of the soil and the cash crop (soybean). The annual crop sequence shown in this example is as follows: millet + soybean / sorghum (or millet) grain crops + forage millet.

Direct seeding in rotation cropping systems with an annual two-crop sequence

These systems function almost like forest ecosystems. They were set up in the experimental units at Sinop, Sorriso and Lucas in central-northern Mato Grosso state, and the results were compared to those obtained with the same cropping systems using mechanized tillage.

On-farm experimental procedures

The tests were carried out under several different soil conditions, as defined according to the cropping history of the fields and whether they were in savanna or forest zones. This provided a representative sample of the different soil fertility conditions found in the region:

– savanna land, with an 18-year cropping history;

– savanna land, during the first year of cropping on newly-cleared land;

– savanna land, during the first and second years of cropping, degraded by 12 years of extensive grazing on *Brachiaria decumbens* cover;

– forest land, during the first year of cropping on newly-cleared land, and on land with a 13-year cropping history.

The annual crop sequences for the rotations were as follows:
– soybean + sorghum and/or millet;
– millet + soybean + sorghum and/or millet;
– rice + *Sesbania* or *Crotalaria*, and conversely *Sesbania* or *Crotalaria* + rice.

Four different treatments were assessed for each rotation:
– two sowing dates (early and late) within the period used traditionally by local farmers — to evaluate the effects on crop yields, along with the equipment capacity and operational flexibility;
– two fertilization regimes (progressive and high) to assess the effects on the performance of the cover crop, on the pest and disease status, on crop yields, and on yield stability relative to the spacing of sowing dates.

Results

Spreading out the sowing period

By using crop sequences with a starter crop and a follower crop, the sowing period for rice and soybean can be staggered over a period of more than 60 days after the first effective rains without substantially reducing yields (Tables III-2 & III-3). This strategy also offers wide operational flexibility and increases the machinery capacity.

Mineral applications: millet crops

In millet + soybean + sorghum and/or millet crop sequences (Figure III-2), millet is planted as a starter crop at the outset of the rainy season (September) for the purposes of biomass production, which increases from day 45 (flowering) to day 80 — this production increases even moreso after high corrective phosphate fertilization. In such conditions, the best millet varieties (cv ICMV-IS 88102) can produce up to 16 t/ha of dry matter. The aerial parts of the plant alone contain 160 N, 67 P, 349 K, 46 Ca, 61 Mg and 7 B, i.e. very high quantities of nutrients that can be taken up by crops after mineralization, especially potassium (Table III-4).

Millet as starter crop: rapid soil cover

In millet + soybean + sorghum and/or millet crop sequences, the millet starter crop quickly covers the soil after sowing and outcompetes with the weed population. It roots at a rate of 3 cm/day, reaching depths of 1.50-2.40 m depending on when the soybean crop is sown, which is generally done 45-80 days after the millet crop was sown (Figure III-2). Before sowing the soybean crop, the standing millet starter crop is withered with a non-selective herbicide applied by ground or aerial treatment (a blend of 720 g/ha glyphosate + 1 000 g/ha 2-4 D amine). Five days after the herbicide treatment, the soybean crop is direct seeded in the standing millet straw, which is flattened down by the passage of the seeding machine.

Table III-2. Soybean yields relative to cropping conditions (kg/ha), 3 years after forest clearing. Experiment carried out on 20 ha of land (Sinop and Sorriso, Mato Grosso state, 1994-1995).

Tillage	Mineral correction	Soybean sowing dates, Early October	early December, 60 days later early October	Early January, 90 days later early October
Direct seeding on millet straw at the end and beginning of the cycle, complete soil protection	– progressive	3 260	3 483	1 904
	– high	3 680	3 370	2 520
Traditional system, offset disc tillage, bare ground	– progressive	2 600	2 100	1 050
	– high	3 140	2 570	1 615

Table III-3. Soybean and rainfed rice yields relative to cropping and soil conditions (kg/ha), on newly-cleared forest land (2-3 years) and after 12 years of grazing in a savanna zone. Experiments conducted in units on 70 ha for soybean and 100 ha for rice (Sinop and Sorriso, Mato Grosso state, 1993-1994).

RICE					
Tillage and sowing	Mineral correction	2nd year of rice (monoculture), oxidized* forest soils	3rd year of rice (monoculture), hydrated* forest soils	Rice after soybean (2nd year of cropping), hydrated forest soils	Rice after 12 years of grazing, oxidized savanna soils
Early sowing and deep tillage	– progressive	3 980	2 171	3 622	3 278
	– high	4 487	3 044	4 871	5 529
Late direct seeding* on *Sesbania* sp.	– progressive	3 705	2 271	3 233	1 444
	– high	4 785	2 947	3 805	3 743
Late sowing* and traditional offset tillage, bare ground	– progressive	-	-	-	1 199
	– high	-	-	-	2 903

SOYBEAN				
		Soybean after rice, oxidized forest soils	Soybean after 2 years of rice, hydrated forest soils	Soybean after soybean, hydrated forest soils
Early sowing and deep tillage	– progressive	3 393	3 457	2 776
	– high	3 316	3 827	3 428
Late direct seeding* on millet straw at the end of the cycle, and starter millet, completely protected soil	– progressive	2 683	2 219	1 727
	– forte	3 463	2 754	2 628
Late sowing* and traditional offset tillage, bare ground	– progressive	2 166	2 177	1 731
	– high	3 120	2 794	2 907

*: 60 days after early sowing at the beginning of October.
Oxidized soils*: free draining and well structured ferrallitic soils.
Hydrated soils*: ferrallitic soils with high clay content (more than 50-60% colloidal content) with poor internal draining.

High-yielding millet, Fazenda Progresso.

Table III-4. Millet dry matter production and mineral contents in the aerial plant parts, after 80 days of growth.

Variety	Mineral fertilization*	Dry matter (kg/ha)	Minerals in aerial parts (kg/ha)					
			N	P	K	Ca	Mg	S
Forage millet	NPK	6 000	62.4	24	138	22	14	18
	thermophosphate	14 000	125	46	344	28	26	28
Millet ICVM IS 88-102	thermophosphate	16 000	163	67	349	46	61	32

*:NPK, annual maintenance fertilization (progressive rectification of mineral deficiencies).
Thermophosphate, high corrective fertilization (immediate rectification of mineral deficiencies).

