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Cereal Technology Interventions for the West African Semi-Arid Tropics

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Abstract

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One of the regions of most concern in Sub-Saharan Africa is the geographical area of the West African semi-arid tropics (WASAT) where there has been little impact from the green revolution and most of the region suffers from inadequate and irregular rainfall and low fertility soils. Decreasing per-capita food production trends and 2-3% per-year population growth trends have convinced some to adopt a Malthusian perspective about the future of the WASAT. This paper evaluates the prospects of agricultural technologies and farm management practices that are currently proposed for the WASAT cereal farming system. The technologies are assessed with respect to their agronomic and economic feasibility, risk and their fit within the farming systems. They are ranked as to their feasibility of adoption by farmers in the short, intermediate and long run. The findings suggest that several agricultural technologies are feasible for use in the short run provided that they are used as a package. The complexity and initial high financial and human capital requirements, however, often prohibit farmers from adopting the total package simultaneously. A stepwise approach to adoption is difficult since separate adoption results in lower profitability and higher risk levels. Government policy intervention may be necessary to enable farmers to adopt single technologies en route to total package adoption.

Introduction

The West African semi-arid tropics (WASAT) includes the countries of Burkina Faso, the inland areas of Senegal and the Gambia, the southernmost

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portions of Mauritania, Mali, Niger and Chad, and the northern tips of Ghana, Benin, Nigeria and Cameroon. It is one of the poorest regions in the world with per-capita yearly incomes between US$80 and US$300 (McNamara, 1985). The economies depend heavily on foreign aid, borrowing and worker remittances. The region exhibits a bottom-heavy age pyramid with population growth rates ranging between 2.5% and 3.0% per year. The growth in per-capita food production (1971–1984) for the region as a whole is negative while levels of food imports (largely from donor agencies) have increased dramatically over the last 25 years (McNamara, 1985; Paulino and Mellor, 1984).

The present man/land ratios in the region, which generally averages 15 persons per km^2 (World Bank, 1985), are extremely low when compared with up to 600 persons per km^2 in parts of Asia (McNamara, 1985). The poorer agricultural resource base of the WASAT, however, cannot support the high man/land ratios of Asia (Matlon, 1985). A case in point is the Central Plateau of Burkina Faso with man/land ratios of 60 persons per km^2 (World Bank, 1985) where high man/land ratios relative to the resource base have already caused a change in the traditional bush-fallow system of cultivating lands for 3–5 years and then leaving it idle for a decade or more to restore soil fertility. In many of the older settlement villages, increased population has meant limited access to new land, a shortening of the fallow rotation period and the cultivation of more marginal land (Norman et al., 1981; Dugue, 1985).

As more pressure is put on the land in the older settlement areas for food production, without technological intervention, soil deterioration will increase and result in a further lowering of yields. As the population pressure increases in the current frontier areas characterized by surplus land and the bush-fallow system, a phenomenon similar to what is now occurring in the older settlement areas of the Central Plateau of Burkina Faso would be expected to prevail throughout most of the WASAT region

In this paper, the farming systems and major production constraints of the WASAT are briefly described followed by the ranking of proposed technological interventions based on agronomic and economic criteria. The central area of Burkina Faso is used as a development model for the regions of the WASAT with similar agroclimatic zones (500–900 mm rainfall zones) and farming systems. Finally, policy implications for technology intervention and future avenues for research and extension are discussed.

WASAT farming systems and major production constraints

According to various sources (Kowal and Kassam, 1978; Norman et al., 1981; Matlon and Spencer, 1984; and Nagy et al., 1987), the main constraints to increased cereal yields and production in the WASAT are: (1) climatological and physical conditions exhibited by low soil fertility, high rates of rainfall loss due to surface runoff, and an unpredictable level and distribution of inter and intra-year rainfall; (2) labor and land shortages — labor shortages in the critical, peak-labor periods of planting and weeding, and limited access to land in the old settlement areas; (3) a poor to non-existent input and product marketing infrastructure (outside the cotton regions); and (4) inadequate information and extension services.

Rainfall is extremely variable over time and space. Rainfall varies up to 15% of the long-term average in the southern WASAT but can vary up to 50% of the long-term average in the north (Nicholson, 1982). Most soils are deficient in nitrogen and phosphorus, low in organic matter, and have a high sand content (60–95%). The soil surface dries after a rain and forms a crust which restricts soil aeration and water infiltration. These soil properties combined with high-intensity rainfall lead to water retention and soil erosion problems.

