A Contribution to Agronomic Knowledge of the Lower Casamance (Bibliographical Synthesis)

by

J. L. Posner

Reprint No. 17 1988

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SPECIAL NOTE FOR ISRA-MSU REPRINTS

In 1982 the faculty and staff of the Department of Agricultural Economics at Michigan State University (MSU) began the first phase of a planned 10 to 15 year project to collaborate with the Senegal Agricultural Research Institute (ISRA, Institut Sénégalais de Recherches Agricoles) in the reorganization and reorientation of its research programs. The Senegal Agricultural Research and Planning Project (Contract 685-0223-C-00-1064-00), has been financed by the U.S. Agency for International Development, Dakar, Senegal.

As part of this project MSU managed the Master's degree programs for 21 ISRA scientists at 10 U.S. universities in 10 different fields, including agricultural economics, agricultural engineering, soil science, animal science, rural sociology, biometrics and computer science. Ten MSU researchers, on long-term assignment with ISRA's Department of Production Systems Research (PSR, Département de Recherches sur les Systèmes de Production et le Transfert de Technologies en Milieu Rural) or with the Macro-Economic Analysis Bureau (BAME, Bureau d'Analyses Macro-Economiques) have undertaken research in collaboration with ISRA scientists on the distribution of agricultural inputs, cereals marketing, food security, farm-level production strategies and agricultural research and extension. MSU faculty have also advised junior ISRA scientists on research in the areas of animal traction, livestock systems and farmer groups.

Additional MSU faculty members from the Department of Agricultural Economics, Sociology, Animal Science and the College of Veterinary Medicine have served as short-term consultants and professional advisors to several ISRA research programs.

The project has organized several short-term, in-country training programs in farming systems research, agronomic research at the farm-level and field-level livestock research. Special training and assistance has also been provided to expand the use of micro-computers in agricultural research, to improve English language skills, and to establish a documentation and publications program for PSR Department and BAME researchers.

Research publications from this collaborative project have been available only in French. Consequently, their distribution has been limited principally to West Africa.

In order to make relevant information available to a broader international audience, MSU and ISRA agreed in 1986 to publish selected reports as joint ISRA-MSU International Development Paper Reprints. These reports provide data and insights on critical issues in agricultural development which are common throughout Africa and the Third World. Most of the reprints in this series have been professionally edited for clarity; maps, figures and tables have been redrawn according to a standard format. All reprints are available in both French and English. A list of available reprints is provided at the end of this report. Readers interested in topics covered in the reports are encouraged to submit comments directly to the respective authors, or to Dr. R. James Bingen, Associate Director, Senegal Agricultural Research and Planning Project, Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824-1039.

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A CONTRIBUTION TO AGRONOMIC KNOWLEDGE
OF THE LOWER CASAMANCE
(BIBLIOGRAPHICAL SYNTHESIS)

by

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1988

This reprint originally appeared as Works and Documents No. 3, I.S.R.A., Systems and Transfer Department, Djibélor Center, published by the Bureau of Macro-Economic Analysis, Senegal Agricultural Research Institute, January 1985.

This reprint is published by the Department of Agricultural Economics, Michigan State University, under the Senegal Agricultural Research and Planning Project Contract 685-0223-C-00-1064-00 at Michigan State University funded by the U.S. Agency for International Development, Dakar, Senegal.

ISSN 0731-3438

Published by the Department of Agricultural Economics, Michigan State University, East Lansing, Michigan 48824-1039 U.S.A.

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FOREWORD

This partial synthesis of the agronomic literature on the Lower Casamance was initiated as soon as the ISRA/Djibélor research program on production systems and technology transfer was set up. This work enabled the Systems Team to base its program on the results of agronomic research and to better understand the constraints of the Lower Casamance ecosystem.

We would particularly like to extend our gratitude to our colleagues Y. M'Bodj, M. Diack, S. Diatta, A. Faye, M. Kamuanga, M. Khouma, G. Pocthier, S. Sall, and M. Touré for their very helpful comments and suggestions.

November 1982

We would also like to thank E. Landais of GCAS for his assistance in the final preparation of this document.

January 1985

A CONTRIBUTION TO AGRONOMIC KNOWLEDGE OF THE LOWER CASAMANCE (BIBLIOGRAPHICAL SYNTHESIS)

J. L. Posner

The structure of this study parallels the topographical sequence of the region: we will examine, in succession, cleared uplands (plateau soils, sloping ocher soils), transition zones (gray occasionally flooded soils), and, finally, land which is submerged during the agricultural cycle (lowlying areas and alluvial plains).

I. BRIEF DESCRIPTION OF AGRONOMIC RESEARCH IN THE LOWER AND MIDDLE CASAMANCE

A research station was established in 1947 at Séfa, in the Middle Casamance, for the purpose of conducting support research on peanuts for the General Tropical Oilseeds Company (Compagnie Générale des Oléagineux Tropicaux). Later, in 1960, IRAT (Institut de Recherche Agronomique Tropicale) assumed responsibility for the station, and its scope was broadened, because of crop rotation problems, to include the improvement of all upland food crops. In 1967, a 47-hectare substation was set up at Djibélor (5 km to the west of Ziguinchor), in the dry Guinean region, for the study of aquatic rice. The Djibélor station has undergone a gradual development: when ISRA (Institut Senegalais de Recherches Agricoles) was created in 1975, it became a full station, and Séfa a substation. In 1980, the Niaguis district granted an additional 40 hectares of upland to the Djibélor station.

Beginning in 1962, IRAT set up a network of PAPEMs (Pre-Extension and Multiple Site Experimentation Support Points, or, in French, Points d'appui de prévulgarisation et d'expérimentation multilocale), which enabled researchers to extend the focus of their studies by planting trials under ecological conditions not found at the experimental stations. PAPEMs were established in the Sindian (Djilacounda) region, at Maniora II - Inor (on the Trans-Gambian road, near Boukiling), at Ndieba (on the Marsassoum road), at Médina, Kamobeul-Enampore (near Djibélor), and Diana Ba (located 40 km from Kolda on the Sédhiou road). At present, the Enampore, Maniora II, and Diana Ba PAPEMs are still part of the ISRA network in the Lower and Middle Casamance.

In addition to the PAPEMs, which represent a more or less permanent infrastructure, ISRA has set up multilocational agronomic trials, in most cases on an annual basis, which are monitored by research assistants who often remain on site throughout the rainy season. Mampalago, Thiar, and Kitim are some of the sites for dry land crops; rice trials are conducted at Mampalago, Mandouar, Simbandi-Balante, and Oussouye. The "Research-Extension Application Unit" ("Section Application de la recherche à la vulgarisation") (SARV) had also set up trials on crop rotation, plowing under green manure, and different rice and corn varieties at Guerina (1966-73) and Néma (1966-69), in cooperation with the agricultural schools.

The "Pilot Village Program" (1968-80) ("Unités Experimentales") did not extend as far as the Casamance region. In this program farmers were monitored by interdisciplinary teams based at Bambey, then at Kaolack, in order to evaluate the impact, under actual on-farm conditions, of new ideas proposed and tested by research. Less formally, G. Pocthier (SARV) established a village test program at Mampalago and Maniora II where development strategies were tested in collaboration with farmer groups or "progressive" farmers.

Apart from the ISRA network, agronomic research activities have been undertaken by development agencies. In the Middle Casamance, the Sédhiou Rural Project (Projet Rural de Sédhiou: PRS) and, in the Lower Casamance, ILACO and its successor, the Casamance Integrated Agricultural Development Program (Programme intégré de développement agricole en Casamance: PIDAC), which were responsible for extension programs, participated in support research. During the period from 1968 to 1973, ILACO conducted various rice trials focusing on the use of fertilizers (basal dressing with phosphate, urea sidedressing), termite control (HCH and Heptapowder), and soil preparation by means of oxen traction for direct seeding (ILACO, 1973). Unfortunately, the lifetime of the project coincided with a period of seriously inadequate rainfall, and the project was not very successful. At present, with a more ample infrastructure and a larger selection of varieties (rice, corn, sweet potatoes, peanuts), PIDAC is starting anew along the same path.

With respect to the overall experimental network, the following points should be emphasized.

