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CHOICE OF TECHNIQUE IN SAHELIAN RICE PRODUCTION†

A series of droughts between 1968 and 1973 in Africa's western Sudan—the vast grasslands that lie south of the Sahara in western Africa—provoked numerous West African countries, particularly the French-speaking countries of the Sahel, to intensify efforts to increase the productivity of agricultural resources and the reliability of food production. Prominent among the crops selected for attention was rice.

This paper reports on investigations of the social and private profitability of alternative ways of growing rice in four Sahelian countries—Senegal, Mali, Upper Volta, and Niger. It depends on the construction and analysis of budgets—in social prices—that are based on information about existing methods and costs of rice production in West Africa and Asia. Efforts were made to ensure that methods are technically feasible and that costs and returns are representative of recent experience.

Attention is first directed to the relative social profitability of manual rice cultivation under seven different types of water control that are presently employed in the region. The influence on social profitability of location of production and method of processing is considered in the second part of the study. Next are examined the social costs and returns from prospective labor-saving changes in farm operations—plowing, seeding, weeding, transporting, and threshing. Finally, the analysis is placed in the context of recent government policy in the four countries.

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THE SETTING

The Sahel proper is a narrow band of arid land with rainfall of about 350 millimeters (mm) or less that extends along the southern "coast" of the Sahara desert eastward from the Atlantic Ocean across the width of Africa and includes M. K. Bennett's drier single crop zone (Map 1).[1] West African countries bordering the southern Sahara, especially the French-speaking ones, have come to be called the Sahelian countries, but by far the greatest part of their arable lands lies in the savanna areas of the western Sudan with rainfall of up to 1,250 mm per year (Bennett's moister single crop zone).[2] The principal occupations are cultivation of cereals and pulses where rainfall and groundwater permit and nomadic pastoralism of cattle and goats in the drier areas. Rainfall varies erratically from place to place and from year to year causing frequent local shortages of foodstuffs and occasional widespread deficiencies.

Senegal, Mali, Upper Volta, and Niger are more or less the same size (Table 1), and population tends to concentrate near the Atlantic coast, along the Senegal and Niger rivers, and on the Mossi plateau. Large parts of Mali and Niger are desert. Population density is relatively higher in Senegal because Dakar was once the administrative center for all of French West Africa.

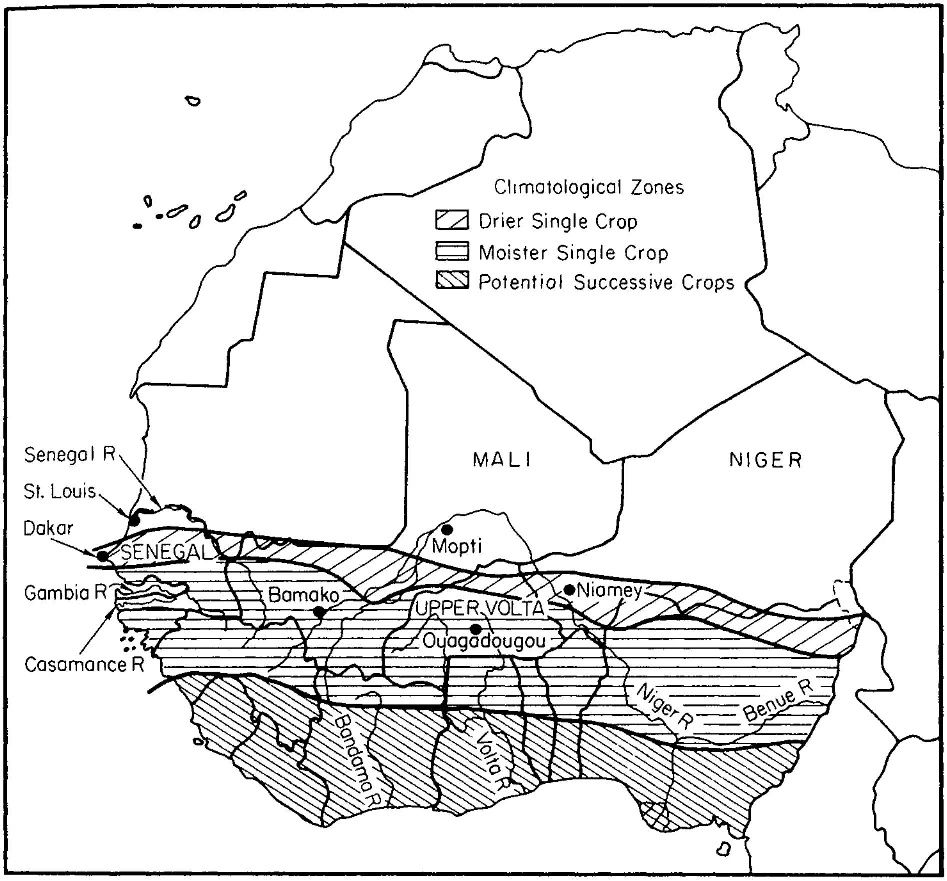
Rice is an ancient crop in West Africa, and it is the dominant staple in well watered areas along the coast from Gambia to central Ivory Coast. Except for the vast delta of the Niger River in central Mali, rice is much less important in the drier interior where sorghum and millet are the basic cereals. But rice is the only foodcrop widely grown in the western Sudan for which an impressive array of technical innovations has already been developed.[3] Furthermore, many West African populations manifest a strong preference for rice; as incomes have risen and cities grown, rice imports have increased rapidly.

Attempts to transfer to West Africa production methods for rice that are successful in the Asian tropics have been confronted with the very remarkable differences in relative scarcity of land and labor in these two parts of the world. Although West African incomes are low, land is plentiful and labor is relatively scarce. In contrast to Asia, where shortage of land makes higher yields imperative, the Sahelian countries could benefit most from increases in the productivity of labor. However, the relationship between land and labor is complicated by the aridity of the Sahelian states and the virtual absence of irrigated works of any significance. Water control needed for improved rice is in short supply, and if capital is to be profitably embedded in the land in the form of irrigation works, yields must also be increased.

[1] *Sahil* is an Arabic word meaning "coast"; its plural *sawahili* is the origin of the word Swahili in East Africa. Boundaries of the West African Sahel are imprecise. It was a transition belt where "nomadic and settled, white and black, meet and mingle, without either having clear predominance" (Fisher, 1977, p. 238).

[2] Over extensive areas of the Sudan, duration of rainfall may be less than 160 days each year (des Bouvries and Rydzewski, 1977, p. 163). This area largely coincides with what is often called the semi-arid tropics—zones with a single season of rainfall (from 300 to 1,000 mm per year, with great spatial and temporal variability), and where there is a surplus of moisture (precipitation exceeding potential evapotranspiration) only during four to five months.

[3] Maize is of little importance in the Sudan, and American work with sorghum has only recently stimulated efforts to develop high-yielding sorghum varieties for the African tropics. Cf. Chabrolin (1977) and Etasse (1977).



MAP 1.—AGROCLIMATIC ZONES OF WESTERN TROPICAL AFRICA*

*After M.K. Bennett (1962), "An Agroclimatic Mapping of Africa," *Food Research Institute Studies*, Vol. III, No. 3, p. 206.

*Drier single crop, less than 650 millimeters (mm) (about 25 inches) in any 5 successive months but more than 250 mm (about 10 inches) in 3 successive months; moister single crop, at least 650 mm within 5 successive months and at least 6 months with less than 100 mm (about 4 inches) per month; potential successive crops, at least 650 mm within 5 successive months and no series of 6 months with less than 100 mm per month.

RICE PRODUCTION

Mali and Senegal accounted for more than 80 percent of total rice production in the four countries in 1976-78 (Table 1). Most Malian rice is produced in the internal delta of the Niger where over 1 million hectares (ha) of land are considered to be suitable for irrigation development (des Bouvries and Rydzewski, 1977, p. 176). In Senegal rice comes from traditional growing areas in the Casamance and from modern irrigation developments along the Senegal River. Rice in Niger is grown along the Niger River near Niamey and in Upper Volta in lowland swamps scattered over the southeast and southwest parts of the

TABLE 1.—SOME CHARACTERISTICS OF FOUR SAHELIAN ECONOMIES, 1960 TO 1978*

Indicator	Senegal	Mali	Niger	Upper Volta
Population, mid-1978 (*millions*)	5.4	6.3	5.0	6.6[a]
GNP per capita, 1978 (*US dollars*)	340	120	220	160
Persons per square kilometer, 1978	27	5	4	24
Hectares of arable land per person, 1978 [b]	0.4	1.6	3.0	0.8
Rainfall in rice-producing areas (*mm per year*) [c]	520-1,590[d]	625-1,370[e]	500-610	850-1,330
Total riceland, 1976-78 (000 *ha*)	74	204	24	42
As percent of cropped land[f]	3.3	10.7	0.5	1.4
Riceland under irrigation, 1972 (000 *ha*) [g]	8	58	1	1[h]
As percent of total riceland	14	35	13	2
Average annual paddy production, 1976-78 (000 *tons*)	107	212	30	33
Annual growth rate of paddy output, 1960-62 to 1976-78 (*percent*)	1.4	0.8	6.8	-0.3
Instability of paddy production, 1960-75 [j]	23.2	10.7	12.5	11.8
Per capita rice consumption, 1976-78 (*kg per year*)	52	21	5	8
Annual growth rate in per capita rice consumption, 1961-63 to 1976-78 (*percent*)	1.3	0.4	6.1	4.0
Total annual rice consumption, 1976-78 (000 *mt*)	270	135	23	45
Annual growth rate in total rice consumption, 1961-63 to 1976-78 (*percent*)	3.7	2.9	9.0	6.1
Rice self-sufficiency, 1976-78 (*percent*) [k]	21	93	67	43

*Sources: Population is from the United Nations (1979), *1978 Demographic Yearbook*, New York; GNP per capita from the World Bank (1979), *Atlas*, Washington, D.C. Population densities and hectares of arable land are based on United Nations Food and Agriculture Organization (1979), *Production Yearbook 1978*, Rome. Rainfall figures are reported by Secretariat des Missions d'Urbanisme et d'Habitat, Government of France (1970), *Fiches Climatologiques à l'Usage des Architectes, Urbanistes, et Aménageurs*, "Senegal," "Mali," "Niger," "Upper Volta," Paris. Total riceland and percent of total cropped area are from United Nations Food and Agriculture Organization (various years), *Production Yearbook*, Rome. Area and percentage of riceland under irrigation for Niger, Senegal, and Upper Volta are based on West Africa Rice Development Association (WARDA) (1975), *Rice Statistics Yearbook*, Monrovia, Liberia; for Mali, figures are those compiled from unpublished government documents by John McIntire in Scott R. Pearson et al.(forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University Press, Stanford. Rice production, consumption, self-sufficiency, and growth rates are calculated from data presented in WARDA (1979), *Rice Statistics Yearbook*, Monrovia. Calculation of the instability of paddy production is based on data from United Nations Food and Agriculture Organization (various years), *op.cit.*, for Mali, Niger, and Upper Volta, from WARDA (1975, 1979), *op. cit.*, and from Senegal (1961-75), Ministère du Développement Rural et Hydraulique, Direction Générale de la Production Agricole, *Rapport Annuel, Campagne Agricole*, Dakar, for Senegal; see Scott R. Pearson et al., *op. cit.*

[a]Probably includes migrants living in the Ivory Coast. Official national figures show only 5.9 (see Upper Volta, 1979, Ministère du Plan et de la Coopération, Institut National de la Statistique et de la Demographie, *Les Estimations des Aggregats de Comptes Nationaux et Indicateurs Economiques de la Haute Volta de 1970 à 1978*, Ouagadougou). Calculations based on growth rates in World Bank (1980), *World Tables*, Second Edition, Johns Hopkins University Press, Baltimore, Md., show 5.6.