All cropping activities take place between the months of May and November with planting occurring within a 3-day period after the first major spring rain. Cereal production is the dominant agricultural activity: 90–95% of all cultivated land is in cereals (Lang et al., 1983). The staple crops of sorghum, millet and maize receive the highest priority of land and labor resources. Drought tolerance of the crops are matched with soil fertility and toposequence (Matlon, 1985; Stoop et al., 1982). Maize is planted on the relatively high-fertility compound land (which receives manure and organic wastes), sorghum on the lower more fertile part of the toposequence and millet further up the toposequence on the poorer land. Cowpeas at low densities are usually intercropped with cereals. Small amounts of groundnuts are grown as a cash crop. Limited areas of rice and condiment crops are grown.

Most of the planting/first weeding occurs over a 6-week period with the household supplying the labor. A limited labor pool exists for hire at this time, because all household labor is dedicated to their own fields. Depending upon the level and distribution of rain, fields may require replanting, transplanting, thinning and further weeding.

Modern inputs are not widely used. Their use is concentrated in the higher-rainfall areas and on the export crops of cotton and groundnuts. Fertilizer use in eight Sahelian countries averages less than 3 kg/ha, and only 15% of farmers use animal traction (Matlon and Spencer, 1984).

Priorities for the proposed WASAT cereal technologies

Table 1 summarizes available and potential technologies and management practices for the WASAT. Each technology is evaluated as to the feasibility of its utilization by farmers in the short run (0–5 years), the intermediate run (5–15 years), and the long run. The criteria used are: (1) availability, (2) technical viability in the field (based on on-station and on-farm research trials), (3) economic profitability (based on budget analysis, benefit–cost ratios, and whole-farm modeling), (4) risk considerations (based on research trials, in-

TABLE 1

Present technical and economic feasibility and time frame of proposed technologies and farm management practices for the WASAT

Technologies and farm management practice	Present agronomic and technical feasibility		Present economic feasibility	Comments
	On-station research	On-farm research		
Available technologies for the short run				
Tied ridging (manual)	+ + +[1]	+ + +	***[2]	Very labor-intensive
Diguettes/dikes	[3]	+ + +	**	Require materials (i.e., rocks)
Complex fertilizer	+ + +	+ +	*	Risk of losing cash outlay
Animal traction	[3]	+ +	*	Preconditions (see text)
Mechanical ridge tier	+ + +	+ +	***	Requires animal traction
Potential technologies for the intermediate run				
Rock phosphate	+	—	—	Solubility and application problems
Improved varieties	+ +	+	—	Requires upgrading of physical environment — few available
Potential technologies for the long run				
Manure/composting	+ + +	+ +	**	Small and finite supply
Mulch	+ + +	+ +	**	Small and finite supply
Plowing/green manuring	+ +	+ +	—	Poor draft animal health
Herbicides	+ +	+ +	—	Further research required[4]
Biol. nitrogen fixation	+	—	—	Further research required
Crop associations:				
- intensification	+ +	+	—	Requires upgrading of physical environment and improved varieties. Labor and management intensive.
- alley cropping	+ +	+	—	

[1]+ + +, High degree of feasibility — research supports a very good agronomic response or is technically very feasible; + +, Feasible — good agronomic response or technically feasible; +, Limited feasibility — agronomic results often inconsistent; —, Not feasible — little evidence to support a good agronomic response or technical feasibility.
[2]***, Highly profitable at present; **, Profitable at present; *, Not always profitable at present; —, Not economically feasible at present.
[3]Not researched at the on-station level.
[4]Can be feasible for sole cropping but problems with mixture of broad and slender leaf plants in crop associations.

cidence of cash outlay loss), and (5) the fitness of the technology within the farming systems (based on whole farm modeling, labor data analysis, farmer survey response).

The available short-run technologies are briefly discussed below. A more detailed presentation of the empirical results upon which Table 1 is based as presented in Nagy et al. (1987).

Tied ridges. Tied ridges (TR) are small depressions made between crop rows, either by hand or by a combination of animal traction and hand tillage, that increase water infiltration and retention. When done by hand, depressions 32 cm long × 24 cm wide × 16 cm deep are made between the rows spaced $1\frac{1}{2}$ m apart. When constructed with animal traction, the fields are first ridged with a cultivator (*houe manga*) equipped with a middle sweep to create a furrow which is then followed by hand tillage to make a 16 cm high ridge perpendicular to the furrow every one to two meters.