1. Researchers at the two experimental stations of Séfa (dry land crops) and Djibélor (lowland and aquatic rice), as well as the PAPEMs and the multiple site trials, have carried out agronomic experiments covering a wide range of topics and crop varieties with different soil types and varying rainfall patterns. Nonetheless, upland agriculture in the Lower Casamance region has not yet been adequately studied. At present we are reduced to extrapolations based on the results of work conducted on the Sudanian plateau of the Middle Casamance region and its prolongation into the northern part of the Lower Casamance region (Ndieba, Inor - Maniora II, Sindian) where the land evolved under vegetation and climatic conditions of the Guinean type.
2. Since 1973, with the exception of the work performed at Mampalago, very little agronomic research in the Lower Casamance region has been conducted under on-farm conditions with farmer participation.

II. CLIMATE[1]

The sole rainy season extends from June to October. Seventy percent of the time, the highest total monthly rainfall (one-third of the annual total) is recorded in the month of August; 20% of the time, in September; and 10% of the time, in July. The rains begin in the east and gradually reach the southwestern part of the Casamance region. The annual amounts of rainfall decrease from Oussouye to Séfa (see table 1). The most striking fact is that during the period 1966-80 there was a 20% reduction in rainfall, and over the last 4 years (1980-84) the average was even lower. At Ziguinchor,

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[1]Master Plan for Rural Development of the Casamance Region (Plan directeur du développement rural pour la Casamance). Climatology, Hydrology, Infrastructure. SOMIVAC, 1978, Volume II, Book 2 (Schillinger).

TABLE 1

RAINFALL TOTALS (MM) IN THE LOWER CASAMANCE

Stations	Oussouye	Djibélor Ziguinchor	Bignona	Séfa
Average for 15 years[a] (1951-1965)	1,610	1,503	1,425	1,079
Average for 15 years[a] (1966-1980)	1,310	1,233	1,125	1,023
1981[b]	1,239	1,221	987	1,059
1982[b]	1,099	1,029	923	861
1983[b]	908	829	618	770
1984[b]	1,190	1,125	949	970

[a]1980 Progress Report, Djibélor Rice Station.

[b]Bio-Climatology Section Archives, Djibélor.

over the past 15 years there were 4 years with less than 1,000 millimeters of rainfall.[2]

Since the Lower Casamance region is considered marginal for mangrove rice, a reduction of 20 to 30% in rainfall is disastrous for yields. With insufficient rainfall, the polders are no longer freed of salt; to the contrary, the salt level increases, and growing aquatic rice becomes impossible. Often a farmer is unable to judge the severity of the climatic situation before the month of August, when it is too late to plant on the plateau: given the impossibility of growing aquatic rice, he no longer has any alternative solution. As a result, the experience of the last 15 years has led most farmers to rely on other crops rather than depending only on the traditional practice of growing mangrove rice. The traditional agricultural systems in the Lower Casamance region are thus undergoing change as a result of the new rainfall pattern.

The calculated potential evapotranspiration (class A pan) is on the order of 1,300 millimeters per year at Ziguinchor. During the rainy season, the water budget prepared by Schillinger (1978) shows a major surplus only during the months of July, August, and September. Beginning in October, periods of drought appear, and calculations performed at Séfa (over an 18-year period) indicate a negative balance for this month more than half of the time (10 out of 18 years) (Bertrand, 1973). Consequently, even for dry land crops, it is clear that there is a significant risk of drought in the case of late seeding.

III. HYDROLOGY[3]

The saline portion of the Casamance River extends 220 kilometers into the country from the mouth and salt water regularly rises as far as 130 kilometers inland. Salt content reaches its maximum level in June and its

[2]Average rainfall in Ziguinchor prior to 1965 measured 1,650 millimeters (Balensi, et al., 1965).

[3]Master Plan for Rural Development of the Casamance Region. Climatology, Hydrology, and Infrastructure. SOMIVAC, 1978, Volume II. Master Plan of Agricultural Development of the Lower Casamance (September 15, 1981). Harza International for SOMIVAC.

minimum level in October (the salinity level at Ziguinchor varies between 19 and 37 grams of salt to the liter). Apart from the Casamance River, there are 5 major basins in the Lower Casamance (see table 2). They are all subject to the seawater effects of the river and the maximum amplitude of the tide is approximately one meter. Since the topography of the region is quite flat, all of the backwaters (bolons and marigots) of the Lower Casamance are also affected by salt over much of their length.

Another result of the level landscape is a lack of runoff in the watershed. On an average, only 6% of rainfall in the Lower Casamance goes into runoff (Harza, 1981) and thereby helps in leaching the mangrove rice fields. Given the shortage of rainfall over the last several years and the increasing accumulation of salt, the number of abandoned mangrove rice fields is multiplying all over the Lower Casamance.

Along the tidal portions of the river basins, we can observe not only a tendency toward increased salinity of the river bed itself, but also a serious tendency toward increased salinity of the underlying water table. This salinization process occurs at the end of the rainy season as a result of high tides feeding the table as well as capillary action. Consequently, not only the polders, but also the rice fields located on the first level of terraces are affected by the rainfall shortage and the problems of salinization.

Above the river plain, we find lowlying hydromorphic land which will be the subject of a separate discussion in this report. These areas are fed by runoff from the plateau and a rise in the level of the water table (Bertrand, 1973). During the period from August 15 to October 1, these soils often benefit from underground water, which gives local rice cultivation a particular character.

In summary, the surface waters of the Lower Casamance are greatly influenced by the sea and, due to rainfall shortages and a very level terrain, the region is experiencing very acute salinization problems in its rice fields. These problems appear to be more serious in the Lower Casamance than in Guinea-Bissau, where there is greater rainfall (2,000-2,500 millimeters), or in Gambia, where the water shed is larger and fresh-water flooding by the river is more extensive.

TABLE 2

SURFACE AREA OF PRINCIPAL WATERSHEDS IN THE LOWER CASAMANCE[a]

Watershed	Area
Baïla	1,642 km^2
Bignona	750 km^2
Kamobeul	700 km^2
Guidel	145 km^2
Agnak	135 km^2

[a]Master Plan of Agricultural Development of the Lower Casamance (September 15, 1981), Harza International.

IV. CLEARED UPLANDS

A. Soil Description

The plateau soils are almost all of the argillaceous sandstone sedimentary formation which composes the Continental Terminal. The center of the plateaus is made up of "associated yellowish brown plateau soils" and is characterized by an impoverished gray humus-bearing horizon followed by a yellowish brown horizon marked by the presence of red hydromorphic spots and an accumulation of clay. Until now, these soils have been classified as gray ferruginous soils with more or less hydromorphic spots or concretions. The well-drained plateau soils make up part of "the associated red soils of the entire configuration and are gradually increasing in clay content. Red soils are classified as ferralitic soils." (Siband, 1974; and Bertrand, 1973).

Below the level of the interfluves, we find "associated sloping ocher soils." These soils are roughly comparable to the "yellowish brown soils," but they have good external drainage due to their topological position and their low clay content in the first horizons (10%); they are characterized by a clear tendency toward acidification. According to Bertrand (1973) and Pocthier (1981b), these soils are found upstream of villages along the Soungrougrou where they are normally cultivated for four years, after which they lie fallow for 1 to 3 years.

In general, the upper layer (0-10 centimeters) of the upland soils in the Middle Casamance contains 2-3% organic matter, 10-13% clay, and more than 50% fine sand. The pH is often below 6, the CEC varies between 4 and 5 meq, and the base saturation is close to 45%. Further down (20-60 centimeters), the organic matter content decreases, as does the base saturation. Work performed by Siband (1974b), has shown that, at a depth of 0-10 centimeters, "red soils" drop from 2.8% organic matter under forest cover to 0.84% on land cleared at least 90 years earlier. The exchange capacity decreases in parallel fashion, from 7.8 meq/100 grams to 2.5 meq/100 grams in the top layer, and the clay content drops from 11.2% to 7.4%. Consequently, there is a decrease in fertility as a function of soil depth and length of cultivation.

Staimesse (1967) has shown that the yellow soils of Oussouye resemble those of the Middle Casamance. However, the upper layer contains less clay and organic matter, with an acid pH on the order of 5. These soils are very deep (>5 meters) and have a homogeneous structure (no induration horizon).