[b]Includes only land cultivated currently or within the previous five years. It thus excludes arable land both in long fallow and in pasture and forest that has never been cleared.

[c]Averages for the period from 1920 to mid-1950s.

[d]First figure, Matam, Senegal river valley; second figure, Ziguinchor in the Casamance.

[e]First figure is average for areas near Mopti and Segou; second figure refers to southern, Sikasso region.

[f]Cropped land includes all cereals, pulses, cotton, and peanuts.

[g]Usually only full water control, except for Mali where land under controlled flooding is included.

[h]1971.

[i]Year of production is year of planting.

[j]This index is calculated as the mean absolute deviation of values from the estimates obtained from a moving, five-year average of logarithmic values, in this case of paddy output. It is a measure of short-term instability and implies constant percentage growth rates during five-year cycles. The lower the value, the more stable the series. See David Murray (1978), "Statistical Measures of Export Earnings Instability," *Malayan Economic Review*, Vol. 23, No. 1, April.

[k]Self-sufficiency is defined as the ratio of net domestic production (production less seeds and losses plus changes in stocks) to total consumption (net domestic production plus net imports). Values are averages weighted for the years 1976 to 1978.

country. Rice production has increased little since independence, and it fluctuates considerably from year to year because of varying rainfall.

Rice requires irrigation throughout most of the savanna, and the unreliability of rainfall and high rate of evapotranspiration make irrigation desirable for other crops as well, even where average annual rainfall might appear adequate. But irrigation and rice cultivation are closely associated, because most improved rices require standing water and rice alone among staple food crops is likely to yield returns high enough to cover the cost of irrigation.[4]

There are no indigenous water control systems for rice production in West Africa, except for mangrove swamps along the coast. The major modern irrigation schemes are located in Senegal and Mali along the Senegal and Niger rivers. The oldest scheme is the Office du Niger in Mali covering 40,000 ha and using gravity-flow irrigation. Some 50,000 ha are also imperfectly irrigated through partial control of the seasonal floods of the Niger River. The Senegalese have constructed nearly 15,000 ha of irrigated fields in the lower Senegal river valley, most of which require expensive pumping. In Upper Volta, the Kou Valley is the major scheme producing rice, using gravity-flow irrigation on about 1,000 ha. Since its construction, water logging has taken nearly one-fourth of the area out of production. There are no major irrigation schemes in Niger. In addition to these large-scale projects, there are numerous small-scale developments located in small flood-plains and bottomlands in areas with higher rainfall. Water-control in all of these depends mainly on rainfall, which is uncertain. Estimates are tentative, but as much as 200,000 ha may already be irrigated to some extent in these four countries, mostly for rice (CILSS, 1980).

There is a large potential for irrigation. Calculations based on estimates of available water suggest that over two million ha could conceivably be irrigated for double cropping in all the Sahelian countries (CILSS, 1980, p. 13; Maton, 1976; Peter, 1976). Of the four countries considered here, Mali and Senegal have the greatest potential with some 1 million and 450,000 ha, respectively. Niger and Upper Volta each have a potential less than 150,000 ha. Little of this potential has been realized so far.

Most irrigation is expensive and programs to expand production are limited by the lack of investable funds. Slow growth of gross national product per capita and low or negative domestic savings rates mean that irrigation investments will probably be minor unless heavily supported by concessional foreign aid. Even if funds are forthcoming, the lack of infrastructure and managerial capacity of the four countries is a significant constraint on the absorption of investment funds to expand irrigated production. (These constraints are illustrated by the density of roads and proportion of advanced students as shown in Table 2.)

Some attributes of the policies that governments of the four countries have chosen in the face of these constraints are listed in Table 3. These policies can be grouped into three major categories: trade control, domestic price regulation, and subsidies on inputs (see Pearson et al., forthcoming, ch. 11).

[4] Experiments with irrigated wheat are being pursued in all four countries, but results have generally been less encouraging than for rice.

TABLE 2.—SELECTED INFORMATION ON CONSTRAINTS*

Indicator	Senegal	Mali	Niger	Upper Volta
(1) Net cereal imports as a percent of earnings from exports, 1960-75	17.9	37.9[a]	5.3	22.7[b]
(2) Export instability, 1968-71[c]	12.5	5.0	11.3	10.0
(3) Instability of per capita food production, 1961-75[d]	14.1	11.5	11.6	8.8
(4) Rate of growth of real GNP per capita, 1960-77 (*percent per year*)	0.15	1.43	-0.74	0.16
(5) Density of all-weather roads (*km per km^2 of land area*)	17	2[e]	3[e]	9
(6) Second- and third-level students, 1975 (*per 000 people*)[f]	16[g]	10	3	3

*Sources: (1) based on trade data in the United Nations (various years), *Yearbook of International Trade Statistics*, Vol. 1, "Trade by Country," New York; (2) come from World Bank (1976), *World Tables, 1976*, John Hopkins University Press, Baltimore, Md; (3) on data in United Nations Food and Agriculture Organization (various years), *Production Yearbook*, Rome; GNP in (4) from World Bank (1980), *World Tables*, 2nd ed., Baltimore, Md.,.(5) on roads in Pneu Michelin (1975), *Africa–North and West*, Map 153, Paris; and (6) from UNESCO (1980), *Statistical Yearbook 1978-79*, Paris.

[a]Excludes 1960 and 1973; 71 percent of imports were in one year, 1974.

[b]Excludes 1960.

[c]Mean squared deviation from five-year centered moving average of total value of merchandize exports. See World Bank (1976), *World Tables,* John Hopkins University Press, Baltimore, Md.

[d]Mean absolute deviation of paddy output from estimates obtained from a moving, five-year average of logarithmic values. It measures short-term instability and implies constant percentage growth rates during five-year cycles. The lower the value, the more stable the series. See David Murray (1978), "Statistical Measures of Export Earnings Instability," *Malayan Economic Review*, Vol. 23, No. 1, April.

[e]Includes areas in the Sahara desert (perhaps two-thirds of Mali and four-fifths of Niger).

[f]Second-level students are those enrolled in schools (including teacher training and vocational) that require at least four years of previous training and prepare students for subsequent university or vocational training. Third-level students are those enrolled in universities or equivalent.

[g]1970.

TABLE 3.—SELECTED ATTRIBUTES OF GOVERNMENT POLICIES

Indicator	Senegal	Mali	Niger	Upper Volta
Ratio of wholesale market price of rice in principal city to price of imported rice [a]	1.4[b]	0.9[c]	1.0[d]	2.0[e]
Rate of subsidy or tax (-) in official domestic price, 1975-76 [f]	25	5	0	-15
Relative domestic prices				
Producer prices, official, 1974-75				
Paddy/millet-sorghum	1.38	1.25	1.68	1.77
Paddy/peanuts	1.00	1.00	0.88	1.03
Paddy/cotton	0.88	0.53	0.74	0.88
Consumer prices, 1975-76				
Rice/millet-sorghum, official	n.a.	2.15	1.91	n.a.
Rice/millet-sorghum, private	1.60	2.09	2.39	2.51
Rate of subsidy on fertilizers, 1975 [g]	68	38	60	53
Rate of subsidy on improved seeds, 1975 [h]	30-40	70	58	50
Rate of subsidy on animal traction equipment, 1975				
Plow	41	9	73	25
Cart	63	19	32	20

*Sources: Cereal prices for Senegal and Mali are from unpublished government records, see Scott R. Pearson et al. (forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University, Stanford, chs. 7 and 9. Cereal prices for Niger are from unpublished government market price series and Ministry of Agriculture (n.d.), "Prix des Produits Agricoles et des Engrais," those for Upper Volta are from Upper Volta (1979), Ministère du Plan et de la Coopération, *Situation Economique et Financière de la Haute Volta: Dossier d'Information Economique*, Ouagadougou and WARDA (1975, 1979), *Rice Statistics Yearbook*, Monrovia, Liberia. Input subsidies for seeds and fertilizers are based on real prices; see Appendix B. Private prices for seeds and fertilizers and subsidies for animal traction for Mali and Senegal are compiled from various sources; see Scott R. Pearson et al., *op. cit.* Official fertilizer prices for Niger and Upper Volta are from Niger, *op. cit.* and Upper Volta, Ministère du Développement Rural, Direction des Services Agricoles (1976), *Rapport Annuel 1975-1976*, Ouagadougou, Upper Volta, October, p. 83.; subsidy rates for seeds and equipment in Upper Volta and Niger are from working documents of the World Bank and U.S. Agency for International Development offices in Washington, D.C.

[a]This coefficient approximates the nominal protection coefficient. The wholesale market price is estimated at 90 percent of the observed retail market price. Values are yearly averages weighted by quantities imported.

[b]For 1967-75, with a range of 0.7 to 2.0.

[c]For 1969-75, with a range of 0.5 to 1.5.

[d]For 1962-76, with a range of 0.5 to 1.7. Because Nigerian prices appear unreliable or heavily influenced by concessional imports, Malian import prices have been used, reduced to take account of lower transport costs to Niamey.

[e]For 1962-76, excluding 1974 when concessional imports resulted in abnormally low prices. Values range from 1.6 to 2.0.

[f]As percent of official wholesale price.

[g]As percent of real market cost at delivery. The calculations used the expected long-run equilibrium of urea as the real price of fertilizer.

[h]The calculations use the estimated, area-wide cost of improved seeds. This value may cause the rate for Mali to be overestimated and for Senegal to be underestimated. The rate for Niger is based on a 1978 selling price for seeds, which may underestimate the extent of the subsidy.

As shown by the ratios of the domestic wholesale market prices to the import prices in Table 3, Malian trade policies have provided disincentives to rice producers, those in Senegal and Upper Volta have benefited producers, and trade policies in Niger have been neutral.

Domestic price policy has two dimensions—the relationship between producer and consumer prices, and the relationship between the prices of rice and of other commodities. The rate of subsidy or tax in the official price structure indicates whether official prices transfer funds to or from producers. Domestic price policies in Mali and Niger are rather neutral in this regard, those in Senegal subsidize producers, and those in Upper Volta tax producers, or they would do so if official prices were maintained and government purchases of paddy were significant. They seldom are.

Comparison of producer prices of rice and competing crops is not very helpful without information about production costs, which was not available, but it does reveal that in Mali, where more than half of the rice is grown, rice prices were less attractive relative to cotton, sorghum, and millet than in the other three countries.[5] Consumer prices for rice seem to be higher per thousand calories than consumer prices for sorghum and millets, consistent with rice's position as a preferred, prestige cereal.

SOCIAL PROFITABILITY OF RICE CULTIVATION UNDER ALTERNATIVE METHODS OF WATER CONTROL[6]

Seven basic systems of water control are employed in rice farming in the four countries. Two rely on uncertain surface flooding and attain yields of less than 1 ton per hectare with no modern inputs. The other five provide partial or complete water control, with yields of 2.5 tons per hectare for improved swamps and controlled flooding and 3.5 tons per hectare for dams and pumping systems.