On-station and on-farm research have shown tied ridges to significantly increase cereal yields (Rodriguez, 1982; FSU/SAFGRAD, 1983; Lang et al., 1984; Dugue, 1985; Nicou and Charreau, 1985; Ohm et al., 1985a, b).

Farmers indicate that they would like to construct more TR but are constrained by insufficient family labor. Linear programming results from representative farm models (Table 2, column 2) indicate that family labor availability constrains the tying of animal-traction-constructed ridges.

Although tied ridge technology is agronomically and economically feasible, labor constraints mitigate against the widespread use of this labor-intensive technology.

Diguettes/Dikes. Barriers to 10–15 cm high, mainly made of rocks and placed on field contour lines 10–50 m apart, slow down rainfall runoff, allowing increased infiltration (Wright, 1985). Although diguettes require further research, they have proved to be profitable and are technologies that could be used at present.

Complex chemical fertilizers. Under on-station and on-farm conditions, significant yield increases for maize, sorghum and millet have been obtained using complex mineral fertilizers (FSU/SAFGRAD, 1983; Lang et al., 1984; Pieri, 1985; Ohm et al., 1985a, b). Yield response to fertilizer is, however, highly variable between sites and years (Spencer, 1985). Nevertheless, some researchers suggest that continuous cropping using chemical fertilizers is potentially possible in the WASAT (see Pieri, 1985, for a literature review).

In Burkina Faso, on-farm farmer-managed trials indicated that fertilizer can be profitable when using fertilizer alone on sorghum and millet in good rainfall years (Ohm et al., 1985a, b). There is, however, considerable risk for the farmer of losing the cash outlay. Both yield and profitability substantially increase, however, when tied ridges and fertilizer are used in combination (Ohm et al., 1985a, b).

The evidence suggests that complex fertilizers can be used at present in the WASAT but the incidence of cash outlay loss by farmers is high unless combined with a water retention technique such as TR. The complementary nature of the two technologies would suggest that they be adopted simultaneously by farmers.

TABLE 2

Whole farm modeling analysis of a tied ridging-fertilizer technology combination with donkey traction, Central Plateau, Burkina Faso

Variable	Traditional management (donkey)	Tied-ridging technology[1]		
		Tied by hand	Tied with machine	
			Two passes	One pass
Total area cultivated (ha)	5.5	5.6	5.7	5.6
Maize				
traditional	0.20			
with tied ridges		0.20	0.15	0.15
Red sorghum				
traditional	0.60			
with tied ridges		0.60	0.68	0.60
White sorghum				
traditional	0.80	0.70		
with tied ridges		0.10	0.80	0.95
Millet				
traditional	3.18	3.15	3.18	1.88
with tied ridges			0.05	1.27
Peanuts	0.76	0.86	0.79	0.71
Total cereals production (kg)				
per household	2103	2604	2970	3354
per resident[2]	150	186	212	240
Net farm income[3] (1000 FCFA)				
per household	215.3	253.2	273.2	296.4
per worker[4]	30.8	36.2	39.0	42.3

Source: Nagy et al., 1985.

[1]Based on application of 100 kg/ha 14-23-15 fertilizer at planting and 50 kg/ha urea, 4 weeks after planting (20 man-hours/ha labor requirement for each application). Labor times of 75 man-hours/ha for tying of the ridges by hand, 20 man-hours/ha to machine-tie with two passes, and 2 man-hours/ha to machine-tie in one pass. Yield estimates in kg/ha for traditional practices and the technological interventions of fertilization and tied ridges in combination are as follows: maize, not fertilized (1090–1730), red sorghum (672–1236), white sorghum (472–913) and millet (320–660); 1985 fertilizer and grain prices were used.

[2]Based on 14 residents/household.

[3]Annualized cost of 4,400 FCFA for machine subtracted in columns 3 and 4.

[4]Based on 7 active workers/household.

Animal traction. An estimated 15% of the farmers in the WASAT use donkey or oxen traction (Matlon, 1985). In general, individual farmers do not use animal traction for more than one mechanized operation, which results in low utilization rates (Jaeger, 1984).