The water characteristics are as important as the fertility of the upland soils. Under forest cover, the infiltration rate is 3 centimeters per hour for "yellowish brown soils" and 4 centimeters per hour for "red soils." These rates drop very quickly when the soils are cultivated. When plowing is done with large machinery, particularly in yellowish brown soils, infiltration can decrease to one-half, or even one-tenth, of infiltration under forest cover (Charreau and Fauck, 1970). Traditional ridging of the soil in furrows tends to segregate large and small particles and encourages the formation of a surface crust and a layering of the sand content which reduces infiltration (Seguy, quoted by Siband, 1972). Reduced infiltration in cultivated fields leads to runoff and erosion in the area. This runoff can be partially controlled by incorporating organic matter, early seeding, and contour planting.

Water retention between pF 2.5 (field capacity) and pF 4.2 (wilting point), in other words water retention which can be utilized by plants, is 25% lower on land cleared for 46 years than under forest cover (Siband, 1974b). Dancette estimates that, in yellowish brown soils, the useful water reserve (Eu) in the first 30 centimeters amounts to 40 millimeters. For rice, the easily utilizable water reserve is 0.25 Eu (compared to 0.75 for crops such as millet and peanuts); it amounts to 10 millimeters of water stored in the soil for rice (and 30 millimeters for peanuts). This low level of water storage in plateau soils, accentuated by an evaporative requirement of 3-4 millimeters per day, increases the dependence of plants on rainfall and thus the importance of a favorable distribution of rainfall throughout the growing season, especially for a crop such as rainfed rice.

B. Soil Fertility and Crop Rotation

Many authors make reference to the deficiency in phosphorus and potassium in the plateau soils of the Middle Casamance (Birie-Habas, 1966; Pocthier, 1981). Pocthier (1968, 1969, 1971) has observed good responses to

P_2O_5 and K_2O by peanuts and rainfed rice at the PAPEM of Ndieba and Mayor; Siband (1972, 1974b) has made the same observation for rainfed rice in the greenhouse and in the field.

For more than 15 years sustained productivity trials ("amélioration foncière") were conducted. The principal objective was to study available techniques for maintaining and improving the fertility of land cultivated on a permanent basis. These trials compared three levels of fertilization and three levels of land preparation (i.e., 9 different treatments). The trials were conducted over several years and adhered to the following crop rotation: a plowed-down fallow, peanuts, millet or corn, and rainfed rice. Table 3 summarizes the results obtained for the principal plateau crops with fertilization (averaged over land preparation techniques).

The effect of the fertilizer is highly positive. For cereals, recommended amounts are in the neighborhood of 40 units of nitrogen for semi-intensive systems and 120 units for an intensive system in the Casamance (see table 4). At the Guerina agricultural improvement center (7 kilometers from Bignona), the performance of semi-intensive systems was monitored over a period of several years, with satisfactory results (see table 5).

In addition to the amount of fertilizer to be used, the date of application is an important variable affecting yield. In his review of nitrogen management in sandy soils, Ganry (1983) made reference to the Séfa trials. The results indicate that corn, after 30 days of growth, can require as much as 5 kilograms of N per hectare per day and that rainfed rice (after 50 days) needs as much as 4 kilograms/day, whereas millet never exceeds the rate of 2.4 kg of N/ha/day. In the first two cases, the requirements exceed the mineralization potential of the soil and the addition of urea is necessary. Incorporating urea at a depth of 5 centimeters can almost <u>double</u> the effectiveness of the treatment in comparison with surface broadcasting.

The substantial increases in yields due to the addition of fertilizers show that the plateau can be continuously cultivated with adequate fertilization and crop rotation. Diatta (1978) proved that after 6 years of crop rotation, good yields can be obtained, on either a degraded soil (Sédhiou) or newly cleared land (Maniora II). With two similar rotations,

TABLE 3

AVERAGE YIELD (KG/HECTARE) OVER FIVE YEARS FOR PLATEAU CROPS IN THE CASAMANCE (SUSTAINED PRODUCTIVITY TRIAL)

	Control (F0)	Fertilizer (F1) Modest Rate	Fertilizer (F2) High Rate	% Increase Fertilizer F2 Comp. to Control
Rice[a] (144B/9)	560	1,170	1,980	235%
Corn[b]	710	2,242	2,913	310%
Séfa Sanio[b]	1,071	1,697	2,418	125%
Peanuts[c]	1,300	1,642	2,097	61%

[a]Average for Séfa, Ndieba, and Velingara, 1971-1974, Pocthier (1978).

[b]Average for Séfa and Ndieba for corn and Velingara for millet, 1968-1972, Pocthier (1973).

[c]Average for Séfa, Ndieba, and Velingara, 1968-1972, Pocthier (1973).

TABLE 4

MINERAL FERTILIZATION (KG/HECTARE) RECOMMENDED FOR PLATEAU CROPS IN THE CASAMANCE

Crop	Formula	Modest Rate (F1)	High Rate (F3)
Millet	14-7-7	150	150 (10-21-21)
	Urea	0	150
Corn	8-18-27	100	300
	Urea	100	300
Rainfed rice	8-18-27	100	250
	Urea	75	200
Peanuts	8-18-27	150	150
	KCL	0	50

[a]Pocthier G. (1982), "Fiches pour l'expérimentation agronomique."

TABLE 5

AVERAGE YIELD (KG/HECTARE) FOR GUERINA PARCELS (1965-1973)[a] (DEMONSTRATION PLOTS)

Crop	1965	1966	1967	1968	1970	1971	1972	1973
Corn	2,960	2,750	2,768	1,183	1,512	2,380	930	2,307
Peanuts	1,884	1,560	1,429	2,205	2,227	1,758	2,100	1,571
Millet	1,108	1,000	866	1,446	1,154	577	420	1,017
Rice	1,754	1,185	1,266	1,178	771	676	0	1,326
Rainfall (millimeters)	1,854	1,268	1,652	689	1,169	804	655	977

[a]Summary of Guerina annual reports, 1965-1973. The parcels were worked by young farmers in training and the rice used at this time (IKP) was often attacked by rice blast.

plowed-in fallow--corn--peanuts--rainfed rice, or plowed-in fallow--millet--peanuts--rainfed rice, the average yields on the degraded soil were 2.2 metric tons/hectare for peanuts, 3 metric tons/hectare for corn, 1 metric ton/hectare for millet, and 2 metric tons/hectare for rainfed rice, over a 6-year period.

Comparable results were obtained on recently cleared land. The Diatta study, which is spread out over 10 years, should provide final results soon. We can already conclude that it is possible, with the addition of 10 metric tons of manure per hectare per year and the recommended amounts of fertilizer, to arrive at cropping systems which do not degrade the soil and which can even regenerate it. Many researchers have recommended the following standard rotation for the Middle Casamance: plowed-in green manure--corn--peanuts--millet, with the possibility of replacing corn or millet with rainfed rice where soil and climatic conditions permit (Nicou, 1978; Charreau and Fauck, 1970).

C. Land Preparation

1. Deep Plowing

Based on agronomic research conducted in Senegal, it is generally agreed that deep plowing (15-20 centimeters) increases yields. In his review of 20 years of research, Chopart (1981a) indicated that deep plowing with oxen can provide an increase in yield of 50 to 70% in comparison to control plots with manual soil preparation for corn and rainfed rice. If the straw remaining from the previous year is incorporated at the time of plowing, the yields are higher still (see table 6). The positive effects of deep plowing can be explained as follows: Senegalese land cleared for a long period of time has very low organic matter content and becomes very compact, given the progressive clay impoverishment of the surface horizon. Deep plowing increases porosity (from 37% to 44-49%), the infiltration rate (by 26%), and rooting depth. These three factors improve the moisture regime for the plant and, accordingly, increase the yield (Charreau and Fauck, 1970; Charreau and Nicou, 1971; Chopart, 1981a).

TABLE 6

EFFECTS OF DEEP PLOWING ON YIELDS OF DRY LAND CROPS IN SENEGAL: AVERAGE OVER 20 YEARS OF STUDY[a]

Crop	Plowing Only	Plowing With Green Manuring
Peanuts	+ 20%	+ 9%
Millet	+ 17%	+ 24%
Sorghum	+ 24%	+ 24%
Corn	+ 54%	+ 75%
Rainfed rice	+ 71%	+103%
Cotton	+ 16%	+ 33%

[a]Chopart, J. L. (1981a), "Le travail du sol du Sénégal."