Role of follower crops

Follower crops, i.e. sorghum (sown before millet) then millet, are direct seeded at the end of the rainy season. This seeding operation is carried out gradually as the soybean crop is harvested, and the seed is treated with a fungicide, which is the only input involved. Follower crop yields can reach 900-1 900 kg/ha for sorghum, 300-850 kg/ha for forage millet and 1 500-2 500 kg/ha for seed millet, depending on the amount of fertilizer the preceding soybean crop received (Table III-5).

Follower crops have many different roles, depending on the variety planted. The very high quality grain, with high protein content and no tannins, can be used in bread-making, distilling fine alcohols, and for making pasta and beer. The whole plant can be ensiled or left as grazings to provide a dietary supplement for livestock in the dry season. In such cases, 50-80 cm of standing biomass should be left for soil cover in the dry season.

Soybean performance

In these cropping systems, soybean yields were always significantly higher than obtained with any mechanical tillage technique in forest or savanna ecosystems with free draining soils. High corrective phosphate fertilization led to the highest sustainable yields.

Rice

Direct seeding techniques were developed for rainfed rice using *Sesbania* and *Crotalaria* legume species as biomass-producing crops, which root in a coiled pattern. The results obtained on newly cleared forest land and degraded savanna rangeland, with a sowing period of more than 60 days, indicated that sustained rainfed rice yields of 4 000 kg/ha could be obtained, even with late seeding (Table III-3).

Conclusion: results dependent on the soil-type

In free-draining ferrallitic oxidized soils of forest or savanna ecosystems, sustained high yields of the main crops (soybean, rice) were obtained by using a cropping sequence with starter and follower crops. These agronomically interesting results were obtained with a sowing period of more than 60 days and corrective phosphate fertilization.

Table III-5. Mean yields of annual crop sequences (2 crops/year; kg/ha), obtained under actual on-farm conditions, on a 60-ha experimental plot (Cooperlucas cooperative, 1994).

Level of soil correction*	Rice + forage millet after grazing,		Rice + sorghum after rice + millet		Soybean + grain millet	
	rice	forage millet	rice	sorghum	soybean	grain-millet
Progressive	3 371	270	1 851	968	2 847	1 184
High, with thermophosphate application	4 997	861	2 982	1 969	3 667	2 240

*:NPK, annual maintenance fertilization (progressive rectification of mineral deficiencies).
Thermophosphate, high corrective fertilization (immediate rectification of mineral deficiencies).

In contrast, in the flattest landscape units with very clayey poor draining soils and 50-60% colloidal content, the straw layer on the soil surface broke down very slowly, at least in the first year of cropping, when sowing was late (Table III-3). In these conditions, even though high crop yields were not sustained when sowing was spread over a 60-day period, this strategy provided total erosion control — an important feature that cannot be obtained with systems involving offset disc tillage. Crop yields were nevertheless the same or higher than could be obtained using cropping systems with any type of tillage technique.

Sorghum in a crop sequence with soybean, direct seeding. Tannin-free white grain variety. Fazenda Progresso.

20 days after direct seeding of soybean on millet mulch cover (millet as starter crop). Fazenda Progresso.

Four-course rotations with annual crop sequences on long-standing cropland

These crop sequences have been very popular with farmers since the outset. This success could be explained by their high agro-economic performance and the fact that they are easy to implement — this cropping system was being used on 2 million ha of land in 1995-96. It was thus essential to find ways of reducing production costs while still achieving high sustainable crop yields.

The results presented below are from a long-term experiment that was conducted on long-standing cropland — 14 years of continuous cropping, which markedly degraded the soil structure. The aim was to optimize mineral fertilization under the dubious economic conditions prevailing in Brazilian frontier farming regions.

Eighteen mineral fertilization treatments were applied in a four-course rotational cropping system with two annual crop sequences involving different direct-seeded crops. The fertilization treatments were designed to progressively correct soil mineral deficiencies, i.e. an agro-economic assessment criterion. The most cost-effective formulas were analysed for yield sustainability and evaluated in relation to results obtained with the most nutrient-rich fertilizers (control).

Agronomic results (Table III-6)

Positive impact of crop rotations

In terms of crop yields, crop rotations always had a greater impact than mineral fertilization.

With soybean, crop yields were positively correlated with the highest quantities of straw left by the starter crop, and this effect was cumulative. However, yields were much lower when soybean was repeated in the crop sequence. These yield increases due to the effects of the thickness of the mulch layer ranged from 17% to 27%, depending on the number of times soybean was repeated in the rotation.

In contrast, rice yields were positively correlated with the frequency of preceding soybean crops. Yields increased spectacularly when soybean was repeated prior to rice in the crop sequence (mean 126% for all fertilizer treatments taken together), in comparison to high biomass-producing preceding crops (rotation III, Table III-6). Indeed, rice yields were found to be negatively correlated with the quantity of straw on the soil surface, i.e. rice yields are lower when there is a high frequency of grass crops in the rotation.

Fertilization: benefits of thermophosphate

A fertilizer with high N-P-K content (25% higher than the recommended fertilizer) was applied along the planting row with rice and soybean crops. This did not prompt a significant increase in rice yields (treatments 7 and 18, Table III-6). However, in all rotations, the best yields and plant-health results were obtained with rainfed rice when fertilizer formulations containing thermophosphate as the basal ingredient were applied every 2 or 3 years (treatments 14 and 16, Table III-6).

Table III-6. Effects of interactions between fertilizers and rotations on rainfed rice yields (cv CIAT 20) and the economic impact. The data correspond to the crop sequence used in the third year of rotations, i.e. rice + sorghum. Tests carried out in actual operational conditions, on 16 ha in Fazenda Progresso (Lucas do Rio Verde, Mato Grosso).

Fertilizer (codes)	Yields (kg/ha)				Production costs (US$/ha)		Net margins (US$/ha)	
	Rotation I		Rotation III		Rotation I	Rotation III	Rotation I	Rotation III
	rice	sorghum	rice	sorghum				
n° 2	2 108	501	5 308	614	444	508	- 141	+ 324
n° 5	2 205	727	5 308	880	421	485	- 82	+ 370
n° 7	2 170	915	5 523	1 020	482	553	- 168	+ 334
n° 14	2 564	786	5 469	1 279	491	553	- 102	+ 342
n° 16	3 489	1 836	6 622	2 112	596	661	- 2	+ 462
n° 18	2 194	654	5 142	924	446	507	- 118	+ 319
Mean	2 545	902	5 562	1 138	480	544	- 102	+ 358

Rotations

Rotation I: rice + sorghum - soybean + sorghum - rice + sorghum - soybean

Rotation III: soybean + sorghum - soybean - rice + sorghum - soybean

This table shows the results obtained for year 3 with each rotation.