In spite of potentially high rates of return, animal traction adoption rates are low in the WASAT. Present internal rates of return of 10% in old settlement areas and 20–30% in frontier areas have been estimated but higher rates of return could be achieved by higher utilization rates (Jaeger, 1984). Higher utilization rates can be obtained by expanding the number of mechanized agricultural operations on each farm.

To obtain the full benefit of mechanization, first-time users must learn to use animal traction units quickly. However, learning curves can be as long as 5 years (Jaeger and Sanders, 1985). Farmer and animal training through extension and an improved trained draft animal market could lead to shorter learning curves and higher adoption rates.

The potential for higher rates of return makes animal traction a feasible technology for the short run. But to accomplish this, the preconditions of higher utilization rates and shorter learning curves must be obtained.

Mechanical ridge tier. To respond to the labor constraint in constructing tied ridges, the IITA/SAFGRAD Agronomy Program designed a mechanical ridge tier (MRT) (Wright and Rodriguez, 1985). The MRT is attached to an animal-drawn cultivator with one large middle sweep. The MRT is essentially a paddle wheel (45 cm in diameter) with four paddles, one scraping the ground, building up earth until it is tripped by the operator every $1\frac{1}{2}$–2 m to create the ties in the furrow between the two ridges.

The MRT was field-tested as part of Burkina's 1985 national farming systems program (Nagy et al., 1986). When the two-pass method is used (first ridging and then using the MRT in separate operations), the MRT substantially reduces the labor requirements from an average of 75 man-hours per ha for the manual tying of animal traction ridges to 20 man-hours per ha. The MRT operation requires only 2 to 3 additional hours above ridging alone when ridging and tying with the MRT are done simultaneously (one pass). Results from Whole-Farm LP models indicate that while available labor constrains the tying of ridges manually to 0.9 ha (Table 2, column 2), it allows 3.0 ha to be tied using the one-pass method (Table 3, column 4) and is highly profitable.

The overall consensus of the field trials is that the MRT can be used at present not only as a labor-saving device but also as a yield-increasing technology.

Policy implications for technology intervention

From the information presented in the previous section and summarized in Table 1, an overall sequence of technology intervention for the WASAT is: (1) technologies that improve the agronomic environment, i.e., water retention and soil fertility improvement of the present cereals-based farming systems (with appropriate policy and institutional support this technology combination can be immediately implemented); (2) the use, when they become available, of improved varieties that can respond to moderate input levels (if varieties are developed for the moderate input levels recommended in (1) above; this technology is expected to be available for farmer adoption in the next 5–10 years); and (3) technologies for a more intensive livestock/cereal/cash crop farming system in the better agricultural areas and a shift back to extensive grazing and forestry in the more marginal agricultural regions. (This would happen in the longer term once the cereals-based farming systems are upgraded and the present long-run technologies as described in Table 1 are made available.)

The first priority of the agricultural policy, research and extension community in the WASAT is to develop and extend technologies to increase the yields of the current cereal-based farming systems which dominate the area. The present focus should be on alleviating the low soil fertility/low soil water retention constraints. Complex fertilizers, the water retention methods of tied ridges, diguettes and dikes, and the labor-saving technologies of animal traction in combination with the mechanical ridge tier are already available for extension.

It appears from the on-farm trials and the whole-farm modeling results that all the available technologies would need to be adopted together as a package before economic incentive and risk levels are adequate for adoption by the farmer. Fertilizer utilization is too risky in poor rainfall years without some simultaneous method to increase the availability of water at the critical time of plant development. Tied ridges by themselves do not resolve the low soil fertility problem. Family labor availability constrains the amount of tied ridging construction and requires use of the labor saving MRT which in turn requires animal traction. Introducing the technologies together would alleviate the soil fertility, soil water and labor constraints and provide high economic incentives at levels of risk that would be attractive to farmers.

The technology package of tied ridging, dikes, chemical fertilizer, and animal traction, however, have all been available to farmers in the WASAT for more than two decades. Yet there has been little adoption by WASAT farmers of any of these innovations in spite of the substantial increase in demand for new cereal technology brought on by increased population, recent droughts and the deterioration of soil quality in the higher population regions.

The principal reason for the failure to adopt the technologies as a package is because of their complexity and the large initial financial, human capital and labor requirements. To overcome these types of problems, empirical evidence indicates that farmers do adopt technologies not as packages but sequentially (individually) en route to total package adoption (Byerlee and Hesse de Polanco, 1986). The problem, however, is that the individual components of the package by themselves either do not have sufficient economic incentive for the level of risk involved or farmers do not have the level of financial, human capital, and labor requirements. Thus most farmers are unable to start the process of stepwise technology introduction which would eventually lead to the adoption of the entire package.