In the Lower Casamance, for upland rice grown at Ndieba, light working of the soil (cross harrowing with a spring-tooth (Canadian) harrow in June) only produced an average gain in yield of 250 kilograms per hectare. More intensive working of the soil (end-of-season plowing with a moldboard plow and fitting in June with the spring-tooth (Canadian) harrow) produced a gain in yield of 800 kilograms per hectare (see table 7). It appears that surface scarification does not produce significant increases in yields for upland rice, whereas plowing (at a depth of 12 to 15 centimeters) provides more interesting results.

2. Minimum Tillage

An alternative practice to deep plowing is minimum tillage. According to Chopart (1981b), this technique does not produce good yields in Senegal because of the brevity of the rainy season and the resulting need for early planting. With this technique, instead of planting early, it is recommended to wait first for weeds to reach a good level of growth and then to kill them with herbicide making a good mulch. The sandy soils of Senegal also respond well to conventional tillage due to the improvement in the physical properties of the soil. With minimum tillage, organic matter incorporation is also impossible. The final reason given by Chopart for the lack of success of this technique is the fact that there are no selective herbicides for millet and peanuts, the two main crops in Senegal.

3. Fall Plowing and the Use of Green Manure

In order to take advantage of the water reserves in the soil and facilitate early planting, many researchers have recommended end-of-season plowing. This technique makes it possible to break the capillary system at the end of the season and store more than 50 millimeters of water in the first two meters of soil. This, in turn, facilitates rapid spring-tooth harrowing in June of the following year, and the land is ready to be seeded (Charreau and Nicou, 1971). In the Sudanian zone (Nioro du Rip, Sinthiou-Maleme), end-of-season plowing fails to produce a gain in yield in

TABLE 7

SUMMARY OF SIX YEARS OF RESULTS ON UPLAND RICE (NDIEBA-SUSTAINED PRODUCTIVITY TRIAL)[a]

Year	1969	1970	1971	1972	1973	1974	Average 6 years	A.G.Y. 6 years
Rainfall (mm)	1,234	1,340	920	--	922	1,207		
Fertilization	Effect of Fertilizing (kg/hectare)							
None (F0)	491	285	880	0	254	191	350	--
Modest (F1)	1,125	428	2,039	0	793	1,219	934	584
Semi-intensive (F2)	783	1,272	2,874	0	1,587	2,136	1,442	1,092
Soil Preparation	Effect of Soil Preparation (kg/hectare)							
Manual (T0)	673	369	1,600	0	391	1,158	699	--
Harrowing (T1)	724	556	1,861	0	718	1,378	873	174
Plow (T2)	1,002	1,060	2,332	0	1,525	1,010	1,155	456
Variety	63-83	63-83	IKP	IKP	IKP	302-6		

[a]Summary of G. Pocthier's personal files.

A.G.Y. = Average Gain in Yield.

N.B.: 1972 - Drought and rice blast - no harvest.

1974 - Negative effect of plowing in (T2) straw from end-of-season 1973 due to poor decomposition (insufficient moisture).

comparison with only plowing at the beginning of the season (Tourte, et al., 1971), but it did facilitate early planting. In the Lower Casamance, where rainfall is more abundant and the range of planting dates is wider, it is not certain that end-of-season plowing can have a significant effect on crop production.

Nonetheless, end-of-season plowing has numerous indirect effects:

1. The draft oxen are in better physical condition in October than in June.
2. Incorporating straw in October can improve the structure and the fertility of the soil for the following year, if enough moisture remains to allow decomposition of the straw.
3. End-of-season plowing also serves to incorporate a sizable amount of stover (2-4 metric tons per hectare), which would otherwise be left for livestock (which consume roughly one-third of the stalks).

As another strategy to increase soil tilth and fertility, researchers have advocated incorporating green fertilizer every four years as part of the crop rotation recommended in the Lower and Middle Casamance. At Guerina and the Agricultural Agents School (Ecole des Agents Techniques de l'Agriculture) at Ziguinchor, the crop rotation established in the 1960s started with a millet forage crop (Séfa sanio). After basal application of phosphorus and shallow plowing, the sanio was planted (around June 15), then cut at a height of 25 centimeters in early September for hay; one month later, the regrowth was plowed down. According to Tourte, et al. (1971), out of 135 separate trials, green manuring was effective in 112 cases. Of the 23 unfavorable trials, 21 were with peanut. In the Lower Casamance, the principles of "end-of-season plowing and green manuring" are not yet understood, and the traditional practice of long fallows is still practiced for restoring soil fertility.[4]

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[4]Incorporating organic matter poses particular difficulties. If the end-of-season plowing is done late, the straw will not decompose and normal plant development at the beginning of the next season will be affected, often with poor emergence. A temporary nitrogen deficiency (immobilization) frequently occurs as well.

D. Erosion

Roose (1967) has summarized the results of erosion studies conducted in Senegal. Work completed in Séfa indicates an average annual loss of 10 metric tons per hectare (i.e., a layer of earth 0.6 millimeter deep) on cultivated land with a 1-2% slope. This loss can be reduced by 50% with one year of fallowing and by no more than an additional 20% with a second year of fallowing. Motorized cultivation can result in a loss of 14 metric tons per hectare, while traditional cultivation of the same land can result in a loss of 8.5 metric tons per hectare. Poorly conducted cultivation can lead to 53% runoff and erosion on the order of 55 metric tons of earth per hectare per year. A main factor causing erosion in Senegal is the kinetic energy of rain drops. Charreau and Fauck (1970) have established that around August 15, when 30 to 50% of rainfall and runoff have occurred, 90 to 95% of total erosion has already taken place. From this observation we see the necessity of establishing plant cover as early as possible in the growing season in order to avoid the "splash" effect of storms (which is another argument in favor of early planting) (Chopart, 1982).

E. Comments

Over the last fifteen years of low rainfall, farmers in the Lower Casamance have concentrated increasingly on plateau crops. With the exception of work conducted at Séfa and on the prolongation of the continental plateau at Ndieba, Maniora-Inor, Mampalago, and Sindian, there is no frame of reference for agronomic research on rainfed crops in the Lower Casamance. It can be stated that some soil-related problems are the same in the Lower and the Middle Casamance (for example: deficiencies in nitrogen, potassium, and phosphorus), but nonetheless certain agronomic problems are specific to the rainfed crops of the Lower Casamance.

The Guerina results (see table 5) indicate that satisfactory yields are possible in the Lower Casamance. New varieties must now be tested with greater emphasis on the southwestern part of the country.

The technical data on the major rainfed crops are based on results obtained in the Middle Casamance. For example, in the case of millet, planting is recommended in early June and flat plowing is advocated. But most of the farmers in the Lower Casamance, in fact, plant 3 to 5 weeks later and still plow in ridges.

Apart from these recommendations which are not always linked to the local agricultural timetable, data is still lacking for crops such as cowpeas, sweet potatoes, and manioc. In terms of phytotechnical aspects, research should begin to formulate specific recommendations for the Lower Casamance.

With respect to strictly rainfed rice, research needs to specify both its potential and its limits. Plateaus and sandy slopes represent an environment characterized by low soil fertility and great sensitivity to rainfall patterns; rice should not be recommended in such places, which are better suited for other crops. For direct seeding of rice, under lowland or upland conditions, all available means (mechanical, chemical, biological) for controlling weeds need to be studied.

Recommended soil preparation techniques need to be reexamined for the Lower Casamance. The work completed on beginning-of-season and end-of-season deep plowing was conducted in the dry Sahelian zone of Senegal, where the fundamental problem remains the lack of water. In the Lower Casamance, the major constraint is not the lack of water, but rather the way in which fields become overrun with weeds. As a result, surface scarification suffices in some cases; in other situations, ridge plowing may be more effective than flat plowing in terms of controlling unwanted grasses.

Finally, with respect to cleared upland, it would be helpful to study the association of crops which make best use of the pattern of rainfall and which provide greatest soil protection. Two possibilities which have not yet been studied in the Lower Casamance are cowpeas in association with corn or sorghum.

V. TRANSITION SOILS BETWEEN THE PLATEAU AND THE ALLUVIAL PLAIN

According to Bertrand (1973), the "gray upland soils" are located along hillsides and on terrace slopes (glacis) connecting with Nouakchottian alluvial deposits. These "old" or "middle" terraces, to use the terminology adopted by the Bambey researchers, are referred to in the Lower Casamance as "upper terraces." Immediately below them lies the recent terrace, where the clay content is often much higher, and which is part of the "alluvial plain," according to the work conducted by Touré (Djibélor Report, 1979).