Fertilizers applied at sowing

All formulations contain the same nitrogen levels for blanket applications on rice and soybean crops (65 kg/ha).

N° 2, recommended NPK fertilizer, without dolomitic limestone (400 kg/ha at 0-20-20 + trace elements on soybean; 400 kg/ha at 4-20-20 + trace elements on rice).

N° 5, 1.5 t/ha ground dolomitic limestone every 3 years + NPK fertilizer (250 kg/ha at 0-20-20 + trace elements on soybean; 250 kg/ha at 4-20-20 + trace elements on rice).

N° 7, strong NPK fertilizer (500 kg/ha at 0-20-20 + trace elements on soybean; 500 kg/ha at 4-20-2 + trace elements on rice) + 1.5 t/ha limestone every 3 years.

N° 14, 1.5 t/ha of thermophosphate every 3 years + 600 kg/ha gypsum every 2 years + 100 kg/ha KCl/year (+N when rice sown)

N° 16, 1.5 t/ha thermophosphate and 600 kg/ha gypsum every 2 years + 100 kg/ha KCl/year (+N when rice sown).

N°18, in the first year, 500 kg/ha granulated thermophosphate + NPK formulation of fertilizer N°7; then mixed formulation (200 kg/ha at 2-20-20 + 200 kg/ha single superphosphate + 80 kg/ha KCl + 20 kg/ha trace elements on soybean; 200 kg/ha at 4-20-20 + 200 kg/ha granulated thermophosphate + 70 kg/ha KCl + 20 kg/ha trace elements on rice).

Cropping techniques

All crops are sown by direct seeding, except rice, which is preceded by deep scarification, leaving more than 50% preceding crop residue on the soil surface.

Direct seeding on soybean crop residue. Fazenda Progresso.

In addition to a high biomass-producing starter crop, soybean requires a thermophosphate + gypsum based fertilizer or formulations combining thermophosphate and soluble P-K-S — sulphur is an essential nutrient for this crop.

Importance of successful starter crops

It is important to have a well established biomass-producing starter crop. In moisture-deficient conditions, above-ground organic matter mineralization is a very slow process, and temporarily reduces moisture supplies to the main crop, in addition to the problem of nitrogen immobilization. This situation often arises after very early sowing, when the first effective rains occur. In such cases, a rectifying starter fertilizer (100 kg/ha ammonium sulfate) should be applied under the planting row.

Flexible equipment handling

Labour capacity and equipment handling flexibility are much better with direct seeding. For instance, after a single 80 mm rainfall, the crop can be direct seeded within 6 h after the rains have stopped. Similarly, when the soil is waterlogged during the rainy season, the crop can be direct seeded after 1 h without precipitation, and there will be no negative impact on crop yields.

Economic results (Table III-7)

Of all of the fertilizers assessed, the best mean increases in farmers' returns and the most sustained mean net margins were obtained with the following formulations (compared to common fertilizers):

– in rotation I (rice + sorghum - soybean + sorghum - rice + sorghum - soybean), with application of a basal dressing of 1500 kg/ha thermophosphate + 600 kg/ha gypsum (treatment 14, Table III-7);

– in rotation II (soybean + sorghum - soybean + sorghum - soybean + sorghum – soybean), with application of a mixed dressing of thermophosphate + soluble N-P-K, or the formulation involving 500 kg/ha single superphosphate + 100 kg/ha KCl on soybean (treatment 18, Table III-7);

– in rotation III (soybean + sorghum - soybean - rice + sorghum - soybean), with application of annual formulations of 500 kg/ha single superphosphate + 100 kg/ha KCl and the mixed formulation of thermophosphate + soluble N-P-K, or 1 000 kg/ha thermophosphate + 600 kg/ha gypsum as basal dressing for 3 years (treatments 14, 16, 18, Table III-7).

The mean net margins obtained using formulations with low manure content (treatment 5, Table III-7) were equal to or higher than margins obtained with common fertilizers. However, there was no increase in these margins for any of the rotations when the soluble fertilizer with high N-P-K content was used (treatment 7, Table III-7).

The cost of direct seeding millet as a starter crop before soybean was found to be equal to or slightly lower than that required for tillage with an offset disc cultivator or mouldboard plough, i.e. slightly less than US$50/ha in 1996, thus highlighting one of the benefits of using this technique.

Table III-7. Mean ne
fertilizer, in four rot
all crops in each rot

Fertilizer (codes)	net margir
n° 2	+ 64
n° 5	+ 67
n° 7	+ 40
n° 14	+ 143
n° 16	+ 118
n° 18	+ 90

Rotations
Rotation I: rice + so
Rotation II: soybean
Rotation III: soybea
Rotation IV: soybea

Fertilizer treatment
These are detailed i

Cropping technique
All crops are sown l
residue on the soil s

Direct seeding of soybean in a crop sequence after maize. Fazenda Taffarel, Sinop, Mato Grosso state.

Paspalum sward, 50 days after a soybean harvest, at the beginning of the dry season. COOPERLUCAS, Mato Grosso state.

t margins and net marginal gains (US$/ha) for the best mineral fertilizers relative to the recommended ations with annual crop sequences sown by direct seeding. The data correspond to mean results obtained for ation over 4 years (Fazenda Progresso, Mato Grosso).

Rotation I			Rotation II			Rotation III			Rotation IV		
gain	CV %	net margin	gain	CV %	net margin	gain	CV %	net margin	gain	CV %	net margin
+ 49	227	+ 102	+ 27	27	+ 153	+ 12	74	+ 118	+ 45	49
+ 28	155	+ 80	+ 2	66	+ 165	+ 19	86	+ 85	+ 6	79
- 16	352	+ 73	- 7	70	+ 152	+ 3	80	+ 105	+ 21	39
+ 91	123	+ 104	+ 25	45	+ 175	+ 42	64	+ 132	+ 67	115
+ 70	103	+ 112	+ 33	58	+ 176	+ 46	111	+ 93	+ 33	114
+ 45	164	+ 123	+ 47	42	+ 170	+ 48	66	+ 90	+ 35	83

ghum - soybean + sorghum - rice + sorghum - soybean.
+ sorghum - soybean + sorghum - soybean + sorghum - soybean.
+ sorghum - soybean - rice + sorghum - soybean.
- rice + sorghum - soybean - rice.

s
Table III-6.

s
y direct seeding, except rice, which is preceded by deep scarification, leaving more than 50% preceding crop urface.