Table 4 shows estimated social costs and profitability of each of the seven systems employing manual cultivation and with varying assumptions about farm wage rates and cost of marketing imported rice. The social costs of rice cultivation at the farm-level vary from a low of about 55 francs per kilogram (kg) on unimproved swamps in the interior countries to a high of over 80 francs in Senegal.[7] The greatest part of this difference is caused by variations in the method of water control. Rice cultivation is cheapest by a wide margin on unimproved inland swamps, mostly found in Mali. Most expensive is production on improved swamps and on land irrigated by large pumps. Cost variations among the other methods are small. The rest of the difference in farm level costs is accounted for by the higher wage rates assumed for the coastal areas. When transport and milling costs are added, the cost of domestic rice production (assuming small-scale milling and shipment to capital cities) ranges from about 75-95 francs in the

[5] Mali also reports the smallest subsidies for fertilizers and ox plows, but this presumably does not much affect the competitive position of most of the rice in production, especially since almost no fertilizer is used, even on improved rices.

[6] For a description of methodology and calculation of social prices, see Appendix A. For the method of estimating inputs and outputs, see Appendix B.

[7] The exchange rate between the Communauté Financière Africaine franc and the U.S. dollar was 250/1 during 1975-76, the period for which the data are applicable.

TABLE 4.—SOCIAL COSTS AND NET SOCIAL PROFITABILITY OF PRODUCTION UNDER ALTERNATIVE SYSTEMS OF WATER CONTROL
(Francs per kilogram of rice)

	Senegal			Mali, Niger, Upper Volta		
	Social costs			Social costs		
Type of water control	Farm production of rice[a]	Total	NSP[b,c]	Farm production of rice[d]	Total	NSP[e]
Traditional						
Unimproved swamp (US)	64.8	83.3	-4.3	54.3	72.9	24.1
Uncontrolled flooding (UF)	80.1	98.7	-19.7	67.9	86.4	10.6
Partial water control						
Improved swamp (IS)	80.6	99.1	-20.1	76.0	94.6	2.4
Controlled flooding (CF)	68.0	86.5	-7.5	64.7	83.2	13.8
Full water control						
Diversion dams (D)	71.5	90.0	-11.0	67.7	86.3	10.7
Small-scale pumping (SP)	68.5	87.1	-8.1	64.8	83.3	13.7
Large-scale pumping (LP)	81.0	99.5	-20.5	77.2	95.8	1.2

*Sources: Based on the best estimates of costs available, including technical coefficients and observed practices and prices (see Appendix B). Although budgets represent somewhat artificial systems, results nonetheless appear to represent fairly well what is known about actual conditions. Detailed budgets are available from the authors on request. Work is done manually in all systems. Transplanting is assumed for all methods except traditional (US and UF) and controlled flooding (CF). Farmers are assumed to use high-yielding seed varieties, fertilizers, and insecticides for all techniques except traditional (US and UF). Adequate and punctual weeding is assumed for all systems. Processing is assumed to be by small-scale, steel hullers, with appropriate associated collection and distribution costs.

[a] Based on farm wages of 250 francs per day.

[b] Net social profitability, which equals world price less total social cost.

[c] Based on a world price of 97 francs per kg.

[d] Based on farm wages of 200 francs per day.

[e] Based on a world rice price of 79 francs per kg.

inland countries to about 85 to 100 francs in the coastal areas. These relationships all depend, of course, on the reliability of assumptions about wage rates and transportation costs.

More interesting is the differing impact of wage rates on social costs of the labor-intensive traditional methods, where a 25 percent increase in wages results in an 18 percent increase in total costs, whereas such a wage increase raises costs of more modern methods by only 5 or 6 percent.

Net social profitability (NSP) is the difference between the costs of imported and domestic rice. In coastal areas (Senegal) where wages are higher, all methods show costs higher than the price of imported rice, making the NSP negative. Lower wage rates in the interior (Mali, Niger, and Upper Volta) and high costs of hauling imported rice inland from the ports, however, make social costs less than the cost of imported rice delivered to the interior. Here, domestic rice production is socially profitable, albeit by only narrow margin for improved swamps and large-scale pumping.

Controlled flooding, largely limited to Mali, appears to be an attractive alternative when land appropriate for traditional methods is exhausted. Its favorable profitability basically results from the low incremental cost of the water control it provides.[8] But it depends on regularly obtaining the assumed yields which may be difficult with this method's only partial water control and more extensive cultivation.

Full water control seems to offer few if any gains over systems requiring smaller investments. Although yields are higher with full water control, so are incremental costs per unit of output (Table 5). Physical gains appear to be more than offset by increased costs, especially for dams and large-scale pumping. The divergence is in fact probably greater than is shown in Table 5 because yields tend to be higher on the small holdings and lower on the large ones associated with major irrigation schemes.

SOCIAL PROFITS AT ALTERNATIVE LOCATIONS AND WITH ALTERNATIVE MILLING TECHNIQUES

The location of production and consumption, and the kind of processes used in rice milling, also affect the competitive position of domestic rice producers. Senegal pays lower prices for imports of rice than do Mali, Niger, and Upper Volta because most rice is consumed near Dakar, whereas the other three countries must pay large inland transport costs. (Prices and transport costs are given in Table 6.)

The interior countries have an important locational advantage in substituting domestic for imported rice. Transport costs provide a significant protective barrier against imports into these landlocked countries, so that rice can be produced at higher social costs and still be competitive with imports. Conversely, of course, inland transport costs constitute a major barrier to rice exports.

Costs are also influenced by the distance between domestic centers of production and consumption. Three situations are examined: distribution costs for principal production areas and main consuming centers 250 to 350 kilometers

[8] Budget estimates are consistent with current results on the Niger delta polders in Mali (Pearson et al., forthcoming, ch. 10).

TABLE 5.—COSTS AND GAINS OF ALTERNATIVE METHODS OF WATER CONTROL*

Type of water control	Social costs of water control (*francs/ha*)		Target yield (*tons paddy/ha*)	Incremental social costs of obtaining target yield compared with yields obtained by other methods [a] (*francs/kg paddy*)			
	Investment annuity	Operation charges		UF	US	IS	CF
Traditional							
Unimproved swamp (US)	0	0	0.9	—	—	—	—
Uncontrolled flooding (UF)	0	0	0.6	—	—	—	—
Partial water control							
Improved swamp (IS)	32,000	10,000	2.5	—	26	—	—
Controlled flooding (CF)	18,000	10,000	2.5	15	—	—	—
Full water control							
Diversion dams (D)	53,000	15,000	3.5	23	26	26	40
Small-scale pumping (SP)	32,000	29,000[b]	3.5	18	20	9	23
Large-scale pumping (LP)	53,000	32,500[b]	3.5	29	33	44	58

*Sources: Based on information in Scott R. Pearson et al. (forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University Press, Stanford, Ca., chs. 2, 8, and 10, and on calculations from detailed production budgets that are available from the authors on request. Assumptions about farm production are the same as those summarized in Table 4.

[a] Values equal the additional social costs of water control divided by the change in yield of the two methods being compared. These figures show the extra cost per additional kg of paddy that must be paid for more secure water control to increase yields over those obtained under less certain techniques.

[b] Includes pumping charges.

TABLE 6.—RICE PRICES AND COSTS, 1975-76*
(Francs per kilogram)

Category	Senegal	Mali	Niger	Upper Volta
Price of rice c.i.f. West African port[a]	62.50	73.75	73.75	73.75
Handling, port charges, and margins	5.25	[b]	5.00	4.25
Inland transportation costs	—	23.05[c]	19.25	15.75
Price at capital city	67.75	96.8	98.0	93.75
Distance from port to capital city (*km*)	—	1,200	1,050	1,150

*Sources: The c.i.f. price of rice is taken from Scott R. Pearson et al. (forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University Press, Stanford, Ca., Appendix B, and Walter P. Falcon and Eric A. Monke (1979-80), "International Trade in Rice," *Food Research Institute Studies*, Vol. XVII, No. 3. Costs for handling, port charges, margins, and inland transportation are based on Scott R. Pearson et al., *op. cit.*, ch. 10. Distances are taken from Pneu Michelin (1975), *Africa–North and West*, Paris.

[a] Based on Thai 5 percent brokens priced at $350/ton, f.o.b., Bangkok, discounted 30 percent to adjust for 25-35 percent brokens except in Senegal, where discount is 40 percent to adjust for 100 percent brokens. Ocean freight estimated at $50/ton.

[b] Included in inland transportation cost.

[c] Average 1974-75.

(km) away; for local marketing within 50 km of the production point; and for distribution from remote areas 600 to 700 km away. The first situation represents the average distance of production from the capital cities in these countries, the second deals with local consumption, and the last is based on distances between the capital city and some of the new rice projects.[9] Distribution costs are cheapest for local consumption, and about 50 percent higher for shipment to capital cities. Development of the more distant production sites would further increase distribution costs to capital cities by another 50 percent.

The type of milling also affects costs, and two milling techniques presently employed in Sahelian countries are considered:[10] large-scale industrial milling and small steel-cylinder hulling. Large mills appear to cost about 50 percent more than small hullers. Transport costs to the mills generally are high because of poor roads and maintenance of vehicles, and they are higher for the large mills because they must draw their supplies from a larger area.

Total social returns, costs, and net profitability for these various locations and milling methods are shown in Table 7. In order to focus attention on location and milling techniques, only one water control system, dams, is considered; its costs are roughly midway between the least and most expensive improved water control systems (Table 4). For different methods of growing rice, however, the same ranking of locations and milling methods will hold as for the production system illustrated here.

In the three interior countries rice is most often processed in small mills and delivered over moderate distances to the principal city (Table 7, line 1). Details of the calculations of social costs for this situation are as follows in francs per kilogram of rice:

Production	67.7
Collection and milling, small huller	12.0
Transportation to main consumption center	6.5
TOTAL	86.2

Social profitability is higher if rice is consumed near where it is produced (line 2, Table 7).

New production areas are often sited at greater distance from the main urban centers, even though they are meant to supply them. This possibility is considered in line 3. Social profitability of domestic rice production can be positive even in Senegal when production and consumption both occur some distance from the ports (line 10).

ALTERNATIVE PRODUCTION TECHNIQUES

At a given location greater social profits can also be earned by adopting new techniques of rice production that either augment the resources available or raise their productivity. Such techniques include investments in irrigation, which

[9] These cost figures are based principally on Pearson et al. (forthcoming, ch. 10). Detailed budgets are available from the authors upon request.

[10] Hand pounding is not considered because it is not often used to process paddy for marketing and could not be relied upon to mill large quantities of additional paddy produced.

makes rice production possible even in the Sahel, and the use of improved seeds and fertilizers to obtain high yields and thereby to raise the productivity of capital invested in irrigation.

Despite the very high costs of land development and irrigation, land-saving innovations can be socially profitable in interior areas of West Africa as shown above, owing largely to natural protection and low wages. However, with higher wages as in the coastal regions, these improved irrigated techniques lose their social profitability and become drains on national resources. Improved rice production to substitute for imports shows social losses in Senegal and in other coastal, higher wage countries like the Ivory Coast (Pearson et al., forthcoming, chs. 2, 8).

In order to change social losses into profits for many improved systems of water control where wages are high, methods need to be developed to raise the productivity of labor absolutely and relative to that of other factors of production. The costs of rice production might be reduced by introducing any of a range of new techniques designed to substitute capital and other inputs for labor in land preparation, seeding, weeding, harvesting, and threshing by employing improved manual equipment, animal traction, small motors, large agricultural machinery, and chemicals.