This transition zone is distinguished by its color, which ranges from light gray to white, by its generally coarse texture, and especially by the presence of underground water at a shallow depth. The upstream portion of these soils is often abandoned because underground water no longer rises to the same level (after 15 years of drought); the middle portion is used occasionally for cultivation of direct-seeded rice; and the lower portion (which includes the fringes of the alluvial plain) is also used for rice, either by direct seeding or by transplanting. In the Middle Casamance, according to Schillinger (1978), the use of gray soils for intensive cultivation of rice is a recent phenomenon.

A. Soil Description and Soil Fertility Studies

Gray water-bearing soils are typically very sandy (50-80% sand) with low organic matter content (1-2%) and reduced exchange capacity (0.5-2.0 meq/100 gm) (Bertrand, et al., 1978). Beneath the gray horizon there often lies a horizon of white sand, sometimes with red or yellow spots of iron accumulation. The upstream portion is an "extremely leached" and the downstream portion is a zone where iron and clay have accumulated (Bertrand, 1973).

1. Chemical Fertilizers

Research conducted at Mayor, Inor, and Diana Ba in the Middle Casamance indicated that these soils are characterized by severe deficiencies in phosphorus and potassium, and that they require, in addition to a basal application of phosphate at the rate of 400 kilograms per hectare, approximately 25 kilograms per hectare per year of P_2O_5 and 60 kilograms per hectare of K_2O (Siband, quoted by Accolaste, 1974). As for nitrogen, given the leaching which occurs, to achieve a harvest of 3,500 kilograms/ha of paddy it is necessary to split the urea application into three: 10 kg N at planting, 50 kg N at the start of tillering (after 20 days), and 25 kg N at floral initiation (after 50 days).

In the Lower Casamance, fertilization has been studied at Enampore and Mampalago. At Enampore, it was shown that the best treatment consisted of basal application of phosphate (400 kilograms per hectare every 4 years), followed by end-of-season incorporation of 6 metric tons of straw, combined with a fertilizer level (NPK) of 60-40-40. At Mampalago (one year of experimentation), the recommendation is the same, except for the amount of nitrogen (40:40:40) (Djibélor Annual Report, 1979, 1980).

2. "Ambulant Fertilizer"

Apart from increases in yield due to fertilizer inputs, it should be noted that the check plots with no fertilizers generally produce 1.5 to 2.5 metric tons of paddy rice to the hectare. Gouze (quoted by Bertrand, et al., 1978) has shown that the ground water contains significant quantities of nitrates (150-600 milligrams/liter). Mr. Ganry (1982) estimated that at Diana Ba nitrogen supplied to the crop varies between 30 to 60 kilograms per hectare per year (due to contact between the root system and the water table, containing from 10 to 20 ppm of mineral nitrogen, over a period of 60 days).

Based on the hypothesis set forth by many researchers, adding nitrogen at the time of early planting would facilitate rapid root growth, which would in turn allow for more effective exploitation of the soil (oral communication from G. Pocthier).

In comparison with the plateau, these low-lying zones respond very favorably to fertilizers, even at very low doses, especially when they are applied early (see table 8).

3. Biological Fertilizer

Work conducted on the nitrogen levels in soils has demonstrated the existence of a residual effect of one crop of rice on a second (see table 9). It is possible that the rhizoflora which develops on one crop of lowland rice can assist in the mineralization or the active fixation of the

TABLE 8

COMPARISON OF THE EFFECTS OF MINERAL FERTILIZER ON RICE YIELDS IN PLATEAU AND TRANSITIONAL SOILS

Zone	Paddy Rice Yield (kg/hectare)					
	Nitrogen		Phosphorus		Potassium	
	0	37.5	0	30	0	30
Gray hydromorphic soils	3,000	4,620	3,690	4,650	4,090	4,500
Plateau soils	840	1,720	1,090	2,290	2,220	2,200

Source: Based on Siband and Diatta, 1974, quoted by Bertrand, et al., 1978, page 253.

TABLE 9

RESIDUAL EFFECT OF RICE ON A RICE CROP WITH NO FERTILIZER (IKP VAR.) YIELDS IN KG/HA[a]

Previous Crop	Rice	Fallow	Difference
Year			
1973	3,942	2,345	+ 1,597
1974	2,745	2,650	+ 95
1974[b]	2,895[b]	1,459	+ 1,436

[a]Accolaste (1974), page 48.

[b]Third continuous year of rice.

nitrogen in the subsequent year. After five years of research, Ganry showed that rice yields, in continuously cropped paddies, held constant at a level of 2,300-2,600 kilograms of paddy per hectare in the absence of nitrogen fertilization, and with no risk of a reduction in nitrogen fertility, when the straw was plowed under at the end of the growing season.

B. Water Table Studies

Studies by Bertrand and Forest (1973) and Guillobez (1973) have shown that the ground water table in gray soils can fluctuate by more than two meters during the rainy season.

Most of the work was conducted in the area served by the PRS Project (Projet Rural de Sédhiou: Sédhiou Rural Project) along the Casamance, upstream from Diana Ba, on the Soungrougrou near Bounkiling, and at three sites in the Lower Casamance near Balingor. Based on these studies, the authors were able to distinguish three phases in the cyclical movement of the water table:

1. A phase during which the water table first rises fairly slowly, from July until the middle of August, then very rapidly in late August, then at an irregular rate from the end of August until the middle of September.
2. A phase of maximum height from the middle until the end of September, during which the underground water reaches either a sub-surface level or, in low areas, the surface of the ground.
3. A drying-up phase after the end of the rainy season, during which the water table first drops very rapidly (1-2.5 centimeters/day, depending on the year and the local topography), then more slowly until the month of June.

In the field, the rise and fall of the water table also corresponds to three different categories of hydromorphic land:

1. The upper portion, where soils are very sandy and where the water table does not rise high enough to supply the water needed for the cultivation of rainfed rice (remaining at a depth greater than two meters below the ground).

2. The middle portion, where the water table does not generally reach the surface of the ground, but where its capillary fringe can supply the water needed for cultivating rice by connecting up with the water absorption horizon due to rainfall infiltration.
3. The lower portion, which is often clayey, where the water table reaches the ground level at the time when rice begins floral initiation and then does not drop below this level until after the panicles reach maturity. This zone is located on the upper part of recent terraces or at the base of this transitional zone.

The speed with which the water level rises in August suggests that it is not simply a matter of a general rise in the underground water level at the base of the Terminal Continental. The water table in gray soils is probably fed instead by hypodermic flow. Thus, after major rains, water infiltrates on the plateau and flows along the ferruginous crust (ironstone) to the gray soil zone, further downslope (Bertrand, 1978).

This interpretation of observed conditions is justified by the presence in the Middle and Upper Casamance of lateritic horizons which act as runoff drains leading toward the gray soils. In the Lower Casamance, on the other hand, there are hardly any outcrops and the underground water is in fact the ground water of the Terminal Continental (Accolatse, 1974).

It is likely that the "buffer" effect of the continental water table modifies the seasonal rise and fall of the water table in the Lower Casamance as compared to the water table of the Middle Casamance.

C. Effect of Ground Water Table on Agricultural Production

At Inor, Kandiadiou, and Diana Ba, the Bambey researchers planted strips of rice and other crops in order to study the influence of the water table on agricultural production. The results obtained are summarized in table 10. Rice production is good in the lower parcels, and the same is true of corn (BDS), so long as the planting date ensures that there is no hydromorphic effect on the corn before maturity. The upper parcels are less suitable for rice but more suitable for corn. Other crops which were tested, such as millet, sorghum, and peanuts requiring a growing season in

TABLE 10

INFLUENCE OF THE WATER TABLE ON RICE (IKP) AND CORN (BDS) PRODUCTION IN THE MIDDLE CASAMANCE[a]

	Average Yields (kg/hectare)			
	Lower Plots[a]		Upper Plots[b]	
	Rice	Corn	Rice	Corn
1971				
Inor	2,540	3,810	1,672	3,845
1972				
Diana Ba	3,397	3,899	3,241	2,924
1973				
Diana Ba	5,044	1,225	3,154	2,113
Average	3,660	2,978	2,689	2,960

[a]Yields quoted in the work of Bertrand (1973), Pocthier (1973, 1974), and Accolatse (1974).