Farmers' choices

Ultimately, rotation choices are based on price conditions affecting farmers (e.g. prices paid for harvested crops, credit interest rates, investments for corrective phosphate fertilization and direct seeding machinery). Simulation analyses have been carried out regularly to provide a decision support tool to assist farmers, cooperatives, banks and farm policy authorities. These data have been widely used, thus promoting rapid extension of economically sustainable soybean-based direct-seeding cropping systems.

Integrating livestock production and agriculture

Agriculture and livestock production as separate activities. Southern Goás state.

Mato Grosso state has 15 million ha of natural and cultivated rangelands, grazed by a herd of about 10.5 million head of livestock (mainly zebu cattle). This herding is done on an extensive basis, with less than 0.5/ha of cattle. Grain production and livestock production activities are completely separate.

Integrating livestock production and farming can cost-effectively enhance agronomic soil management in terms of the high quantity of biomass produced by fodder grass crops (e.g. *Brachiaria brizantha* and *Panicum maximum*) that is left on the soil surface and in the cultural profile. It should be possible to develop reproducible systems involving rotations with direct-seeded grain-producing crops and forage-grass rangelands which are less dependent on economic conditions and provide complete soil protection.

Since 1990, two complementary strategies have been assessed in the experimental unit at Fazenda Progresso:
– rotations, for two consecutive periods (3-4 years), grain production systems and livestock production systems;
– annual crop sequences with grain and forage crops, with crops seeded on permanent plant cover which is used for grazing purposes after harvest.

Nelore cattle in *Panicum maximum* grazingland, Fazenda Progresso.

Rotations: 3-4 years of cropping and 3-4 years of rangeland

At Fazenda Progresso, the two steps below are now fully controlled:
– using land for grazing after the main crop has been harvested, for a period of 3-4 consecutive years;
– growing grain crops on former rangeland, for a period of 3-4 consecutive years.

Direct seeding of sward

Soybean and rice crops are sown early in October and harvested in late February. Grassland is direct seeded gradually as these crops are harvested. *Panicum maximum* (cv Tanzânia) or *Brachiaria brizantha* (cv Brizantão) are planted with seed that has been pretreated with fungicides (thiabendazole + thirame).

This system was set up on 400 ha at Fazenda Progresso, with excellent results. There was a stocking rate of 2.2/ha of 27 month-old steers during the dry season (84 days), with an average daily gain of 423 g/head. In the rainy season, there was a stocking rate of 4-6/ha head of cattle with rotational grazing and electric fencing. All of the zootechnical indices were much better than could be obtained with traditional extensive livestock production systems (Table III-8).

Table III-8. Zootechnical indices for traditional livestock production and livestock production integrated in crop rotations (Fazenda Progresso, Mato Grosso, 1995).

Index	Traditional system	Integrated system
Birth (%)	55	85
Mortality (%)	10	5
Age at slaughter (years)	4	2 to 2.5
Weight at slaughter (kg)	255	245
Interval between calving (months)	22	14

In 1995, Fazenda Progresso had a herd of 1 500 head of cattle grazing on 400 ha of grassland that had been growing since 1990. This grazingland showed no signs of degradation after 4 years of intensive grazing without any maintenance fertilization. This highlights the incredible potential of these soils when managed reasonably with direct seeding, and the use of renewable biomass is encouraged.

Changing from grazingland to cropland

At the end of the rainy season (mid-April), livestock is let out into the grassland at a high stocking rate, with the aim of grazing it back as much as possible. Farmers then have three options for cultivating this grazingland.

The first option involves ploughing under the grass cover with a heavy offset cultivator, followed by deep finishing tillage with a mouldboard plough. The farmer then undertakes two operations at the beginning of the following rainy season: the tilled field is prepared using a tine cultivator and sown with rainfed rice. The 3-year rotational crop sequence using direct seeding is as follows:

– 1st year, rice + sorghum in sequence;

– 2nd year, millet starter + soybean + sorghum follower in sequence;

– 3rd year, millet starter + soybean + sorghum and/or millet in sequence.

The second option involves a non-selective herbicide treatment (glyphosate at 1440 g/ha dosage) at the end of the rainy season. Several operations are then carried out in succession: when the next rains occur, glyphosate is applied to volunteer vegetation and other emerging plants (720 g/ha); then soybean is direct seeded, with possible herbicide control of volunteer vegetation using fluazifop P butyl or another soybean selective graminicide (quizalofop, fenoxaprop, etc.).

The third option involves tillage with a Paraplow (an oblique-tined decompacting implement) at the end of the rainy season (early May), which destroys the root systems while not upsetting the cultural profile. At the next rains, glyphosate is applied to volunteer vegetation and other emerging plants (720 g/ha), then soybean is direct seeded, with possible herbicide control of volunteer vegetation using fluazifop P butyl. Grain crops can then continue being grown for another 3-4 years (6-8 successive crops), and then a grass crop is direct seeded to provide grazingland for the next 3-4 consecutive years. Note that at Fazenda Progresso an assessment of root profiles undertaken after 18 months under *P. maximum* Tanzânia cover revealed deep rooting (deeper than 2.5 m), with roots containing high exudate levels from 80 cm depth.

Function of grassland as vegetative soil cover

In annual grain crop and grassland sequences, the crop is planted on permanent sward sustained by rhizomes, stolons or seeds (Figure III-3). This plant cover is mainly made up of other species, especially weeds, which could provide high quality forage. These species include: grasses - *Cynodon dactylon* (especially hybrid Tifton varieties), *Paspalum notatum* (many varieties), *Pennisetum clandestinum* (several varieties), *Axonopus, Stenotaphrum* species, etc.; legumes - *Arachis pintoi, A. repens, Lotus uliginosus, L. corniculatus, Trifolium semipilosum, Tephrosia pedicellata, Calopogonium mucunoides, Stizolobium aterrinum, Pueraria phaseoloides,* etc.

Table III-9. Mean organic matter levels after 3 years of direct seeding, on *Paspalum* sp. sward or straw (Fazenda Progresso, Mato Grosso, 1992).

Soil horizon (cm)	Organic matter (%) under residue (straw)	under sward *(Paspalum)*
0-10	2.5	3.1
10-20	2.7	3.3
20-30	2.6	3.2

Every year, after the grain harvest at the beginning of the dry season, the sward is used for grazing or hay cropping — this is the period when fodder is most needed.