An option is to wait for the research community to develop new technologies that will, individually, provide a sufficient economic incentive at low risk, and with lower financial, human capital, and labor requirements, that will be attractive to farmers. The review of the constraints to cereal production and the review of the available and future technologies for the WASAT (Table 1) point out that such technologies will not likely be available in the short run and will probably not be available in the intermediate run (10–15 years). The pressing problems of the WASAT require more immediate solutions. Another option is to develop support programs that will enable farmers to sequentially adopt the presently available technologies en route to the adoption of the total package.

Implementation of support programs to increase the present cereal production in the WASAT would include: (1) the subsidization of fertilizer, animal traction and the MRT, which will enable farmers to absorb the risks involved in the adoption of the technologies; (2) credit programs for the cash outlays required by farmers for fertilizer and animal traction; (3) farm management training and demonstration, especially on efficient utilization of animal traction and fertilizer, from the extension service; (4) development of the input and product market infrastructure, while ensuring that input/product market prices are favorable to the adoption of the available technological interventions.

Within an overall support program, the current priorities for extension and local governments are to demonstrate the available technologies on farmers' fields and to ensure that the appropriate preconditions exist for animal traction adoption through various animal traction programs. Their assistance is also required to properly construct diguettes and dikes. Priorities for current on-farm testing include further design studies on a mechanical ridge tier device and on fertilizer recommendations.

For the intensive livestock/cereal/cash crop systems that will hopefully develop in the future, the technologies as described in Table 1 can now be productively studied at the experiment station and in on-farm trials so that these systems can be available to farmers after the next decade.

Summary and conclusions

An evaluation of the proposed technologies for the WASAT based on availability, technical viability, economic profitability and riskiness, and the fit within the farming systems suggests that a technology package is currently available to extend to farmers. The current priority is to further develop and extend the technology package of tied ridging, diguettes/dikes, chemical fertilization and animal traction and the mechanical ridge tier to increase yields in the current cereal-based farming systems of the WASAT.

The technologies, however, act as complements and need to be adopted together as a package before economic incentive and risk levels are adequate for farmer consideration. The technology package, however, is too complex to be adopted all at once and requires substantial initial investment, human capital, and labor, which the farmers do not have. Farmers have been shown to adopt technologies individually or in clusters in a stepwise pattern to break up packages into manageable units. A problem arises because the complementary nature of the package is such that if adopted as individual technologies, either the economic incentive for the level of risk is inadequate or the initial investment or the human capital requirements are still too high. Farmers are therefore unable to start the process of stepwise adoption en route to the adoption of the entire package.

Support programs are therefore required to enable farmers to start the process of stepwise technology adoption. Because other new technologies will probably not be available in the short or intermediate run, such support programs are essential. Although support programs, which include subsidization, are costly, they must be weighted against continued food import and donor agency famine relief costs and the social costs of the region from inadequate food supplies.

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References

Byerlee, D. and Hesse de Polanco, E., 1986. Farmers stepwise adoption of technological packages: Evidence from the Mexican Altiplano. Am. J. Agric. Econ., 68: 519-527.

Dugue, P., 1985. Soil preparation in the Sudan-Sahelian zone: Prospects and constraints. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, pp. 33-53.

FSU/SAFGRAD, 1983. FSU/SAFGRAD 1982 Annual Report International Programs in Agriculture, Purdue University, West Lafayette, IN, 95 pp.

Jaeger, W.K., 1984. Agricultural mechanization: the economics of animal traction in Burkina Faso. Ph.D. thesis, Stanford University, Stanford, CA, 240 pp.

Jaeger, W.K. and Sanders, J.H., 1985. Profitability of animal traction: Field study in Burkina Faso. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, pp. 291-307.

Kowal, J.M. and Kassam, A.H., 1978. Agricultural ecology of the savanna: a study of West Africa. Oxford University Press, Oxford, 415 pp.

Lang, M.G., Cantrell, R.P. and Sanders, J.H., 1983. Identifying farm level constraints and evaluating new technology in Upper Volta. Staff paper, Department of Agricultural Economics, Purdue University, West Lafayette, IN, 23 pp.