[b]The lower plots are the first four strips and the upper plots are the following four strips.

excess of 120 days, turned out to be more sensitive to hydromorphic effects than corn and all produced better results on the upper plots (Bertrand, 1973; Pocthier, 1972, 1973, 1974).

According to Bertrand (1973), the water table clearly influences rice production when it is located at a depth of less than 1 to 1.2 meters below the ground at the time of harvest (around October 25). Given that the capillary fringe ranges from 40 to 60 centimeters, and taking into account the speed with which the water level drops in October, it is possible to identify the portion of the topographical sequence which favors the cultivation of lowland rice (which has a growing season 10 to 20 days longer than do varieties of strictly rainfed rice).

At Diana Ba, Pocthier (1972, 1973) ran trials on off-season crops, either after fallowing, corn or rice. Since the underground water level recedes very quickly at the end of the rainy season, this type of "recessional crop" is very risky. In the Lower Casamance, as we mentioned earlier, the water table is in fact the true water table or the Terminal Continental, and it may rise and fall more slowly than in the Middle Casamance. In some valleys of the region, farmers manage to grow sweet potatoes, without watering, after the rice harvest.

D. Iron Toxicity and Salinity of the Water Table

In contrast to the provision of nutrients and the favorable water conditions associated with the rise in the water table level, there are several problems which are encountered. During the phase when the water table is fed and consequently rises, surface and hypodermic runoff can bring in considerable amounts of iron which are deposited in the first paddies retaining water. This abundance of iron can result in the phenomenon known as "bronzing" and lead to a reduction in the yield.

Several authors (Virmani, 1976; Van Breemen and Moorman, 1978) have observed that the problem of iron toxicity is particularly acute in sandy soils located at the edge of the plateau. Tanaka and Tadano (1972) demonstrated that plants with potassium deficiencies are more sensitive to "bronzing" because of their low radicular activity. To rehabilitate paddies affected by this phenomenon, these authors suggest adding lime to raise the pH, increased fertilization with potassium, and drainage designed to avoid the development of anaerobic conditions.

Movement of saline river water into the water table is a problem as serious as iron toxicity in the Lower Casamance. At Balingor, for example, work conducted by Guillobez (1973) indicates that, along a fringe 300 meters wide, there was a salinity gradient from the Bignona marigot toward the rice fields. This salinization of the water table and increase in salt due to the evapotranspiration of rice can prevent the crop from reaching maturity and result in major decreases in yields. If the water table at Balingor is the "true" water table, it will be necessary to wait several rainy seasons to reconstruct and modify the present gradient toward the river. Based on the report on the Baïla watershed (Louis Berger Inc., 1981), in some places the water table level has dropped by six meters over the past 15 years.

E. Comments

In general, the gray transition soils are unproductive, but close to villages. In the lower areas, fairly high rice yields are possible even in the absence of fertilization and the higher areas have, for the most part, been abandoned. A study conducted in the Middle Casamance (Bertrand, 1973) described the cyclical movement of this shallow water table.

However, fifteen years of drought in the Lower Casamance (particularly the southwest) have caused the water table level to drop; the period during which the lowlying areas are flooded has grown shorter. In this zone, research should be oriented toward developing the practice of direct seeding of rice in the lower areas, and the introduction of other crops in the upper areas. Appropriate production techniques need to be defined within this specific context.

VI. SUBMERGED ZONES--INLAND VALLEYS AND ALLUVIAL PLAINS

This part of our discussion will summarize the agronomic work carried out on the alluvial soils of the Lower Casamance. Most of the work has been conducted by ISRA and ORSTOM researchers within the zone itself, which was not the case for work conducted on the upland and transitional soils.

The alluvial soils include mangrove soils, tannes (acid sulphate soils), recent terraces, inland valleys, and some upper terraces (which were already discussed in the previous section). The only agricultural crop possible in this zone is rice. The production techniques used depend on the soil texture, water conditions, and certain factors associated with particular ethnic groups. For example, the Mandinkas practice direct seeding at the beginning of the rainy season (July), while the Diolas practice transplanting toward the end of the rainy season (September).

The following discussion will basically summarize knowledge acquired concerning this hydromorphic environment in the Lower Casamance, with an emphasis on problems associated with rice production.

A. Geomorphology and Chronological Sequence

In the Lower Casamance, most of the upland valleys were created at the time of the great Ogolian regression. Most of the alluvial infilling which followed can be attributed to the Nouakchottian transgression. Parts of this alluvial plain have subsequently been overlain by plateau colluviums.

Minor fluctuations in the sea level deposited the recent terraces which, at the present time, are no longer submerged by the river, but which are still part of the alluvial plain. In general, the altitude of the recent terraces varies from 0.5 to 1 meter above the average level of the river, while the altitude of the upper terraces ranges between 2 and 6 meters (Vieillefon, 1975).

Closer to the river lie the mangrove mud flats and tannes. According to Vieillefon (1975), these mud flats follow a chronological sequence of botanical colonization. Initially there were sedimentary deposits which eventually protruded slightly above the level of the low tide. At this point, mangroves (Avicennia) began to take hold. As the bank gradually developed, an ever greater portion of the ebbing water would fail to escape and radial trenches began to form. These water networks where Avicennia could no longer take hold became a favorable site for Rhizophora (potentially acid sulfate soil).

The bank gradually grew in size until water could no longer reach the center. Due to evaporation, the zone became saline and very acid and the mangroves died. The bare tanne depression deepened because of the fact that the sedimentary deposits lost a good portion of their water and organic matter. Once hollowed out in basin form, the tanne was subjected to temporary flooding during the rainy season, which permitted slight desalinization, and a halophillic grassland (Paspalum vaginatum, Sesuvium Philoxerus) took hold. These herbaceous tannes gradually developed into rice fields as the salinity progressively dropped and the pH again increased (para-acid sulfate soil).

B. Chemistry of Submerged Soils

Many soils of maritime origin which developed under mangroves contain a large amount of sulfur (2-6%). In areas with high levels of sulfates, iron oxides, and organic matter, under conditions of anaerobia (Rhizophora forest), the amount of sulfates decreases and an accumulation of pyrites (FeS_2) follows. These sulfides can then be gradually oxidized as sediments accumulate and the zone rises above the high tide level. Oxidation of the pyrites produces jarosite and sulfuric acid. If aeration occurs slowly over a period of years, the pH at the site does not fall below 3 or 4, although heavy drainage can drive the pH down to 2 (Moormann and Breemen, 1978).

Nonetheless, most of the rice paddies in the Lower Casamance are located on land where the profile is saturated with water only during the rainy season. Once these soils are flooded, the amount of oxygen trapped in the soil is exhausted by microorganisms within roughly 48 hours. A reducing environment then develops and there is a proliferation of anaerobic microorganisms which utilize the oxide compounds as electron acceptors. As the oxygen content gradually decreases, nitrates, manganese dioxide, iron oxides, and sulfates are successively reduced. During the period of saturation, the reduced substances are more soluble and undergo a change in color. In general, the soils are gray-blue or gray-green in the event of permanent waterlogging, or gray speckled with rust, ocher, or yellow in the case of temporary or partial waterlogging. Flooding results in an increase in the pH and anaerobic decomposition of organic matter, which in turn produces toxic organic acids and an increase in the partial pressure of CO_2 (Beye, 1977).

In general, the amount of organic matter, active manganese and iron and the initial pH determine the dynamics of the chemical and electrochemical characteristics of submerged soils. The principal advantages of submersion are: an increase in the solubility of phosphorus; an increase in the pH; desalinization and, in general, a reduction in weed infestation. The principal problems are the risk of toxicity due to iron (above 600 ppm), manganese, organic acids, and sulfates.