Crop and sward establishment techniques

The overall goal is to establish a sward in a cropfield (by seeding or cuttings, depending on the species) so as not to immobilize the productive area. Early competition between the crop and the colonizing sward is hindered by herbicides or selective growth regulators, until the crop manages to cover the soil completely. Competition is thus minimized under the shade of the crop. After harvest, the sward quickly takes over and can then be grazed, or harvested for hay if legumes or Bermuda grass are growing. The next year, when the vegetation begins growing again after the first rains, the herbicide paraquat is applied twice at 5 day intervals (200 g/ha, then 100-200 g/ha) to control perennial grasses. Soybean is then direct seeded and the herbicide fluazifop P butyl is used post-emergence at low dosages (72 g/ha active ingredient) in order to avoid destroying the rhizomes, until the point when the soybean crop covers the soil completely. Soybean varieties with high initial vegetative development should be cropped in these conditions. This system reduces production costs by around 30% in comparison to the system involving direct seeding on rice straw. It can be further improved by using a growth regulator at low dosage, e.g. mefluidide at 100 g/ha on *Pennisetum clandestinum*, instead of a contact herbicide prior to direct seeding a soybean crop. Efficient herbicide treatment techniques are now available for most annual crops using this permanent system (soybean, maize and sorghum). Cropping operations are minimized, i.e. contact herbicides are applied immediately before direct seeding, with post-emergence herbicides applied at low dosage at harvest.

Direct seeding system, maize + Calopogonium, Fazenda Progresso.

This system is also excellent for supplying organic matter to the red-yellow ferrallitic soils in humid frontier agricultural areas of western Brazil (Table III-9). In addition, some comparable results obtained in Brazil, Africa, Madagascar and Réunion indicate that this type of system is best for promoting very high fauna activity. This is clearly exemplified by case of the dung beetle *Diloboderus abderus*, which thrives on *Calopogonium* sward in Fazenda Progresso. In acid ferrallitic and allophane soils, earthworms survive very well under stolon-producing grasses such as *Paspalum* and *Pennisetum* species (Séguy *et al.*, 1992; Michellon & Perret, 1996).

An example of a system with *Calopogonium mucunoides* and a short-season crop

The system involving a sequence of *Calopogonium* + maize or sorghum or short-season rice is not grazed, but it can be under dry conditions. The advantage of this system is that it efficiently reduces production costs for cereal-based systems. It was first used at Fazenda Progresso, and very high maize yields were thus obtained during the 1986-1992 period (6.5 t/ha). It was more recently tested at the Cooperlucas experimental unit, where maize yields of more than 9.2 t/ha were obtained in 1994. From 1989 to 1992, in the pre-Amazon region and within the framework of an AGRIPEC project, implementation of this system reduced mineral fertilizer and herbicide doses by half — it was only necessary to apply them every other year with the following rotation: maize + *Calopogonium* (with inputs) - sorghum + *Calopogonium* (without inputs).

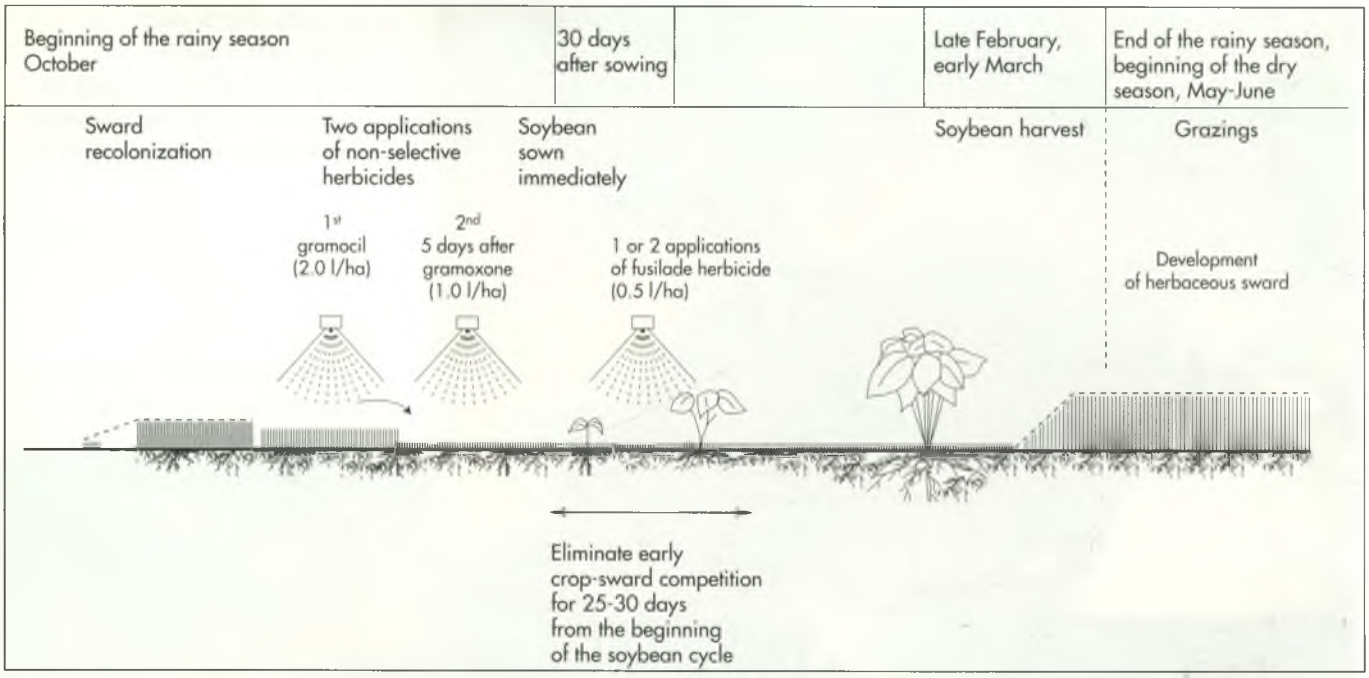


Figure III-3. Cropping systems + permanent herbaceous forage cover. These systems are based on direct seeding, combining livestock production and grain crops. The example shown here is a main soybean crop on a sward of *Paspalum notatum* cv. Pensacola.

Calopogonium is broadcast-sown (mixed with fertilizer) at the same time as the main crop. The pre-emergence herbicides pendimethaline and alachlore are *Calopogonium*-selective in rice and maize cropfields, respectively. After the cereal crops are harvested, *Calopogonium* completely covers the soil at a rate of 8-10 t/ha of dry matter, in addition to the crop residue that is present. *Calopogonium* seeds fall on the ground at maturity and germinate during the next cycle, thus ensuring its survival. The next year, the contact herbicide diquat (or triclopyr, fluoroxypyr — which is selective for maize) can be used before direct seeding operations. The same sequences can be used with legume species belonging to the following genera: *Pueraria, Tephrosia, Centrosema, Macroptilium, Stizolobium, Dolichos,* etc.