Lang, M.G., Cantrell, R.P., Ohm, H.W. and Sawadogo, S., 1984. FSU/SAFGRAD 1983 Annual Report. International Programs in Agriculture, Purdue University, West Lafayette, IN, 95 pp.

Matlon, P.J., 1985. A critical review of objectives, methods and progress to date in sorghum and millet improvement: a case study of ICRISAT/Burkina Faso. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, 179 pp.

Matlon, P.J. and Spencer, D., 1984. Increasing food production in Sub-Saharan Africa: Environmental problems and inadequate technological solutions. Am. J. Agric. Econ., 56: 671–676.

McNamara, R.S., 1985. The challenges for sub-Saharan Africa. Sir John Crawford memorial lecture, 1 November, Consultative Group on International Agricultural Research, Washington, DC, 49 pp.

Nagy, J.G., Ames, L.L. and Ohm, H.W., 1985. Technology evaluation, policy change and farmer adoption in Burkina Faso. International Progams in Agriculture, Purdue University, West Lafayette, IN, 37 pp.

Nagy, J.G., Ohm, H.W., Ames, L.L. and Schaber, L.D., 1986. Analysis of the IITA/SAFGRAD mechanical ridge tier. International Programs in Agriculture, Purdue University, West Lafayette, IN, 21 pp.

Nagy, J.G., Sanders, J.H. and Ohm, H.W., 1987. Cereal technology development — West African semi-arid tropics: a farming systems perspective. End of Project report, SAFGRAD/Purdue University Farming Systems Unit, International Programs in Agriculture, Purdue University, West Lafayette, IN, 85 pp.

Nicholson, S.E., 1982. The Sahel: a climatic perspective. Club de Sahel, Developpement des Cultures Fourragères et Ameliorantes en Zone Soudano Sahelienne (CILSS). Food and Agriculture Organziation, Rome, 145 pp.

Nicou, R. and Charreau, C., 1985. Soil tillage and water conservation in semi-arid West Africa. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, pp. 9–32.

Norman, D.W., Newman, M.D. and Ouedraogo, I., 1981. Farm and village production systems in the semi-arid tropics of West Africa: an interpretive review of research. ICRISAT Res. Bull. 4, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, 94 pp.

Ohm, H.W., Nagy, J.G. and Pardy, C., 1985a. FSU/SAFGRAD 1984 Annual Report. International Programs in Agriculture, Purdue University, West Lafayette, IN, 123 pp.

Ohm, H.W., Nagy, J.G. and Sawadogo, S., 1985b. Complimentary effects of tied ridging and fertilization with cultivation by manual and donkey and ox traction. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Program in Agriculture Purdue University, West Lafayette, IN, pp. 61–73.

Paulino, L.A. and Mellor, J.W., 1984. The food situation in developing countries: Two decades in review. Food Policy, 9: 291–303.

Pieri, C., 1985. Food crop fertilization and soil fertility: The IRAT experience. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, pp. 74–109.

Rodriguez, M., 1982. Rapport Annual, 1982. Programe d'agronomies du mais de IITA/SAFGRAD, Ouagadougou, Burkina Faso, SAFGRAD, IITA, 122 pp.

Spencer, D., 1985. A research strategy to develop appropriate agricultural technologies for small farm development in Sub-Saharan Africa. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture, Purdue University, West Lafayette, IN, pp. 308–325.

Stoop, W.A., Pattanayak, C.M.M., Matlon, P.J. and Root, W.R., 1982. A strategy to raise the productivity of subsistence farming systems in the West Africa semi-arid tropics. In: Sorghum in the Eighties. Proc. Int. Symp. Sorghum, International Crop Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 519–526.

World Bank, 1985. Desertification in the Sahelian and Sudanian zones of West Africa. Miscellaneous publication, World Bank, Washington, DC, 62 pp.

Wright, J. and Rodriguez, M., 1985. 'Trap' project tied-ridging with animal power; end of project report. Maize Agronomy Program, IITA/SAFGRAD, 39. USAID, Ouagadougou, Burkina Faso, 22 pp.

Wright, P., 1985. Water and soil conservation by farmers. In: H.W. Ohm and J.G. Nagy (Editors), Appropriate Technologies for Farmers in Semi-Arid West Africa. International Programs in Agriculture. Purdue University, West Lafayette, IN, pp. 54–60.