The results of several years of greenhouse studies conducted by Beye, Touré, and Arial (1979) indicated that, from a chemical point of view, under submerged conditions, there are two large soil families:

1. The hydromorphic soils of the small interior valleys and the recent terraces. These soils are characterized by an intense period of reduction during the first month following submersion. Given the fairly low redox potential (<200 mv), the levels of soluble iron are often very high during the first six weeks. The iron content then decreases due to the effect of precipitation in the form of $FeCO_3$ and $Fe(OH)_8$. Initially, the pH is generally around 5.5. After a temporary drop of one pH unit following the production of carbonic acid by the anaerobic oxidation of organic matter, the pH rises again to above 6. Given this high pH and the position of these soils in the topographical sequence, problems of aluminum toxicity and salinity do not occur.
2. The hydromorphic soils with origins closely linked to mangroves. There are important differences between soils such as those found at Tobor and the more evolved soils such as those at Mandouar, but, in general, the influence of submersion on the pH level is not very pronounced. Also, in contrast with the soils of the first group, these soils do not undergo a significant reduction and the redox potential always remains above 300 mv. With respect to iron content, the soil at Tobor is above generally accepted lethal concentrations for plants. This is due to the high level of active iron in the soil, the evolved organic matter content, and the absence of carbonates. At Mandouar, a steady growth in the iron

content was observed during the 18 weeks of the trial, although the content always remained below the levels recorded at Tobor.

C. Classification and Fertilization of Aquatic Rice Fields

With respect to soil improvements for rice production, there are two major categories of interest: rice paddies located in lowlying inland valleys and those on the alluvial plain.

1. Inland Valley Rice Fields

These rice paddies are located in the valleys situated upstream of the alluvial plains and they are not affected by a salinity problem. They appear as mineral hydromorphic soils (unit 15) on the map by Vieillefon (1975) (example: Djibélor). The soils are generally characterized by a fine texture and high natural fertility (table 11). They are often surrounded by a sandy upper terrace, such as we discussed in the previous section (gray transitional soil). Based on several years of experimentation (Beye, 1977a), the recommended level of fertilizer to obtain a yield of 4 tons of paddy rice per hectare is as follows:

1. Recycling of straw (5-6 metric tons/hectare) through end-of-season plowing;
2. Input of 200 kilograms/hectare of 8-18-27 at the time of transplanting;
3. Sidedressing 100 kilograms of urea: 25 kg one week after transplanting, 50 kg one month later, 25 kg two months later.

2. Alluvial Plain Rice Fields

The two chief categories of rice fields are those located on the mangrove soils (potentially acid sulfate soils) and those on the sandy flood plains (para-acid sulfate soils). Between the two, we encounter tanne soils or newly developed areas (as at Tobor) which cannot be cultivated due to high electrical conductivity and very low pH levels (acid sulfate soils).

TABLE 11

ANALYTICAL CHARACTERISTICS OF HYDROMORPHIC SOILS IN THE LOWER CASAMANCE[a]

Analytical Characteristics	Clay (%)	Sand (%)	pH (1:2.5)	EC mmhos (1/10)	O.M. (%)	Active Iron (%)	Exch. Bases meq/ 100 gm	Saturation (%)
Soil types								
Inland valley (E1)	47.5	28.1	4.8	0.24	6.01	3.0	11.68	60
Upper terrace (P6)	5.7	91.6	4.6	0.12	2.31	2.9	1.15	75
Loamy-clayey acid soil on plains (P7)	50.0	33.2	4.8	0.39	3.98	1.41	11.35	22
Sandy	24.3	69.5	3.9	6.0	0.9	16.6	7.8	82
Acid sulfate soil	12.0	79.6	4.6	12.8	1.0	6.5	5.2	--

[a]Source: Beye, Touré, Arial (1979), "Etude de la chimie des principaux sols submergés de Basse-Casamance," Agronomie tropicale, 34(3):171-300, and Senegal Identity Card mimeo by M. Touré.

Work conducted to reclaim this truly unproductive zone will be discussed later.

a. <u>Mangrove Rice Fields</u>

The traditional Diola system for reclaiming mangroves is based on the judicious use of the movements of the tide. According to Pelissier (1966), over a period of seven to ten years, in the absence of fresh water, farmers managed to leach the salt from their fields without lowering the pH. This result was obtained by allowing a continual readmission of salt water during the dry season. In years of abundant rainfall, this type of field produces as much as 3 metric tons of rice to the hectare with no fertilizer and, in many cases, no weeding. The double dike system, which makes it possible to tap all the resources of the mangrove (wood, charcoal, fish, pasturage, rice farming), is well adapted and admirable, but requires a great deal of labor. Given the last 15 years of low rainfall and the flight of young people toward the cities, the future of mangrove rice cultivation is in question (Schillinger, 1978).

Nonetheless, research conducted on mangroves, while not extensive, has indicated a very positive response to lime and phosphorus. At Mandouar, Beye (1972a) demonstrated that a single application of 15 metric tons of lime per hectare produced an average annual increase in yield of 2.3 metric tons of paddy rice per hectare, as compared to the control case, over a period of 4 years.

On mangrove soils at Médina, an application of 1.2 metric tons of Taïba rock phosphate per hectare had positive after-effects (on the order of 600 kilograms of paddy rice per hectare per year) over a period of 7 years (Pocthier, 1971). On a sandy soil at Djibélor, after three years of experimentation, the mineral fertilization level of 80-60-60 NPK proved to be the best, but yields were very mediocre nonetheless (200-1,600 kilograms per hectare) (Recherches rizicoles, 1979a).[5]

[5] Due to the rainfall deficit, trials on fertilizer application in saline zones are difficult to interpret. Frequently, problems of excessive salinity result in such drastic decreases in yields that they mask any positive effects of the fertilizer.

b. Flood Plain Rice Fields

Rice fields located on former mangrove soils which have evolved into para-acid sulfate soils are much more extensive than those on the mangrove soils themselves. These soils have a distinct texture: according to Balensi, et al. (1965), 70% of all rice fields in the department of Oussouye are sandy (>80% sand).

In these para-acid sulfate soils, the organic matter content is often low (table 11). Incorporating straw can, unfortunately, introduce serious problems in sandy soils: the inhibition of plant growth, the immobilization of nitrogen, and the accumulation of toxic elements (ferrous ion), especially when it is done immediately before submersion and transplanting (Beye, 1977c, 1978). Consequently, the solution advocated by researchers is either to practice fall plowing to allow aerobic decomposition of the straw, or to incorporate a more processed substance such as manure or compost.

In general, the recommended level of fertilizer (to obtain a harvest of 3-4 metric tons to the hectare) is a combination of 100 kilograms/hectare of nitrogen at tillering and 40 kilograms/hectare of phosphorus. Particularly sandy soils need an additional 50 kilograms/hectare of potassium or 20 kilograms of potassium and 6 metric tons of straw per hectare, (Kamobeul) (Recherches rizicoles, 1979a; Schillinger, 1978).

In very acid rice fields, iron toxicity ("bronzing") is often a problem. During two growing seasons, Beye (1972a) compared the effects of agricultural lime, lime silicate, and crushed shells, in doses of 3 and 6 metric tons per hectare, as a means to raise the pH and combat this problem. The pH measured at the time of harvest had risen by one unit in the case of the second dose, and by one-half unit in the case of the first dose. For each of the applications studied, the yield was better than in the control plots, except in the case of the application of 3 metric tons/hectare of shells.

The rice fields located on flood plains are often characterized by a phosphorus deficiency as well. Beye (1973a) determined that supertriple phosphate (45%) is more effective than Taïba rock phosphate (37%), due to its water solubility. Both of these products, when applied at the rate of 100 kilograms of phosphorus to the hectare, increase yields by fully 250% when compared with control parcels. Other phosphorus trials indicated that dissolved magnesium phosphate was not superior to supertriple, and, with the application of 40 kilograms/hectare of P_2O_5, the yields doubled, from 1.6 to 3.2 metric tons/hectare (Djibélor Annual Report, Recherches rizicoles, 1980).

During the same year (1980), fertilization trials using peanut shells in order to increase the potassium and silica content of acid soils on the plain failed to demonstrate a positive effect on rice productions.

D. Improvement of Unproductive Soils

1. Improvement of Acid Sulfate Soils through the Application of Fertilizers

With mineral applications (agricultural lime, crushed shells, manganese dioxide) and organic applications (manure, straw, compost, peanut shell ashes, green fertilizer), ISRA researchers attempted to make the acid sulfate soil environment productive. Positive results were obtained for those treatments which contributed to the leaching of salt, raised the pH level, and supplied phosphorus.