Rural redevelopment

In all of the frontier agriculture areas, mechanization has systematically led to almost total deforestation, apart from the gallery forests growing along the rivers. This has left vast barren areas that are now susceptible to the winds, erosion, and the predators are disappearing, etc.

These open rural areas should be redeveloped by planting new forest stands, which act as climatic and biological regulators. Since 1992, CIRAD has been conducting experiments on this topic in frontier agriculture areas of western Brazil. Two strategies are currently being investigated. The first involves building wide-based terraces for the purposes of erosion control. At the top (to avoid bothering mechanized cultivation operations), 1 m wide strips are planted with high biomass-producing and drought-resistant forage species, such as Bana grass, a sterile hybrid of *Pennisetum purpureum* and *P. typhoides, P. purpureum* and *Tripsacum laxum* — it is essential that these species produce vegetatively (cuttings) in order to avoid polluting the cropfields. The second strategy also involves wide-base terraces, but maize or sorghum crops are sown

Cultural profile after 5 years of continuous direct seeding. Intense biological activity: 20 galleries per square metre, bored by coleopteran dung beetle larvae. Fazenda Progresso.

Cultural profile under a millet starter crop, 45 days after sowing. Maeda, Fazenda Recanto, Goiás state.

Nodulation in a soybean crop that was direct seeded in millet mulch. Fazenda Progresso.

Direct seeding of rainfed rice on rainfed millet + *Calopogonium* mulch. Sulamerica Project, Piauí state.

with the arrival of the first rains. After the maize or sorghum crops are harvested (grain or silage), short-season millet is direct seeded on part of the terrace for the purposes of grain production. Non-photosensitive millet or long-season sorghum crops are planted on the other part to produce high quantities of green fodder for the dry season. This green fodder can be used as mulch — to recycle organic matter on the soil surface and protect the soil — or to provide green or ensiled fodder for livestock.

Conclusion

The keystone: direct seeding and cover crops

Agrobiological soil management is based on tropical rain forest processes and tailored to agricultural activities. The high quantity of crop residue biomass left on the soil surface, along with the annual biomass produced by starter and follower crops, protects the soil completely against erosion. The latter crops are direct seeded before or subsequent to the main cash crop, and act as biological pumps for the benefit of the main crop. These starter and follower crops also maintain and minimize loss of soil mineral reserves, while sustaining the structure of the cultural profile and enhancing weed, pest and disease control.

Three types of cropping systems assessed in Brazil

Three types of cropping systems were set up and tested:

– grain production systems with direct-seeded annual two-crop sequences (one main crop + one starter and/or follower crop that act as biological pumps). These are millet + soybean + sorghum and/or millet, soybean + sorghum and/or millet, rice + sorghum and millet, crotalaria + rice crop sequences, which can be organized in various types of crop rotations, depending on the economic constraints;

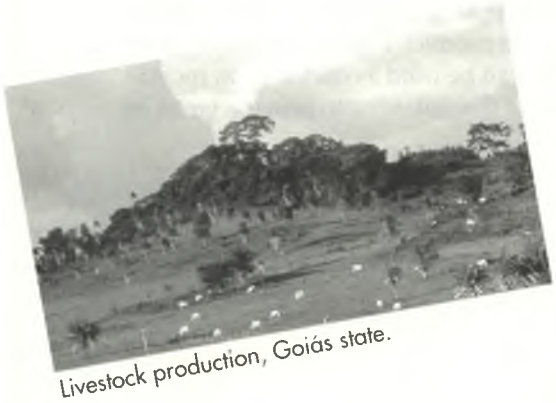
– the systems involve rotations with direct-seeded grain crops (for 3-4 years) followed by grazings (for 3-4 years);

–permanent grain production systems on perennial swards, which are either grazed or mowed yearly following the grain harvest.

Biological factors determining high crop yields

The agroeconomic results obtained with direct-seeded annual two-crop sequences highlighted that biological factors are crucial for obtaining high sustainable yields, cost-effectively, under conditions with 2000-3000 mm annual precipitation, on ferrallitic soils in savanna and forest zones of western Brazil.

As long as it is not limiting, the level of mineral fertilization was found to be of secondary importance, whereas the organic matter management technique is vital. Very little fertilizer is required with these direct seeding systems with respect to the high yields obtained per unit area. Acidity (aluminium toxicity) can be easily rectified since the cropping system is "closed", in the same way as forest ecosystems — with minimal nitrogen, potassium, calcium and magnesium loss.


Livestock production, Goiás state.

More efficient use of machinery and lower production costs

Thanks to the direct seeding techniques used, combined with better cropping-calendar planning (staggered sowing and harvesting dates), the capacity of mechanized equipment is 1.5- to 1.8-fold higher than with traditional cropping systems, with high operational flexibility. Production costs are more than 20% lower than with cropping systems involving tillage.

Almost immediate adoption: 2.2 million hectares within 5 years

Farming systems that combine grain cropping with livestock production are still in the experimental stage and have not yet been widely adopted by farmers. Nevertheless, these systems show considerable promise for cost-effectively tapping the moisture and photosynthetic potential of humid tropical frontier agriculture zones. Farmers, however, are quite interested in the direct-seeded annual two-crop sequences that have undergone long-term evaluation. In 1997, these technologies are being implemented on more than 60% of the cropping area in frontier regions of Brazil. Indeed, from 1991 to 1997, the use of these strategies increased to the extent that they have now been adopted on 2.2 million ha of cropland, mainly in the states of Goiás (with rainfall ranging from 1 200 to 1 600 mm/year), Mato, and Mato Grosso do Sul — extending far beyond the framework of the present project.

Sustainable agriculture and forest conservation

Technical and agronomic solutions are available to tap the potential of this vast reservoir of acid soils in the humid tropical zone of Brazil. The cropping systems developed here should help improve agricultural sustainability, diversification, cost-effectiveness, while conserving and increasing the soil potential. Even more than alternative practical solutions, new Brazilian agricultural policies are needed to ensure the successful adoption of these techniques by farmers. For the benefit of the Brazilian economy, these policies should be drawn up as soon as possible in order to take advantage of the rich granery existing in humid savanna regions of the western part of the country. This situation is quite urgent as the agricultural frontier has now reached the edge of the Amazon forest. This support for sustainable agriculture in savanna zones is chiefly aimed at conserving the forest in the coming years. Finally, these agrobiological soil management systems, adapted to Brazilian agricultural frontiers, have already been assessed on broad surface areas — they could thus now be transferred for the purposes of enhancing agriculture in other tropical regions of the world.