Net gains resulting from eight different packages are summarized in Table 8.[11] Land preparation—usually accomplished in West Africa with a short-handled hoe—can be facilitated by using ox-drawn moldboard plows and harrows, two-wheeled power-tillers (10-15 horsepower), and small, four-wheeled tractors (about 35 horsepower) along with appropriate implements. Weed control—usually done entirely by hand in West Africa—can be facilitated by small, hand-pushed, one-row rotary hoes, tined-cultivators pulled by oxen, and selective chemical herbicides like 2-4-D and propanil. Mechanical weed control requires row seeding, either by hand or with mechanical drills. Finally, harvesting can be facilitated by motorized threshing and winnowing using a small axial-flow thresher powered by a small engine or a larger stationary thresher powered by its own motor and pulled by a tractor. This part of the analysis assumes that several innovations usually associated with the Green Revolution in Asia have already been adopted, including water control for irrigation, transplanting where required, careful and timely weeding, high-yielding seed varieties, fertilizers, and insecticides.

The most striking conclusion to emerge from Table 8 is the consistently favorable results for animal traction and improved manual equipment. The gains are especially large when land preparation and weeding are viewed as a package. These results are consistent with the growth of animal traction in Mali, Senegal, and the northern Ivory Coast (Pearson et al., forthcoming, chs. 2, 8, 10). The technique appears to be relatively less widely used in Niger and Upper Volta, although its use in the latter country seems to be spreading.[12] The costs of the ox

[11] Although some results are preliminary and subject to change as more information on new techniques becomes available, the major patterns emerging from Table 8 appear relatively insensitive even to significant changes in data and assumptions.

[12] Some observers have asserted that the high cost of keeping and using oxen makes them uneconomical (e.g., Delgado, 1978; Nicolas, n.d.; Zalla, 1976), arguing that farmers' incomes increase only marginally even with liberal subsidies and that the risk of damage to crops or loss of oxen strongly discourages their use.

package described here would have to increase by about one-third or more to eliminate the estimated net social gains.

The use of motorized techniques gives highly negative results, except under special conditions. Tractor plowing and seeding usually increase the cost of production, unless it is assumed that line seeding replaces transplanting, that yields can be maintained, and that wages are 25 percent higher than those used in

TABLE 7.—SOCIAL RETURNS, COSTS, AND PROFITS OF ALTERNATIVE LOCATIONS AND MILLING TECHNIQUES*
(Francs per kilogram of rice)

	Social returns (cost of imported rice, main consumption center)	Social costs	Net social profitability
Interior countries			
Small-scale hullers			
1. Production at average distance, consumption at main center	97.0	86.2	10.8
2. Consumption at production center	99.2	84.0	15.2
3. Production at distance, consumption at main center	97.0	89.9	7.1
Large-scale mills			
4. Production at average distance, consumption at main center	97.0	90.8	6.2
5. Consumption at production center	99.2	88.6	10.6
6. Production at distance, consumption at main center	97.0	94.5	2.5
Senegal			
Small-scale hullers			
7. Production at average distance, consumption at main center	79.0	86.2	-7.2
8. Consumption at production center	81.2	84.0	-2.8
9. Production at distance, consumption at main center	79.0	89.9	-10.9
10. Production and consumption distant from port	84.9	84.0	0.9
Large-scale mills			
11. Production at average distance, consumption at main center	79.0	90.8	-11.8
12. Consumption at production center	81.2	88.6	-7.4
13. Production at distance, consumption at main center	79.0	94.5	-15.5
14. Production and consumption distant from port	84.9	88.6	-3.7

*Source: See text.

Table 8. The use of large stationary threshers also fails to lower costs, and losses increase if tractors are used to transport paddy.

These comparisons suggest that major labor savings result not from mechanization itself, but rather from a shift to less intensive cultivation techniques that do not involve transplanting. The change from transplanting to direct seeding alone gives a net gain of about 3,400 francs (equivalent to 17 days of labor) for ox cultivation and about 5,100 francs (equivalent to 26 days of labor) for tractor cultivation. However, if the shift causes yields to fall by more than 100 kg/ha, there may be a net loss. Losses of this size are probable unless other improvements such as line seeding and improved weed control are adopted simultaneously.

Small mechanized threshers offer positive results; a doubling of their operating costs would be necessary to offset these estimated gains. But if winnowing labor cannot be saved as well, most of the gains disappear. Power tillers, on the other hand, seem unlikely to be profitable at current costs. Even if the area assumed to be cultivated were more than doubled to 25 ha per season (possible under favorable conditions, United Nations, 1976), returns would still be negative at assumed wage rates.

Although the most profitable type of weed control seems to be ox cultivation, use of herbicides could reduce costs, especially if it controlled weeds better and thereby raised yields. Even with no interactive effects on yields, the innovation would become profitable with modestly higher wage rates. If costs of herbicides in West Africa were as low as in Asia, it could even be very profitable.

Labor-saving technique	Percentage increase in value of labor productivity	Value of marginal product of nonlabor costs (francs saved per franc spent on nonlabor costs)
Ox cultivation, advanced package (land preparation, transport, line seeding, and weeding)		
Compared to transplanting	38 to 43	1.9
Compared to broadcast seeding	32	1.3
Ox cultivation, basic package (land preparation and transport only)	8 to 11	0.6
Small-scale threshers	6 to 7	1.1
Manual rotary hoe	5 to 6	10.0
Herbicides	-3 to -4	-0.2
Power tillers	-13 to -18	-0.4
Tractor-thresher package (land preparation, line seeding, threshing, and transport)		
Compared to transplanting	-71 to -76	-0.3
Compared to broadcast seeding	-98	-0.4

These various labor-saving techniques can be compared more directly by examining both the degree to which they increase the economic return to labor still used in production and by calculating the reduction in total costs relative to the increase in nonlabor costs (i.e., value of their marginal product):[13]

It is clear that ox cultivation increases labor productivity most. At the other extreme, the use of large motorized equipment could cause the return to labor to fall to zero. Manual equipment, very small motors, and chemicals affect labor productivity little. Improved manual equipment offers the highest returns to expenditures, although the physical scope for increases in productivity is relatively limited. With ox cultivation, total added expenses can be substantial relative to the net gain achieved.

The ranking of labor-saving techniques based on this analysis is consistent with expectations. In countries where both labor and capital are expensive, major improvements in the economic productivity of labor are unlikely to occur when substantial equipment services are substituted for labor. Simpler equipment that does not rely on motorized power provides good prospects for improving marginal returns, even though total labor saved may not be large. Conversely, highly mechanized methods lower the productivity, calculated in economic prices, of the labor that is actually used despite the great savings in labor time.

The effects of labor-saving innovations are summarized in Table 9. The coefficients can be used to assess the net effects on social costs that would result from the adoption of any of the new techniques for the various water control systems. As long as no significant interactions exist other than those noted in Table 8, the techniques can be added within each column, provided that only one method is chosen for land preparation, for weed control, and for motorized threshing. By comparing the expected changes in costs with NSP figures in Table 4, the possible effects of these new techniques on the profitability of rice production can be estimated. Decreases in costs raise the NSP, and increases lower it.

Calculations for the basic cases indicate that the rise in wage rates from 200 to 250 francs per day increases the social costs of production by 5 to 6 francs per kilogram milled rice. They also show that animal traction offers good potential for offsetting higher wage costs. If combined with small threshing machines, the use of oxen could increase social profitability by 6 to 8 francs per kilogram milled rice. The effects of motorized techniques are negative; the most advanced, involving both full mechanization and the use of herbicides, increases total social costs by 10 to 15 percent. This second type of innovation illustrates well a situation in which physical labor is saved but total costs rise. Indeed, the use of tractors, large threshers, and herbicides coupled with large mills would make unprofitable the currently profitable production in low wage inland areas. This result would be especially marked for controlled flooding.

[13] Equating the ratio of (a) what has to be spent on nonlabor costs to win a reduction in total costs with (b) the value of the marginal product of these nonlabor costs requires that the increase in nonlabor costs can be used either to reduce total costs (substituting for labor) or to increase output (no change in labor), and that the change in total revenue in one case equals the change in total costs in the other. In other words, the condition assumes a production function with constant elasticity of substitution.

TABLE 8.—NET SAVINGS OVER MANUAL CULTIVATION FROM CHANGES IN TECHNIQUES, INLAND COUNTRIES*

(Francs per hectare, except as noted)

Description	Labor saved (*days/ha*)	Value of labor saved[a]	Other indirect savings[b]	Additional direct costs of techniques	Other indirect costs[c]	Possible yield effects	Net gain
Basic manual system, dam irrigation[d]	250	50,000	—	104,108	—	3.5	—
Ox land preparation and transport	36-41	7,800[e]	812[f]	5,264	112	ambiguous	3,236
Power tillers	45	9,000	860[f]	14,410	576	nil	-5,126[g]
Tractor plowing, seeding, and transport[h]							
Compared to transplanting	95	19,000	1,760[i]	21,051[g]	2,697	negative	-2,988
Compared to broadcasting	58	11,600	3,024[i]	22,209	521	ambiguous	-8,106
Manual rotary hoe	12	2,400	48	223	0	nil	2,225
Ox-drawn seeder and weeder							
Compared to transplanting	55	11,000	720[f]	972	2,186[j]	negative	8,562
Compared to broadcasting	20	4,000	2,140[f,k]	972	2	positive	5,166
Herbicides	30	6,000	120	7,070	274	nil	-1,224
Small motorized threshers							
2.5 mt/ha yield	23	4,500	0	2,120	0	positive	2,380
3.5 mt/ha yield	32	6,300	0	2,968	0	positive	3,332
Large-scale stationary threshers[l]							
Without transport	27	5,400	0	13,045	0	negative	-7,645
With transport by tractor	37	7,400	0	17,122	0	negative	-9,722

*Source: Figures are based on assumptions summarized in Appendix B and on data in detailed farm budgets that are available from the authors. For comparative purposes, production information is given for manual production under irrigation with diversion dams.

[a]At 200 francs/day.

[b]Includes estimated interest on working capital for labor and other inputs saved.

[c]Includes the estimated value of charges for working capital on expenses for operation and maintenance of new equipment and on other additional inputs.

[d]Values are totals per ha, not incremental savings or costs.

[e]Based on 39 labor days.

[f]Includes 500 francs saved because there is less use of hand tools.

[g]Assumes double cropping.

[h]Requires 35 hp tractor, disc plow, disc harrow, seed drill, and trailer.

[i]Includes 1,000 francs for hand tools.

[j]Includes 35 kg extra seeds for drilling.

[k]Includes 25 kg seeds saved by drilling

[l]Assumes yields of 3.5 tons/ha.

TABLE 9.—EFFECTS OF LABOR-SAVING INNOVATIONS*
(Francs per kilogram of rice)

Production system	Method of water control[a]						
	US	UF	IS	CF	D	SP	LP
	Total social costs (farm production, milling, transport)						
Base case 1: manual, wages at 200, inland	54.3	67.9	76.0	64.7	67.7	64.8	77.2
Base case 2: manual, wages at 250, inland	64.8	80.1	83.2	70.6	73.3	70.4	82.8
Base case 3: manual, wages at 250, coastal	64.8	80.1	80.5	68.0	71.5	68.5	81.0
	Changes in farm costs under new techniques[b]						
Land preparation							
Ox plowing and transport (basic package)	5.5	8.3	1.5	2.3	1.2	2.3	2.3
Power tiller	—	—	-4.3	-4.3	-3.1	-2.2	-2.2
Tractor plowing, seeding, and transport	—	—	—	-5.0	-1.8	—	-1.3
Weed control							
Manual rotary hoe	—	—	1.4	—	0.9	0.9	0.9
Ox seeding and weeding	—	—	5.2	3.2	3.7	4.0	4.0
Herbicides	—	—	-0.8	-0.8	-0.5	-0.5	-0.5
Threshing							
Small threshers	—	—	1.4	1.4	1.4	1.5	1.5
Large threshers excluding transport costs	—	—	—	-3.9	-3.9	—	-3.3

Combination							
Advanced ox package	—	—	6.7	5.5	4.9	6.3	6.3
Advanced ox package with small threshers	—	—	8.1	6.9	6.3	7.8	7.8
Tractor plowing, seeding, and transport with large thresher	—	—	—	-8.9	-5.7	—	-4.6
Tractor plowing, seeding, and transport, large thresher, and herbicides	—	—	—	-9.7	-6.2	—	-5.1

*Sources: Figures are calculated largely from data presented in Tables 4 and 8. Details are contained in budgets that are available from the authors on request. See also comments on Table 4.