Under greenhouse conditions with the Tobor soil, Beye, et al. (1975) demonstrated that rice production was possible only after:

a) An intensive leaching which reduced the conductivity from 43.5 to 3 mmhos/cm.

b) A liming equivalent to 28 metric tons of lime to the hectare in order to raise the pH from 2.5 to 5.5.

c) A twelve-week presubmersion before transplanting in order to get past the free iron peak which occurs in anaerobic conditions.

In practice, these conditions cannot possibly be met in the Lower Casamance, where fresh water represents a limiting factor and agricultural lime is expensive.

In 1979 and 1980, a trial with two different levels of phosphorus (0 and 50 kilograms/hectare) and two different pH levels (4.5 and 5.5) was conducted at Simbandi, Kamobeul, and Djibélor on acid sulfate soils which were, however, more mature than the soils of Tobor. At Djibélor, the yields obtained were on the order of 3 metric tons/hectare in 1979 and 2 metric tons/hectare in 1980. At Simbandi, for the first year the harvest came to 2.5 metric tons/hectare, and for the second year, 3 metric tons/hectare. In general, the yields were best with a pH of 5.5 and the addition of P_2O_5 (50 kilograms/hectare) (Khouma and Touré, 1981).

2. Improvement of Saline Soils through Site Development

Site development (polders, drains, salt dams) in the Lower Casamance focuses on the desalinization of the soil by means of fresh water retention and partial exclusion of brackish water. The difficulty encountered in these systems involves finding a happy medium between the exclusion of saline water and the drying out of the soil, which may provoke a drastic decline in the pH. The low levels of rainfall in recent years have dramatically reduced the amount of fresh water available for leaching the salt out of these fields, thus diminishing the benefits of site development.

Nevertheless, after monitoring the Médina polder for five years, Beye (1979c, 1973b, 1972b) was able to reach the following conclusions:

1. For the polders which were gravity drained (A, B, H), the shallow drainage system spaced at a distance of 20 meters (57% clay) and blocking the entry of brackish water (polder B) resulted in the leaching of 50% of the salt in the upper layer (0-20 centimeters deep). Unfortunately, in years of little rainfall the salt content in the polders quickly rose again.
2. With respect to the pH level, the drainage system allowing the entry of brackish water every 5 days during the off-season in order to avoid total drying out of the soil (polder A) proved to be the best. The pH held steady around 5.5. In polder B, the drop in the pH due to oxidation of the upper layer was also monitored. The pH

rose from 3.6 in July to 4.4 in August and as high as 5.0 in October.

Site development at Tobor and Guidel resulted in a drastic drop in the pH, and the rainfall deficit increased the salinity. Marius and Cheval (1980) confirmed what Beye had concluded about polder B after five years of trials at Médina. They found that the upper layer (0-50 centimeters) at Guidel had evolved considerably after 15 years and was no longer very acid (pH>4). In a sense, the site development (drainage) converted the surface horizons from an acid sulfate soil to a para-acid sulfate soil. Now, with more fresh water (greater rainfall levels, fresh water retention dikes), the polders could become viable once again for rice production.

From another angle, Beye (1973c) compared the desalinization effects of straw mulch, end-of-season plowing, and bare soil. After four years, all three methods resulted in a decrease in the electrical conductivity of the soil, and the straw mulch proved to be most effective with a reduction, at the beginning of the rainy season, of 1 to 5 mmhos when compared to the other methods. The mulch served to lessen resalinization during the dry season by reducing evaporation.

E. Production Techniques and Agricultural Mechanization

During the years 1967-1974, a rice agronomy program was initiated. Below we will briefly review the principal recommendations developed by this program.

1. Preparation of Rice Fields

Traverse (1971, 1973) found that the best method for preparing the heavy rice soils was the use of a peanut lifter on an "arara" toolbar. With irrigated rice, he proposed that plowing with a reversible plow, followed by surface cultivation with a spring-tooth (Canadian) harrow were the two most productive methods (5.1 and 4.8 metric tons/hectare respectively) (Traverse, 1971). In both situations, the research conducted advocated flat preparation of the soil.

In 5 years of trials on saline rice soils, contradictory results have been obtained with respect to comparing ridge and flat soil preparation (Recherches rizicoles, 1979b). Furthermore, the trials have focused on the width of the ridge, with the objective of minimizing ground lost in the furrows. No difference in yield was observed between traditional ridges measuring 90 centimeters and experimental ridges measuring up to 540 centimeters in width (Recherches rizicoles, 1979b).

In addition to work conducted on soil preparation methods, Traverse (1973) modified the SISCOMA reversible plow so that it would be better adapted to aquatic rice cultivation, with a floating front shoe and an elongated plow. In collaboration with CEEMAT in 1978 and 1979, tests for adapting Bouyer, Staub, Granja, Motostandard, and Iseti two-wheeled ("walking") tractors were conducted in sandy and clayey-loamy rice soils. In general, using a reversible plow requires 20 hours of labor and consumes 30 to 35 liters of gasoline per hectare. Using a rotary cultivator requires less time (15 hours per hectare) and consumes less gasoline (15 liters per hectare).

Studies conducted on the time required to perform certain tasks showed that a well-maintained Ndama bull can provide the following work:

light traction	-	7 hours/day
heavy traction	-	4.5-5.5 hours/day
working in mud	-	3.5 hours/day

This method of work requires 8.5 days/hectare to prepare aquatic rice fields with animal traction at Djibélor, compared with 191 man-days with the local fulcrum-shovel called a cayendo (Traverse, 1974a).

2. Method of Seeding

The best date for direct seeding falls between June 15 and July 15, with a spacing of 33 centimeters between rows and 100 kilograms of seed per hectare. For transplanted rice, 6 to 7 ares (1 are = 100 square meters) need to be seeded in the nursery, at a rate of 6 kilograms of seed to the are, in order to cover a one-hectare parcel. The recommended level of fertilizer (NPK) in the nursery is 100-100-100 kilograms/hectare.

With respect to the method of transplanting on ridges, the traditional system (three rows of single plants) gives the same results as those obtained by other systems (several shoots in each hole) (Recherches rizicoles, 1979b).

F. Comments

It is very useful to classify rice fields as those in inland valleys and those located on the alluvial plains. This classification is further refined by distinguishing among mangrove rice fields (potentially acid sulfate soils), tanne rice fields (acid sulfate soils), and rice fields along the edge of plateaus (upper recent terraces). In addition to these categories based on soil genesis, it is important to study the other factors influencing the system of rice production (length of submersion, depth of ground water or surface water) and the method of planting (direct seeding, transplanting).

With respect to fertilization, the present recommendations are still tentative. We need to achieve a better knowledge of farmer opinions and strategies concerning fertilizer applications, in order to understand why some proposed schemes are rejected or, alternatively, adopted by farmers. In this regard, the Program proposes to study traditional techniques for working the mangrove and tanne soils.

Finally, with the development of anti-salt dams, shallow wells, and the expansion of animal traction, the team will need to propose and test new strategies for improving the rice production systems of the Lower Casamance.

VII. GENERAL CONCLUSION

From 1967, when it was founded, until 1969, the Djibélor station housed only two research programs: soil science and varietal improvement, principally focussed on aquatic rice. Later, a program on "agricultural mechanization and production agronomy for aquatic rice" (1970-1976) and an entomology program (1970) were established. Recently, other programs in the area of crop protection have been set up: plant pathology (1981) and weed science (1981). All of these programs focus on rice. However, the present drought cycle, extending over a period of 15 years, has resulted in greatly increased cultivation of plateau land. Thus, it would seem to be crucial that agronomic research rapidly develop production packages appropriate for dry land crops in the Lower Casamance, to further the agricultural development objectives of the region.

For the aquatic and hydromorphic zones, technical packages formulated by researchers operating in "controlled environments" (Stations and PAPEMs) already exist for obtaining substantial increases in rice yields. However, these recommendations have not been tested on actual farms and, as of the present time, have only rarely been adopted by farmers.

We propose, at the conclusion of this review, to undertake a research program which would be complementary to those already in progress and which would strive to develop solutions to the real problems faced by farmers in the Lower Casamance. The priorities for an agronomic research program of this sort are as follows:

1. Establishment of recommendations specifically for the Lower Casamance for each dry land crop;
2. Evaluation of recommendations already developed for rice production on farms;
3. Implementation of support research on mangrove rice soils, within the framework of the anti-salt dam program;
4. Evaluation (at all levels) of the integration of new production techniques into the cropping systems of farmers.

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