Forest-savanna interface, Sorriso prefecture, Mato Grosso state.

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Abstract

L. SEGUY, S. BOUZINAC, A. TRENTINI, N. A. CORTES — **Brazilian frontier agriculture.**

I- The agricultural innovation extension method.

II- Managing soil fertility with cropping systems.

III- Direct seeding, an organic soil management technique.

Since the 1980s, Brazilian agriculture has extended to the humid tropical edge of the Amazon basin in western Brazil and onto the acid soils of the savanna *(cerrados)* where annual rainfall ranges from 2 000 to 3 000 mm. Frontier farmers, coming from the southern states, have introduced soybean monocultures and disc tillage techniques to develop highly mechanised farms of 200-2 000 ha. These farming practices have caused soil erosion on a catastrophic scale. Since 1986, the Franco-Brazilian research team and its development partners have demonstrated the extent of cropland degradation and the economic isolation of these areas. A participatory method of agricultural development, known as innovation-extension, has been developed in the western cerrados and a number of other regions of Brazil. The aim of innovation-extension is to propose cropping systems to farmers and professional agents in agricultural subsectors that are compatible with sustainable regional development and which can be reproduced inexpensively on a large scale. This experience has revealed that fertility management for degraded acid soil cannot be separated from economic risk, which has led to the development of a wide range of diversified agricultural systems now spread over more than 2 Mha of land in western and central western Brazil. Crop diversification is based on the production of one or two cereal or forage crops per year (soybean, rainfed rice, maize, sorghum, millet, leguminous crops, forage grasses, cover crops, etc.), which may be associated with livestock production. Annual crop sequences are integrated into 3 or 4 year rotations. The most productive and innovative systems all use direct seeding: the main commercial crops — soybean, rainfed rice, maize — are sown directly into a well-established and inexpensive cover crop such as millet, sorghum or crotalaria, which precedes and succeeds the main cash crop. These cover crops produce cereals or fodder and a large amount of biomass which is necessary for maintaining fertility. In this way there is permanent plant cover to protect the soil from erosion. Cover crops are important in recycling nutrients that have been leached deep into the soil and thus there is minimum nutrient loss in the soil-plant system. Yields of more than 6 t of maize, 3-4 t of soybean and more than 4 t of rainfed rice per hectare have been attained. Farmers regard these systems as productive, profitable, stable and consider that they optimise and offer flexibility for the use of machinery.

Key words: regional agricultural diagnostic survey, modelling, cropping system, erosion, soil fertility, direct seeding, cover crop, fertilisation, upland rice, soybean, maize, millet, sorghum, humid tropics, Brazil.

Résumé

L. SEGUY, S. BOUZINAC, A. TRENTINI, N. A. CORTES — **L'agriculture brésilienne des fronts pionniers.**

I- La méthode de création-diffusion agricole.

II- La gestion de la fertilité par le sytème de culture.

III- Le semis direct, un mode de gestion agrobiologique des sols.

Les fronts pionniers agricoles du Brésil ont atteint, depuis les années 80, la zone tropicale humide de l'ouest en bordure du bassin amazonien, en savanes *(cerrados)* de sols acides, sous une pluviométrie annuelle comprise entre 2 000 et 3 000 millimètres. Les agriculteurs pionniers, venus des Etats du sud, ont apporté leur pratique de travail du sol aux disques et la monoculture de soja, en mettant en valeur des exploitations fortement motorisées, de 200 à 2 000 hectares. Ce système a conduit à une érosion catastrophique du sol. La recherche franco-brésilienne et ses partenaires du développement sont intervenus à partir de 1986 et ont mis en évidence les dégradations du milieu cultivé, ainsi que l'isolement économique de ces zones. Une démarche agronomique participative, appelée création-diffusion, a été élaborée dans différentes régions brésiliennes, dont les *cerrados* de l'ouest. Elle a pour but essentiel de proposer aux agriculteurs et aux professionnels des filières agricoles des systèmes de culture compatibles avec un développement régional durable, reproductibles à grande échelle et au moindre coût. Cette expérience souligne que la gestion de la fertilité des sols acides dégradés ne peut être dissociée de celle du risque économique, qui passe nécessairement par la mise au point d'un large choix de systèmes diversifiés, aujourd'hui diffusés sur plus de 2 millions d'hectares dans l'ouest et dans le centre-ouest du Brésil. Sur le plan de la diversification des cultures, ils s'appuient sur la production de grains ou de fourrages (soja, riz pluvial, maïs, sorgho, mil, légumineuses et graminées fourragères, plantes de couverture...), associée ou non à l'élevage, à raison d'une ou deux cultures par an. Les successions annuelles sont intégrées dans des rotations triennales ou quadriennales. Sur le plan des techniques culturales, les systèmes les plus performants et novateurs utilisent systématiquement le semis direct : les cultures principales commerciales — soja, riz pluvial, maïs — sont implantées en semis direct sur d'importantes couvertures végétales fournies, au moinde coût, par des cultures de mil, de sorgho ou de *Crotalaria* qui précèdent et succèdent la spéculation principale. Celles-ci fournissent grains ou fourrages et surtout une grande quantité de biomasse nécessaire à l'entretien de la fertilité ; elles assurent une couverture végétale permanente du sol cultivé, le protégeant totalement de l'érosion. Elles sont de puissants recycleurs des éléments nutritifs lixiviés en profondeur ; les pertes en éléments fertilisants dans le système sol-plante sont minimales. Les rendements obtenus atteignent plus de 6 tonnes par hectare en maïs grain, 3 à 4 tonnes en soja et plus de 4 tonnes en riz pluvial. Du point de vue de l'agriculteur, ces systèmes apparaissent productifs, lucratifs, stables et offrent une capacité accrue des équipements et une meilleure flexibilité d'utilisation.

Mots-clés : diagnostic agronomique régional, modélisation, système de culture, érosion, fertilité du sol, semis direct, plante de couverture, fertilisation, riz pluvial, soja, maïs, mil, sorgho, zone tropicale humide, Brésil.