[a]Initials denote unimproved swamp (US), uncontrolled flooding (UF), improved swamp (IS), controlled flooding (CF), diversion dams (D), small pumps (SP), and large pumps (LP).

[b]Positive signs represent reduced costs, negative signs increased costs.

Moving from inland to coastal areas decreases costs in all improved systems by about 2 francs per kilogram because of lower costs of imported fertilizers. The accompanying loss of natural protection near the coast, however, means that net social profitability falls by roughly 16 francs per kilogram because imported rice is cheaper (Table 4). It is clear that neither a single new technique nor any feasible combination of them can reduce costs sufficiently to compete with lower costs of imported rice on the coast. However, savings from the use of oxen and small threshers could give some inland areas the potential to compete with imported rice in West African coastal cities, and Sengalese rice produced on both unimproved swamps and land irrigated with small pumps could become socially profitable in Dakar.

The effects of these new techniques can be illustrated by considering again improved farm production techniques under dam irrigation. As Table 10 shows, labor in the fully manual system constitutes one-third of total costs and accounts for almost two-thirds of costs exclusive of investment and maintenance costs for water control. Each labor day produces 14 kg of paddy, roughly double the productivity in traditional systems. The use of the advanced ox cultivation package together with small threshers could double the physical productivity of labor (relative to manual cultivation), and the use of tractors, herbicides, and threshers could almost triple it, assuming yields can be maintained. At the same time, labor's share of total costs would fall to only 10 to 20 percent and to no more than one-third of costs exclusive of water control.

As shown in Table 11, these savings are made possible largely by increases in equipment and, to a lesser extent, increases in intermediate inputs. Although all labor-saving innovations increase the physical productivity of direct farm labor, only those that lower total costs can make the remaining labor more efficient economically. Some of the motorized systems that offer the largest reduction in labor inputs also have the highest costs of production.

These results indicate that in West Africa there are only limited ways of saving labor economically. Despite the relatively high cost of African farm labor, new techniques, except perhaps animal traction, are sufficiently costly to preclude their extensive use to raise the productivity of labor in growing rice. If new techniques are to be made attractive to farmers, policies need to be tailored to reduce their high cost.

Two approaches might help in the short term. Some changes in farm practices may raise yields with little increase in labor costs. Changes in the timing and method of land preparation, planting, chemical applications, and harvesting, for example, can increase yields significantly, but they require good water control as well as good management. In West Africa, the marginal cost of good water control is high, and new farming practices are often not adopted because they are, in fact, uneconomical, given binding seasonal labor constraints. Furthermore, machinery that is cheaper, more robust, and less expensive to operate can be substituted for labor at small increase in overall costs. Major improvements are unlikely to occur, however, until the development of infrastructure and institutions reaches the point where capital equipment and other inputs can be provided at lower prices and used more efficiently.

ACCOMPANYING POLICY CHANGES

A critical assumption in social profitability analysis is that distorting government policies are ignored. The analysis thus far has, in effect, assumed away any policies that would provide incentives (subsidies) or disincentives (taxes) to rice production. The findings are that for the interior countries all seven basic systems of water control have positive social profits and would therefore be privately profitable as well, in the absence of price-distorting policies. Conversely, none of the seven methods is socially profitable for Senegal, and hence each would require government support before it would be privately profitable there. If the objective were to expand rice production efficiently (to maximize increases in income), none of the governments would need to intervene at all, and additional rice would be produced in the inland countries and not in Senegal. But if Senegal sought another solution for reasons of self-sufficiency, it would need to find some combination of higher rice prices, mainly through restrictions of imports of rice, and subsidies of capital or recurrent inputs to make any of these techniques profitable for farmers, millers, and traders in most of Senegal.

All four countries in fact employ a wide range of policies which affect the private profitability of rice farming. Domestic rice prices are raised or lowered relative to the import price by taxes and subsidies. During the past several years, the Malian government has set the domestic market price 10 percent below the import price. If the Malian government were to maintain this policy, the future long run market price of rice would be 87 francs per kilogram instead of the expected import price, 97 francs per kilogram. In Niger the government seems to have followed a neutral trade policy, and domestic and world prices are approximately equal. The two other countries on average have protected rice, causing local prices to exceed world prices. Senegal prices have been about 140 percent of c.i.f. prices. At a future world price of 79 francs per kilogram, this translates into a domestic price of 111 francs.[14] In Upper Volta, imports have been limited to such an extent that local prices have been about double the world price; if this policy were continued in the future, the domestic price might be as high as 188 francs per kilogram.

All of the Sahelian countries establish official farm and wholesale prices for rice. In the absence of effective buffer stock mechanisms, these official prices prevail in actual market transactions in only two situations: first, if the government happens to set the producer price high enough (and the consumer price low enough) so that its official marketing agency becomes competitive in the market, i.e., it approximates the market-clearing prices; and, second, if the official agency has access to supplies from government projects or can enforce compulsory deliveries at lower than market prices. When governments obtain paddy at below market prices, they transfer income from vulnerable producers to selected consumers. But typically governmental marketing agencies do not have the policing power to influence the market price of rice much, and price is maintained instead though trade policy.

[14] See Appendix A for a discussion of Senegalese rice import prices.

TABLE 10.—FARM LABOR INPUTS WITH DAM IRRIGATION*

New techniques	Total labor (*days/ha*)	Physical productivity of labor (*kg paddy/ labor day*)	Direct labor as percent of total costs	Direct labor as percent of costs exclusive of water control
Base case: manual, inland	250	14.0	32.4	58.1
Ox plowing and transport (basic package)	213	16.4	28.1	51.1
Power tiller	205	17.1	25.3	43.7
Tractor plowing, seeding, and transport	155	22.6	19.2	33.2
Manual rotary hoe	238	14.7	31.3	56.7
Ox plowing, seeding, weeding, and transport	158	22.2	22.1	42.1
Herbicides	220	15.9	28.3	50.3
Small threshers	218	16.1	28.9	52.5
Advanced ox package with small threshers	126	27.8	18.1	35.1
Large thresher, excluding transport costs	222	15.8	27.2	46.7
Large tractors and large threshers	127	27.6	15.1	25.4
Tractors, large threshers, and herbicides	97	36.1	11.5	19.2

*Source: Figures are calculated largely from information given in Tables 4, 8, and 9. Additional details are contained in budgets that are available from the authors on request. Labor is valued at 200 francs per day. See also comments on Table 4.

Nevertheless, it is interesting to examine price policy to obtain an idea of government transfers (subsidies or taxes) that are implied for the rice that does move through official channels. Table 12 shows official wholesale and consumer prices and costs of collection, milling, and distribution in 1976. In Niger the official price system appeared to be about in balance, since estimated private marketing costs were approximately equal to the difference between official consumer and producer prices, and the government treasury neither subsidized nor taxed the system to any important extent. Nearly the same conclusion holds for Mali, although Malian price policy resulted in a subsidy cf 3 francs per kilogram, or 5 percent of the official consumer price. In contrast, Senegal, which reduced its official consumer price from 94 francs to 74 francs in 1976 without lowering its official producer price, has had to subsidize official purchases by about 39 percent of its new consumer price. The opposite result appears to hold for Upper Volta, but the reported marketing costs for that country seem unusu-

TABLE 11.—TOTAL FARM COSTS WITH DAM IRRIGATION*
(Thousand francs)

New techniques	Total social costs: Per ton milled rice	Total social costs: Per hectare[a]	Costs for inputs (*per hectare*): Direct labor	Equipment	Intermediate inputs	Land investment	Working capital
Base case: manual, wages at 200 per day, inland	67.8	154.1	50.0	2.5	31.5	68.0	2.2
Ox plowing and transport (basic package)	66.6	151.4	42.6	7.3	31.5	68.0	2.1
Power tiller	71.1	161.7	41.0	19.0	31.5	68.0	2.2
Tractor plowing, seeding, and transport	70.9	161.3	31.0	26.4	33.6	68.0	2.3
Manual rotary hoe	66.8	152.0	47.6	2.7	31.5	68.0	2.2
Ox plowing, seeding, weeding, and transport (advanced)	62.8	143.0	31.6	7.8	33.6	68.0	2.0
Herbicides	68.3	155.4	44.0	2.5	38.5	68.0	2.4
Small-scale threshers	66.5	151.2	43.7	5.8	31.5	68.0	2.2
Advanced ox package with small-scale threshers	61.5	140.0	25.3	11.1	33.6	68.0	2.0
Large-scale threshers, without transport	71.6	163.1	44.4	17.0	31.5	68.0	2.2
Tractors and large threshers	73.9	168.1	25.4	40.9	31.5	68.0	2.3
Tractors, large threshers, and herbicides	74.4	169.3	19.4	40.9	38.5	68.0	2.5

*Source: See Table 10.
[a] Details may not add to totals because of rounding.

ally low, and their possible underestimation could explain the apparent tax in the official pricing system.[15]

The third type of government policy affecting private profitability of rice production involves subsidies on investment or recurrent inputs. Clearly, input subsidies will differ by production technique and project. For purposes of illustration here, attention in Table 12 is restricted to subsidies associated with dams. Land improvements and maintenance and extension services are assumed to be free and represent subsidies of 29.9 and 4.4 francs per kilogram, respectively. The degrees of subsidization of fertilizers and of seeds differ among the countries; they range in total from 2.5 francs per kilogram to 3.7. Taken together the four input subsidies amount to more than half of social costs of rice farming in all countries, largely because of the massive subsidy on land improvement.

The net impact of government policies in this example can be shown for the prototypical technique assuming that recent policies remain in effect. In Mali trade policy reduces private profitability by 10 francs per kilogram, but this effect is more than offset by input subsidies that increase profitability to farmers by 37 francs per kilogram.[16] If the government neither taxes nor subsidizes marketing, the net transfer to farmers would be 27 francs per kilogram. In Senegal the effect of government policies would be to transfer to producers 69 francs per kilogram, 32 francs from trade policy and 37 francs from input subsidies resulting in high private profitability of a socially unprofitable technique. The effect in Niger and Upper Volta, which begin with modest levels of positive social profitability, would be to enhance private profitability greatly. In short, trade and input subsidy policies of all four governments—with the single exception of Malian trade policy—transfer income to producers and thus make rice growing more privately profitable.

With respect to all seven methods of water control, high wage, coastal areas (i.e., Senegal) incur only social losses. At coastal wage rates some water control methods also give social losses in inland areas (e.g., Mali). The question then arises as to why Senegal—or any country experiencing negative social profitability—would desire to expand rice output. The answer mainly centers on the importance of alternative objectives, such as enhancing food security or distributing income.[17] To expand output in Senegal with any of the seven methods, the amount of social loss would have to be offset by transfers through government policy if farmers were to be persuaded to engage in the illustrated technique.

[15] Both WARDA (1975) and Gotsch et al. (1978) report private marketing and milling costs in Upper Volta of roughly 15 francs per kilogram. The systems used in the quantitative analysis in this paper suggest that these costs, including indirect taxes, should equal about 25 francs per kilogram. This would lower the tax to 2 instead of the 12 shown in Table 12.

[16] Total subsidies may in fact be somewhat less than this example suggests. Mali demands a user fee from farmers participating in government irrigation projects (in 1975-76, in Mopti this fee equaled 100 kg of paddy per hectare, for example), and the seed subsidy might be lower because improved seeds can apparently be produced more cheaply there than elsewhere. Furthermore, in Mali most production is not fully manual, as is assumed for this illustration.

[17] This set of issues is discussed in Pearson et al. (forthcoming, ch. 7).

SUMMARY AND CONCLUSIONS[18]

A technique generates social profits if, in the hypothetical absence of distorting government policies and imperfections in product and factor markets, the value of its output exceeds the costs of its inputs. According to this measure of economic efficiency, the least costly technique for producing rice in all situations is traditional cultivation on unimproved swamps. The combination of improved water control and modern, yield-increasing inputs cannot compete effectively with this basic system, and total costs per kilogram of rice rise in every case. The most efficient means of producing rice under secure water control appears to be by irrigation with small pumps. Even in high-wage countries, where it is currently practiced, it is nearly competitive with unimproved swamps, and in all cases it is better than traditional, uncontrolled flooding. Two other attractive alternatives include controlled flooding—although the system assumed is largely hypothetical and depends importantly on high yields being obtained—and diversion dams, if double cropping can be achieved. Production on improved swamps and with large pumps is most expensive, with costs per kilogram of rice some 40 percent above the least expensive, unimproved techniques and 15-20 percent above the more attractive improved alternatives.

Location affords the three interior Sahelian countries (and remote areas of Senegal) substantial natural protection from competition with outside supplies because rice imports incur high inland transportation costs. Mali, Niger, and Upper Volta could produce rice with social costs as much as 20 percent higher than those in Senegal and still be competitive with foreign supplies. Largely because of this high degree of natural protection, manual production (at wages of 200 francs per day) on all seven of the base water control methods is socially profitable in the interior countries, but none is in Senegal. For improved systems, the higher inland cost of imported inputs is more than offset by the higher world price of rice and the lower cost of labor in these inland countries. The margin is as much as 11-14 francs per kilogram of rice (or 10-15 percent of its social value) for some of the improved systems, but it is nearly inexistent for production coming off improved swamps and fields irrigated by large-scale pumping. Natural protection also permits efficient substitution of local production for imports in areas distant from ports. With respect to milling, large-scale mills incur social costs nearly 40 percent greater than those of small-scale hullers, and this cost premium is about 5 percent of social returns.

None of the labor-saving changes considered here appears to offer large cost reductions. Despite the fact that all of the innovations raise the physical productivity of labor used in producing rice, few increase the total economic productivity of the activity, as indicated by the decline in social profits or increases in social losses. By and large, the most favorable reductions in costs are given by

[18] These conclusions reflect the conditions appropriate to the typical production systems and are based on expected long run prices for rice and major inputs. Although this analysis is illustrated only with one improved system—dam irrigation—the others could be treated similarly. The systems described here are, by necessity, modal types that mask the large variations that may be observed among seemingly similar projects. Results for any individual production scheme may be better or worse, depending on technical coefficients and government policies that are specific to it.

TABLE 12.—EFFECTS OF GOVERNMENT POLICIES ON PRIVATE COSTS AND PROFITABILITY OF DIVERSION DAMS, 1976*

(Francs per kilogram of rice)

	Senegal	Mali	Niger	Upper Volta
I. Trade policy				
A. Cost of imported rice	79[a]	97	98	94
B. Wholesale market price of rice	111	87	98	188
C. Transfer to producers	32	-10	±	94
II. Price policy				
A. Official wholesale price of rice	74	55	81	81
B. Official producer price of rice	64	31	54	54
C. Costs of collection, milling, and distribution	39	27	26	15
D. Subsidy or tax(-) necessary to maintain official prices	29	3	-1	-12
III. Input subsidy policy				
A. Land improvements and maintenance				
1. social costs	29.9	29.9	29.9	29.9
2. private costs	0	0	0	0
B. Extension services				
1. social costs	4.4	4.4	4.4	4.4
2. private costs	0	0	0	0
C. Fertilizers				
1. social costs	3.35	5.1	5.1	5.1
2. private costs	1.1	3.2	2.0	2.4

D. Seeds				
1. social costs	1.1	1.1	1.1	1.1
2. private costs	0.8	0.3	0.5	0.6
E. Social and private costs of unsubsidized inputs[b]	32.9	27.3	27.3	27.3
F. Total social costs of farming	71.5	67.7	67.7	67.7
G. Total private costs	34.8	30.8	29.8	30.3
H. Total input subsidies	36.7	36.9	37.9	37.4
I. Ratio of total input subsidies to total social costs	0.51	0.55	0.56	0.55

*Source: Based primarily on information given in Table 3 and on data contained in detailed budgets that are available from authors on request.
[a]Assumes 25-35 percent brokens; see Appendix A.
[b]Farm labor, insecticides, small tools, and working capital.

techniques using improved tools and animal traction, while the greatest increases in costs are incurred for large-scale mechanization. The most promising, animal traction, decreases social costs by less than 10 percent, or about 6 francs, while the worst, a combination of tractors, large threshers, and herbicides, raises social costs by nearly 10 percent. In general, the degree of social profitability declines with increases in the capital intensity and scale of the labor-substituting innovations. Even the earnings of labor remaining in rice production fall when highly intensive, motorized techniques and chemicals are used, despite the favorable assumptions underlying the estimates.

In general, the four countries have provided substantial positive incentives to rice production. All offer large input subsidies, amounting to more than half of estimated social costs of production in the improved production systems; the main subsidy is on land improvement and maintenance which are often provided virtually free to farmers. Because of quite different effects of trade policies, net transfers to rice producers from government policy appear to be modest in Mali, somewhat larger in Niger, substantial in Senegal, and very high in Upper Volta. In all countries, the existing set of policies creates incentives that are more than sufficient to offset any underlying negative social profits in the seven basic methods of production.

The analysis points up some of the difficulties faced by Sahelian countries to expand their food production, as well as the inappropriateness of much of the new agricultural technology borrowed from Asia and applied to Sahelian conditions. Despite the importance of water control coupled with a package of improved seeds, fertilizer, and insecticides in raising yields and expanding physical output of rice, these new techniques are often not efficient except where geographic isolation reduces wages and provides natural protection. The high capital costs of increasing water control are seldom offset by sufficiently higher yields. Moreover, the capital and operating costs of replacing labor are often not compensated by the value of the labor saved. As a result, higher productivity for major primary factors—land and labor—is won using intermediate inputs and capital investments that often raise, rather than lower, total costs. Economic productivity declines.

To overcome this dilemma of being unable to expand production profitably, most governments must subsidize often inefficient rice production, wasting both scarce public funds and national resources. The study suggests a few orientations for development that may help alleviate the difficulties. In the near-term, small-scale, decentralized production systems (e.g., tillage by oxen, irrigation by small pumps, use of portable, motorized threshers) should be encouraged. Not only do these make farmers less dependent on centralized, highly sophisticated services and equipment, but their costs may fall and their efficiency may rise as support facilities and infrastructure develop to meet the growing demand. Over the longer run, research efforts might profitably focus on the development and use of cheaper, more robust equipment, and governments might promote repair and service institutions to increase the effectiveness of this equipment. Eventually, yields must be made to rise through more intensive management and husbandry to make better use of modern inputs and irrigation water. Such intensification will be attractive in African conditions only when real returns to labor also rise.

CITATIONS

*Alicbusan, L.C. (1965), "The Rate of Substitution of Man Hours by Animal or Machine Horsepower-Hours in Rice Production," International Rice Research Institute, Los Banos, Philippines.

*Barker, Randolph et al. (1972), "Employment and Technological Change in Philippine Agriculture," *International Labor Review,* Vol. 106, Nos. 2-3, August-September.

*Bono, M., J. d'Arondel de Hayes, and R. Vandevenne (1978), "Le Coûtu Semences Selectionnées et Conditionnées d'Espèces Vivrières: Mil, Sorgho, Maïs, Riz, Niébé, "*L'Agronomie Tropicale,* Vol. 33, No.2.

*des Bouvries, C. and J.R. Rydzewski (1977), "Irrigation," in C.L.A. Leakey and J.B. Wills, eds., *Food Crops of the Lowland Tropics,* Oxford University Press, Oxford.

Byerlee, Derek (1979), "Rural Labor Markets in West Africa with Emphasis on the Semi-Arid Tropics," paper presented at the Workshop on Socio-economic Constraints to Development of Semi-Arid Tropical Agriculture, ICRISAT, Hyderabad, India, February 19-23.

Chabrolin, R. (1977), "Rice in West Africa," in C.L.A. Leakey and J.B. Wills,eds., *Food Crops of the Lowland Tropics,* Oxford University Press, Oxford.

Chandavarkar, Anand G. (1971), "Some Aspects of Interest Rate Policies in Less Developed Economies: The Experience of Selected Asian Countries," *International Monetary Fund Staff Papers,* Vol. 18, No. 1, March.

Comité Inter-état pour la Lutte Contre la Sécheresse dans le Sahel (CILSS) (1980), Club du Sahel, *The Development of Irrigated Agriculture in the Sahel,* "Review and Perspectives," Paris.

*DeDatta, S.K. and Randolph Barker (1977), "Economic Evaluation of Modern Weed Control Techniques," in J.D. Fryer and S. Matsunaka, eds., *Integrated Control of Weeds,* University of Tokyo Press, Tokyo.

*DeDatta, S.K., R.A. Morris, and Randolph Barker (1978), "Land Preparation and Crop Establishment for Rainfed Lowland Rice," International Rice Research Institute, Los Banos, Philippines, November.

Delgado, Christopher L. (1978), "An Investigation of the Lack of Mixed Farming in the West African Savannah: A Farming Systems Approach for Tenkodogo, Upper Volta," Discussion Paper No. 74, Center for Research on Economic Development, University of Michigan, Ann Arbor, November.

*Duff, B. (1978), "Mechanization and Use of Modern Rice Varieties," in International Rice Research Institute, *Economic Consequences of the New Rice Technology,* Los Banos, Philippines.

Etasse, C. (1977), "Sorghum and Pearl Millet," in C.L.A. Leakey and J.B. Wills, eds., *Food Crops of the Lowland Tropics,* Oxford University Press, Oxford.

Falcon, Walter P. and Eric A. Monke (1979-80), " International Trade in Rice," *Food Research Institute Studies,* Vol. XVII, No. 3.

Fisher, H.J. (1977), "The Eastern Magrib and the Central Sudan," in R. Oliver, ed., *The Cambridge History of Africa,* Vol. 3, Cambridge.

*Gotsch, Carl H., John McIntire, Frederick Roche, and J. Dirck Stryker (1978), "Investment in Large-scale Infrastructure, Irrigation, and River Basin Management in the Sahel," U.S. Agency for International Development Sahel

Infrastructure Policy Study, Food Research Institute, Stanford, November.

*International Rice Research Institute (1979), "Constraints to Rice Production," *Annual Program Review*, Los Banos, Philippines, January.

*International Rice Research Institute and Institute of Agricultural Engineering and Technology, University of the Philippines (1978), "The Technical and Economic Characteristics of Rice Postproduction Systems in the Bicol River Basin," Los Banos, Philippines.