Resumen

L. SEGUY, S. BOUZINAC, A. TRENTINI, N. A. CORTES — **La agricultura brasileña de los frentes colonizadores.**

I. El método de creación-difusión agrícola.

II. La gestión de la fertilidad por el sistema de cultivo.

III. La siembra directa, un modo de gestión agrobiológica de los suelos.

Desde los años ochenta, los frentes colonizadores agrícolas del Brasil han alcanzado la zona tropical húmeda del oeste a orillas de la cuenca amazónica, en sabanas *(cerrados)* de suelos ácidos, bajo una pluviometría anual comprendida entre 2 000 y 3 000 milímetros. Los agricultores colonizadores, procedentes de los Estados del sur, han aportado su práctica laboral del suelo con discos y el monocultivo de soja, valorizando así las explotaciones muy motorizadas de 200 a 2 000 hectáreas. Sin embargo, este sistema ha generado una erosión catastrófica del suelo. La investigación franco-brasileña y sus colegas del desarrollo intervinieron a partir de 1986, poniendo de relieve las degradaciones del medio cultivado, así como el aislamiento económico de dichas zonas. Se ha implantado una acción agronómica participativa, llamada creación-difusión, en diferentes regiones brasileñas, incluidos los *cerrados* del oeste. Su principal objetivo es proponer a los agricultores y los profesionales de los sectores agrícolas sistemas de cultivo compatibles con un desarrollo regional duradero, reproducibles a gran escala y al menor costo. Esta experiencia subraya el hecho de que la gestión de la fertilidad de los suelos ácidos degradados no puede disociarse de la del riesgo económico, que requiere necesariamente poner a punto una amplia variedad de sistemas diversificados, que hoy se difunden en más de dos millones de hectáreas en el oeste y el centro-oeste del Brasil. En lo referente a la diversificación de los cultivos, ésta se basa en la producción de granos o forrajes (soja, arroz de secano, maíz, sorgo, mijo, leguminosas, gramíneas forrajeras, cultivos de cobertura, etc.), asociada o no a la ganadería, a razón de uno o dos cultivos por año. Las sucesiones anuales se integran en rotaciones trienales o cuadrienales. Respecto a las técnicas de cultivo, los sistemas más eficaces e innovadores utilizan sistemáticamente la siembra directa: los principales cultivos comerciales (soja, arroz de secano, maíz) se implantan en siembra directa sobre vastas coberturas vegetales proporcionadas, al menor costo, por cultivos de mijo, sorgo o cáñamo de Bengala, que preceden o suceden a la especulación principal. Estas plantas suministran granos o forrajes y, sobre todo, gran cantidad de biomasa necesaria para la conservación de la fertilidad; además, proporcionan una cobertura vegetal permanente del suelo cultivado, protegiéndolo totalmente de la erosión, y son potentes recicladores de los elementos nutritivos lixiviados profundamente. Las pérdidas de elementos fertilizantes en el sistema suelo-planta son mínimas. Los rendimientos obtenidos alcanzan más de 6 toneladas por hectárea de maíz en grano, entre 3 y 4 toneladas de soja y más de 4 toneladas de arroz de secano. Desde el punto de vista del agricultor, estos sistemas parecen productivos, lucrativos y estables, ofrecen una mayor capacidad de los equipos y una mejor estabilidad de utilización.

Palabras clave: diagnóstico agronómico regional, modelización, sistema de cultivo, erosión, fertilidad del suelo, siembra directa, cultivo de cobertura, fertilización, arroz de secano, soja, maíz, mijo, sorgo, zona tropical húmeda, Brasil.

Resumo

L. SEGUY, S. BOUZINAC, A. TRENTINI, N. A. CORTES — **A agricultura brasileira das frentes pioneiras.**

I- O método de criação-difusão de tecnologias.

II- A gestão da fertilidade pelo sistema da cultura.

III- O plantio direto, um modo de gestão agrobiológica dos solos.

As fronteiras agrícolas do Brasil, alcançaram, desde os anos 80, os trópicos úmidos do Oeste, na margem da floresta amazónica, nos cerrados de solos ácidos, sob uma pluviometria anual entre 2 000 e 3 000 mm. Os agricultores pioneiros, vindos dos estados do sul, trouxeram as suas práticas de preparo do solo com grades e a monocultura da soja, explorando fazendas altamente mecanizadas, de 200 à 2 000 hectares. Este sistema levou a uma erosão catastrófica do solo. A pesquisa francobrasilera e seus parceiros do desenvolvimento interviram a partir de 1986 e evidenciaram as degradações do meio cultivado, como também o isolamento econômico destas zonas. Um enfoque agronômico participativo, chamado de criação-difusão, foi elaborado em diferentes regiões brasileiras, entre elas os cerrados do oeste. Ele tem como meta essencial de propor aos agricultores e aos profissionais do setor agroalimentar sistemas de culturas compatíveis com um desenvolvimento regional sustentável, reprodutíveis em grande escala e a custo mínimo. Esta experiência destaca que a gestão da fertilidade dos solos ácidos degradados, não pode ser dissociada da gestão do risco econômico, que passa necessariamente pelo ajuste de uma larga escolha de sistemas diversificados, difundidos hoje em mais de 2 milhões de hectares no oeste e centro-oeste do Brasil. No plano da diversificação das culturas, eles são construidos sobre a produção de grãos ou de forragens (soja, arroz de sequeiro, milho, sorgo, milheto, leguminosas e gramíneas forrageiras, plantas de cobertura, etc.) associada ou não a pecuária, à proporção de 1 a 2 culturas por ano. Estas sucessões anuais estão integradas em rotações trienais ou quadrienais. No plano das técnicas culturais, os sistemas mais performantes e inovadores utilizam a prática sistemática do plantio direto ; as culturas principais : soja, arroz, milho, são implantadas com plantio direto sobre importantes coberturas vegetais, fornicedas a custo mínimo, por culturas de crescimento rápido que precedem a cultura principal e são cultivadas também em sucessão da mesma no final do estação chuvosa (milhetos, sorgos, crotalárias). Estas fornecem grãos e forragens e sobretudo uma grande quantidade de biomassa necessária a manutenção da fertilidade ; elas garantem uma cobertura vegetal permanente do solo cultivado. Elas o protegem totalmente contra a erosão por uma forte biomassa renovável a custo mínimo. Além disso, elas são possantes recicladores dos elementos nutritivos lixiviados em profundidade. As perdas em elementos fertilizantes no sistema solo-planta são minimas. As produtividades alcançam mais de 6 toneladas por hectare de milho grão, 3 a 4 toneladas de soja, e mais de 4 toneladas de arroz de sequeiro. Do ponto de vista do agricultor, os sistemas mostram-se produtivos, lucrativos, estáveis e oferecem uma maior capacidade dos equipamentos e uma melhor flexibilidade de utilização.

Palavras-chaves: diagnóstico agronômico regional, modelização, sistema de cultura, erosão, fertilidade do solo, plantio direto, planta de cobertura, fertilização, arroz de sequeiro, soja, milho, sorgo, trópicos úmidos, Brasil.

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