*Ivory Coast (1976), Ministère de la Recherche Scientifique, Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, *Rapport Annual 1975*. Bouaké.

Maton, Guy (1976), "Les Possibilités de Développement des Ressources en Eau du Sahel de l'Afrique de l'Ouest," *L'Economie des Pays du Sahel*, EDIAFRIC-La Documentation Africaine, Paris.

McKinnon, Ronald I. (1973), *Money and Capital in Economic Development*, Brookings Institution, Washington, D.C.

*McMennamy, John A. and Jose S. Policarpio (1977), "Development of a Portable Axial-Flow Thresher," International Rice Research Institute, Paper No. 77-06, Los Banos, Philippines.

Murray, David (1978), "Statistical Measurement of Export Earnings Instability," *Malayan Economic Review*, Vol. 23, No. 1.

Nicolas, Guy (n.d.), "Introduction de la Culture Attelée au Sein d'une Société Hausa (Vallée de Maradi, Niger)," n.p.

Olivier de Sardan, Jean-Pierre (1969), "Système des Relations Economiques et Sociales Chez les Wogo (Niger)," *Memoires de l'Institut d'Ethnologie, III*, University of Paris, Paris.

*Pearson, Scott R., J. Dirck Stryker, and Charles P. Humphreys et al. (forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University Press, Stanford.

Pearson, Scott R., N. Akrasanee, and Gerald C. Nelson (1976), "Comparative Advantage in Rice Production: A Methodological Introduction," *Food Research Institute Studies*, Vol. 15, No. 2.

Peter, Jean (1976), "Les Ouvrages de Régularisation de la Première Génération Envisagés d'Ici 2050," *L'Economie des Pays du Sahel*, EDIAFRIC-La Documentation Africaine, Paris.

*Poulain, J.F. et al. (1976), "Amélioration de la Fertilité des Sols Agricoles au Mali: Bilan des 13 Années des Travaux (1962-1974)," *Agronomie Tropicale*, Vol. 32, No.4.

*Pradhan, S.N. (1968), "Recent Improvements Made to Hand Operated and Animal Drawn Rice Cultivation Equipments," Cinquième Session du Comité International du Riz, Groupe de Travail sur les Aspects de Genie Agricole de la Production, du Stockage, et de l'Usinage du Riz, Kandy, Ceylon, September 5-8.

*Sinka, M.P. (1968), "A Report on the Recent Improvement Made to Hand-Operated and Animal-Drawn Rice Cultivation Equipment," Cinquième Session du Comité International du Riz, Group de Travail sur les Aspects de Genie Agricole de la Production, du Stockage, et de l'Usinage du Riz, Kandy, Ceylon, September 5-9.

*Stout, B.A. (1966), *Equipment for Rice Production,* United Nations Food and Agriculture Organization, Agricultural Development Paper No. 84, Rome.

*United Nations, Food and Agriculture Organization and the Agricultural University of Wageningen (1976), *Mechanization of Rice Production: India-Nigeria-Senegal,* Rome.

West Africa Rice Development Association (1975), "The Irrigated Rice Area of the Kou Valley, Upper Volta," Case Study No. 1, Monrovia, June.

World Bank (1980), *World Tables,* Second Edition, Johns Hopkins University Press, Baltimore.

Zalla, Tom (1976), "A Proposed Structure for the Medium-Term Credit Program in the Eastern ORD of Upper Volta," U.S. Agency for International Development, Washington, D.C., February.

APPENDIX A
SOCIAL PRICES FOR DOMESTIC FACTORS AND RICE

Net social profitability is a measure of economic return in the absence of distorting government policies and imperfections in factor markets. Discussions of assumptions and qualifications associated with this concept are contained in Pearson et al. (forthcoming, Appendix A) and in Pearson et al. (1976). Market imperfections due, for example, to economies of scale or the existence of externalities or monopoly elements in the economy, are difficult to measure and are probably not so quantitatively important as the distortions introduced by government. Hence, emphasis here is placed on the effects of government policies.

Shadow Prices of Domestic Factors

There are three considerations in determining appropriate shadow prices. (Those used in the calculations are given in Table A.1.) The first is scarcity. A factor is considered to have a positive shadow price only when it is scarce, that is, when increased use of that factor in rice production will cause output elsewhere to diminish. Land is considered to be abundant, provided adequate water can be supplied. Therefore, land has a zero shadow price, although the cost of delivering water must be accounted for in land development costs and in the operation and maintenance of irrigation systems. In certain localities near towns where good flood land is available, local markets in land exist (Nicolas, n.d.; Olivier de Sardan, 1969), but these private land prices reflect localized scarcity and the lack of investment that would augment the supply of wet land, not a land shortage in the economy.

The shadow price of a scarce factor will be adequately approximated by its market price if imperfections and other distortions in the market are minor. These conditions are largely fulfilled for labor. Analysis in Mali, Senegal, and forest-zone countries indicates that labor markets function well and are closely integrated.

TABLE A.1.—SHADOW PRICES USED IN ANALYSIS*

Domestic factor or output	Senegal	Mali	Niger	Upper Volta
Land (*rent in francs/ha*)	0	0	0	0
Unskilled labor (*wage rate in francs/day*)[a]	250	200[b]	200	200
Capital (*real annual interest rate in percent*)				
Traditional, short-term	25	25	25	25
Traditional, long-term	15	15	15	15
Lending to individuals by government projects and commercial banks	8	8	8	8
Domestic public funds for government agencies	5	5	5	5
Concessional foreign lending	5	5	5	5
World price equivalent for rice (*francs/kg*)	68	97	98	94

*Source: Based largely on information in Scott R. Pearson et al. (forthcoming), *Rice in West Africa: Policy and Economics*, Stanford University Press, Stanford, Ca., especially Appendix B, and on Walter P. Falcon and Eric A. Monke (1979-80), "International Trade in Rice," *Food Research Institute Studies*, Vol. XVII, No. 3.

[a]For men.

[b]Actual observations also show wages as high as 250.

Wage rates in Niger and Upper Volta are lower than in Senegal, reflecting the higher national income there. Malian wages—based on actual field observations—seem to be higher than those of its neighbors, perhaps in part because of the success of its rice projects. However, for simplicity in presentation, Malian wages used in the analysis are assumed to equal those in Niger and Upper Volta.[1] There is little evidence of seasonal variations in wages (Byerlee, 1979). Nor is any distinction made in the analysis for observed differences between wages of men and women. Although traditional rice cultivation is often the responsibility of women, improved methods draw heavily on male labor. Moreover, in some tasks, such as transplanting and winnowing, women are often paid on a par with men.

The third consideration pertains to segmentation in factor markets. If such segmentation is caused by structural economic factors that prevent the markets from equilibrating, it is appropriate to employ a series of shadow prices for that factor, one for each segment of the market (Chandavarkar, 1971; McKinnon, 1973). There appear to be significant imperfections in the capital markets of the four countries, caused principally by variation in the cost of lending among

[1] The effect of using the higher wage in interior countries can be seen by examining "Base case 2" in Table 9. Compared to the low wage case, total social costs rise by 7-9 percent for improved techniques, and by 18-19 percent for traditional methods. Net social profitability remains positive in all cases, however.

markets, by limitations in the capacity to absorb cheaper funds allocated to major projects such as land improvement, and by restrictions imposed by donors of concessional aid. As a result, five different credit markets are identified: short term borrowing in the traditional credit market, investment of own funds by farmers, lending by government rice projects and commercial banks, domestic public funds for government agencies, and concessional foreign lending. Traditional credit for working capital is the most expensive, and concessional foreign lending and domestic public funds for land development are the cheapest. All interest rates reflect real costs of capital. Concessional foreign lending is costed at 5 percent on the assumption that each Sahelian country will have available to it an approximately fixed annual amount of concessional aid, constrained either by donors' quota or local absorptive capacity, so that rice projects are competitive with other domestic projects, the income from which is foregone if the rice projects are undertaken.

World Price of Rice

The world price is used to evaluate the profitability of domestic production of rice since rice imports are the major alternative to increased domestic output. Estimates used in the analysis are based on an assumed long run world rice price of $350 per ton, in 1975 dollars for Thai 5 percent brokens, f.o.b. Bangkok (Falcon and Monke, 1979-80). Because of the similar quality of rice imports (25-35 percent brokens) and similar inland transport costs, the value of rice in world price equivalents in all the interior countries is 94-98 francs per kilogram. In the analysis, a world price of 97 francs per kilogram, the median value, is used for the interior countries.

The value for Senegal is about 79 francs per kilogram, reflecting the lack of further inland transport costs. A large portion of Senegal's rice imports is 100 percent brokens. The discount for this lower quality rice is about 11 francs per kilogram, relative to 25-35 broken rice. For ease of presentation, it is assumed that Senegalese consumers are willing to substitute better quality, higher priced domestic rice for lower quality, cheaper imports, and hence the low quality discount is ignored. Relaxing this assumption would decrease the social return to Senegalese rice production and hence reduce social profitability by as much as the full amount of the quality discount.

APPENDIX B
TECHNICAL COEFFICIENTS AND COST OF RICE PRODUCTION

This appendix contains discussions of the technical and economic coefficients that have been assumed for manual rice production, the assumptions used to estimate changes in costs resulting from new labor-saving techniques, and the coefficients for collecting, milling, and distributing rice.[1]

[1] Social prices, which exclude taxes and subsidies, are used throughout. For a fuller explanation and prices of primary factors, see Appendix A. The figures given here are based on information collected from numerous studies and surveys of rice production in both Asia and Africa. Sources for the information used in making these various estimates are marked with an asterisk in the Citations.

TECHNICAL AND ECONOMIC COEFFICIENTS

In examining the coefficients of production, it is necessary to distinguish at the outset those employing only human labor in the fields and those employing animal or mechanical draftpower.

Manual Production

Production systems relying exclusively on human labor differ according to their methods of water control and their use of high-yielding varieties of rice, fertilizers, and insecticides. Farmers using these modern inputs are also assumed to follow approved farm practices, including timely and thorough soil preparation and weeding and planting in lines.

Total labor inputs range from 90 to 250 man-days per hectare and vary according to type of water control:

Unimproved swamp (US)	115
Uncontrolled flooding (UF)	90
Improved swamp (IS)	258
Controlled flooding (CF)	188
Dams and pumping (D, SP, LP)	250

These labor times represent modal values, and variations of 25 percent may not be uncommon. In general, the level of labor input is consistent with the use of improved inputs and the expected yield. For example, transplanting is assumed for all improved techniques except controlled flooding, and higher weeding times are considered to be necessary with the increased use of fertilizers.

Seeding rates are assumed to vary largely with the type of seeding used. Transplanting from a nursery requires the least seed, about 40 kg per hectare, while broadcast seeding requires from 100 to 120 kg per hectare depending on whether improved or traditional varieties are used. Direct seeding, in pockets or by drilling, has an intermediate seeding rate, assumed to be 75 kg per hectare. Traditional seeds are valued uniformly at 47 francs per kilogram, based on rice import prices in the interior countries, and improved seeds are valued at 100 francs per kilogram based on data from seed multiplication schemes in Senegal, Mali, Upper Volta, and the Ivory Coast. With a renewal of improved seeds every four years, average annual seed costs for improved irrigated production amount to about 60 francs per kilogram.

Although recommended application rates for fertilizers vary considerably among rice projects, general recommendations for irrigated rice suggest a dosage of 60 N, 35 P_2O_5, and 30 K_2O in kilograms of nutrients per hectare, applied as a mixture of 75 kg urea and 150 kg compound fertilizer. Response to fertilizer obviously varies greatly, but results from research trials and actual projects in Africa and Asia indicate that a response rate of 10-15 kg paddy per kilogram of total nutrients—or about one ton per hectare—may be a reasonable level to anticipate for farmers having access to irrigation. The social value of fertilizer is based on the long run world price of the nutrients, plus transport and delivery costs. Using available price projections, the values assumed for this analysis are (in francs per kilogram):

	Senegal	Mali, Niger, and Upper Volta
Urea	50	68
Compound fertilizer (10-25-16)	25	43

The cost of insecticide treatments, primarily against stem borers, appears to vary greatly, depending on the product and the rate and frequency of application. An intermediate value of 7,500 francs per hectare has been assumed.

The cost of working capital is based on the value of labor, seeds, fertilizers, insecticides, and other expenditures incurred during the growing season. Interest rates vary depending on the source of credit (see Appendix A), and the duration depends on the time of application. For inputs applied at the beginning of the season, a period of 6 months is used, and shorter periods are used for inputs applied later. No interest charges are made for harvesting and transport costs.

The cost of small hand tools is difficult to ascertain, and estimates vary from almost nothing to over 4,000 francs per hectare per year. An estimate of 2,500 francs is used for improved manual irrigated production, although lower values are assumed for traditional cultivation (1,000) and for techniques using other equipment (1,500 to 2,000 depending on number of tasks mechanized).

Five types of irrigation have been used in the analysis, representing different methods of water control, different levels of security, and varying costs. Investment, annuity, and operation and maintenance costs are given below (1,000 francs per hectare):

	Initial investment cost	Depreciation plus interest[2] *(per crop)*	Operation and maintenance *(per crop)*
Improved swamps (IS)	250	32	10
Controlled flooding (CF)	250	18	10
Diversion dams (D)	750	53	15
Small-scale pumping (SP) *(250 m^3/hour)*	500	32	29
Large-scale pumping (LP) *(2,000 m^3/hour)*	1,500	53	32.5

Observed costs for a given system may vary by 100 percent, and those tabulated represent midpoint values. The cheapest system is controlled flooding, but it is also the least secure, which limits potential for further intensification to raise yields. The most expensive systems are diversion dams and large-scale pumping, with roughly three times the annual capital cost of controlled flooding. In

[2] At 5 percent annual interest rate.

principle, both provide full water control, but in practice it is not often realized owing to design and management problems. Improved swamps and small-scale pumping have similar annual capital costs, about half-way between the extremes. The figures for pumping assume double cropping.

Maintenance costs on the infrastructure are assumed to be either 10,000 francs per hectare per year or 2 percent of the investment cost if that is larger. Variable costs for pumping include charges for fuel and oil, repairs, and personnel. Although available calculations use various assumptions about overhead costs, amounts of water delivered, and repair coefficients, they indicate values of about 17,500 francs per hectare per crop for large-scale systems and 19,000 francs for small ones.

Extension costs vary widely, largely because of differing assumptions about the number of farmers and fields an agent can supervise and the complexity of the technical package. Available evidence suggests that 10,000 francs per hectare is the minimum needed to achieve yields consistent with improved irrigation.

Yield estimates vary enormously across regions, projects, and years. Norms used in this analysis are consistent with actual data, but they give only an indication of relative differences in yields. Yields estimated for manual cultivation, in tons of paddy per hectare, are 0.6 for uncontrolled flooding (UF), 0.9 for unimproved swamps (US), 2.5 for both improved swamps (IS) and controlled flooding (CF), and 3.5 for diversion dams (D) and pumps (SP and LP). Yields assume normal rainfall; because they are likely to decline more in bad years than to rise in good ones, long run averages could be lower than those assumed, especially for traditional techniques. Yields for improved techniques are roughly half those obtained on research stations. Yields on improved swamps are probably more likely to exceed norms than those under controlled flooding, which are extrapolated from experiences with swamps since little or no fertilizer is currently used with controlled flooding. Higher yields with dam and pump irrigation reflect better water control.

Labor-Saving Techniques

Eight techniques for land preparation, weed control, and harvesting are considered. They are based on innovations already in use, although not necessarily in these countries. All substitute animal, mechanical, or chemical inputs for direct farm labor. Changes in other inputs sometimes occur and are taken into account, but they are usually unimportant. Yield effects are assumed to be unimportant, mainly because the literature seldom provides unambiguous evidence of positive effects that could be ascribed to the innovations considered here. In addition to the basic hand cultivation, there are three techniques for land preparation—ox plowing, power tillers, and tractor plowing; three techniques for weed control—rotary hoe, line-seeding and cultivation, and herbicides; and two techniques for threshing—small axial-flow threshers and large-scale stationary threshers.

Land-preparation. —Manual land preparation with short-handled hoes *(dabas)* is typical of farming in West Africa, and an average of about 50 man-days appears needed to prepare heavier soils for wet-rice cultivation. The use of a team of oxen—with a moldboard plow and a tooth harrow worked by two persons—is estimated to save about 70 percent of manual labor needed for land preparation. Heavier soils, smaller animals, puddling, and three men per team would all reduce the labor savings from using oxen; the estimate here is perhaps optimistic. Since ox traction packages often include a cart, there can also be savings in transport at harvest, estimated at 60-77 percent of transport labor.

The net costs of animal traction are difficult to ascertain in part because few data are reliable, assumptions about farm size and off-farm use vary, and income from meat and manure is difficult to estimate. Costs used here assume that the equipment is used on 6-12 ha, depending on the task. Results are invariant with respect to either farm size or initial investment, since the existence of a rental market is assumed to permit excess capacity to be hired out and missing material to be hired in. No account is taken of gains from meat production, although animals are assumed to hold their value rather than to depreciate. Net costs for the basic package amount to 5,264 francs per hectare per year, of which about half is attributed to feed supplements, risk of mortality, and labor costs for herding. It is difficult to assess whether these costs are either high or low.

Power tillers (10-15 horsepower) can be used to prepare land on relatively small areas, primarily for irrigated rice, but their use in West Africa is limited. Available data suggest that about 20 hours per hectare is a reasonable but possibly low estimate of operating time required to prepare wet land for transplanting. This innovation is estimated to save 90 percent of direct farm labor used for land preparation, at a cost of 14,410 francs, including driver. This estimate assumes double cropping, which is not always possible; on the other hand, initial investment costs may be overestimated.

Tractor cultivation employs a small, four-wheeled tractor (about 35 horsepower) and appropriate implements (plow, harrow, seed drill, and trailer). It cannot be used easily on small fields, and its application is limited to systems with controlled flooding, dam irrigation, and large-scale pumping. Because land preparation, planting, and transport are all mechanized, labor savings are significant—58 man-days compared to manual systems using broadcast seeding and 95 days compared to systems using transplanting.[3] Experience in West Africa shows that the use of tractors often lowers yields by 0.5 to 1.0 tons paddy per hectare compared to norms with transplanting, but this analysis assumes, perhaps optimistically, that subsequent manual work is adequately carried out to avoid such declines. The estimated cost of such cultivation ranges from 21,051 to 22,209 francs per hectare, for double and single cropping, respectively. These costs assume that operations require a total of 20 hours per hectare and that a tractor can handle 35 ha per season, both of which seem to be conservative. However, if larger (65 horsepower) tractors are used, as is the more common practice, costs may rise by 10 percent; and if direct seeding reduces yields in line with observations, costs would rise further.

Weed control.—Because so many factors affect the complexity and the efficacy of weeding, it is not easy to compare different methods. Estimates suggest that hand

[3] Broadcast seeding and transplanting are assumed to require 5 and 40 man-days per hectare, respectively.

weeding, potentially the most effective method, requires from 13 to 60 man-days per hectare, although 35 man-days is used in this analysis as being reasonably consistent with both fertilizer use and expected yields. A small one-row rotary hoe pushed by hand is the simplest alternative to hand weeding, but it requires puddled soil and row seeding—usually transplanting. Although the additional cost of the equipment is not very great—estimated at 223 francs per hectare per year, labor savings are assumed to be limited to no more than 12 man-days because of the supplemental hand weeding required to clean within rows. This method is rarely used in Africa, although it has been used in Madagascar.

A more rapid method of weeding is with a tined cultivator drawn by oxen. Because this method also requires row seeding, usually drilling, an ox-drawn, mechanical seeder is assumed to be used. Labor savings may come from both faster seeding (2 and 37 man-days compared to broadcasting and transplanting, respectively) and faster weeding (about 18 man-days). Assuming that the basic ox package is already owned, the incremental cost of this method is 972 francs per hectare, the sum of capital costs and maintenance of the two new implements.

The fastest method of weed control is by herbicides, but herbicides are not widely used on rice in West Africa, and actual costs are difficult to determine. They are estimated to be about 7,000 francs per hectare, which is higher than some observations in West Africa but lower than costs reported from Asia. The treatment assumed here employs a mixture of propanil (7.5 liters/ha) and 2-4-D (1.25 liters/ha) applied with a back sprayer. Because no additional hand weeding is assumed to be necessary, chemical weed control may save up to 30 man-days of labor.

Threshing.—The three major harvesting activities—cutting with a sickle, threshing with a flail and winnowing with a basket—comprise roughly one-quarter of total labor time in manual production, and appear to require about 20 man-days per ton of paddy. Innovations available to save cutting labor (estimated at about 10 man-days) such as combine harvesters and small, motorized cutter-binders, appear too expensive. At present it seems feasible to mechanize only threshing and winnowing, estimated to require about 6 and 4 man-days per ton of paddy, respectively. The use of a small, motorized thresher of the type developed at IRRI might save up to 9 man-days per ton at a cost of only 848 francs, assuming 0.4 tons of paddy per hour.[4] These calculations are speculative and probably optimistic, but feasible if losses can also be reduced.

The alternative threshing system is a large, stationary thresher with its own motor but which must be moved by a tractor. Based on actual conditions in Mali, labor savings amount to about 8 man-days per ton of paddy at a cost of 3,727 francs. The calculation assumes that about 0.7 tons of paddy are threshed per hour, which is below capacity.

Post-Harvest Activities

Two milling techniques are used in this analysis: a large-scale industrial mill with a capacity of about 4 tons of rice per hour and a cost of 7.4 francs per kilogram of rice, and a small-scale, steel-cylinder huller with a capacity of less

[4] This thresher is self-feeding with axial flow and screens to separate paddy from chaff.

than 0.2 tons of rice per hour and a cost of 5.1 francs per kilogram. Both mills are assumed to achieve a 65 percent outturn and to furnish rice of similar qualities. Costs are based mostly on actual results observed in Mali, where milling costs appear to be relatively low.

The cost of transporting paddy from farm to mill varies with the size of the mill. For large mills, which must draw supplies from 50 to 100 km away, they are estimated to be 6 francs per kilogram, slightly more than the average cost in Senegal, slightly less than the average cost in Mali. Costs for delivering paddy to small mills over about one-fourth that distance are assumed to be 4.5 francs per kilogram.

The cost of distributing rice from mills to wholesalers in consuming centers varies with distances (francs per kilogram rice):

Average distance	(250-300 km)	6.5
Short distance	(about 50 km)	4.3
Long distance	(about 650 km)	10.2

Although distances in Senegal tend to be longer and those in Niger shorter, the cost over the average distance is used for all countries because transport costs tend to be cheaper in Senegal and more expensive in Niger. The short distance is used when it is assumed that rice is consumed in producing areas by either farmers or villagers. The cost for long distance distribution is used to evaluate the impact of future rice production being planned to take place considerably farther from major consuming centers than current production.