PN-AAT-821 42171

The Technical Potential for Increased Food Production in the West African Semi-Arid Tropics

Peter J. Matlon

Paper presented at the
Conference on Accelerating Agricultural Growth in Sub-Saharan Af.ica,
Victoria Falls, Zimbabwe
29 August - 1 September 1983.

The Technical Potential for Increased Food Production in the West African Semi-Arid Tropics

Peter J. Matlon*

INTRODUCTION

Objectives and Approach

This paper examines the technical potential for increased agricultural production in the West African Semi-Arid Tropics (WASAT) and analyzes the principal factors which determine the rate and feasibility of such growth. We define technical potential broadly as a function of (1) available production technologies, (2) the necessary physical conditions (climate, soils, surface and ground water systems, and biological base), and (3) the sufficient institutional and economic conditions which set the limits within which the production potential can be feasibly achieved.

Our perspective is dynamic in that we outline the major currents of change in existing farming systems and identify the implications of these changes both for the appropriateness of technological alternatives and for long-term stability of the region's resource base. Where possible we attempt to estimate the time frame within which various sets of technical options are likely to be most appropriate, and under what conditions.

Because of space limitations (and the author's relative expertise) we have focused our discussion on the crops sector with a peripheral treatment of livestock only to the extent that the latter interacts with crops production. Moreover, within the crops sector primary emphasis is placed on cereal production which in most countries of the WASAT absorbs 50-80% of total farm level resources.

Paper presented at the conference on Accelerating Agricultural Growth in Sub-Saharan Africa, Victoria Falls, Zimbabwe, 29 August - 1 September, 1983. The conference was jointly organized by the University of Zimbabwe and the International Food Policy Research Insitute.

*Principal Economist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), B.P. 1165, Ouagadougou, Burkina Faso, West Africa.

The author wishes to thank Wilhem Stoop of the Royal Tropical Institute who reviewed and commented on earlier drafts of this paper. ICRISAT Conference Paper No. CP. 193.

Organization

The first part of the paper presents an overview of the region's resource base and describes the types of traditional farming systems which have developed to exploit it. That section concludes with a discussion of how demographic and social changes are currently ushering in a period of transition from extensive to intensive land use patterns.

The second part critically examines a range of mechanical, biological, and chemical production technologies which are either now available or under research and attempts to assess the potential impact of each on the region's agricultural output. In this analysis we compare results derived from on-station research with that observed under farmers' conditions and suggest changes in research objectives and methods as well as in the design of agricultural interventions to reduce the substantial performance gaps which invariably occur.

In part three we synthesize the principal issues and draw a number of conclusions concerning the potential for technology induced agricultural growth, possible consequences, and needed modifications in research priorities.

PART I:

THE PHYSICAL ENVIRONMENT AND FARMING SYSTEMS IN THE WASAT

GEOGRAPHICAL COVERAGE

The semi-arid tropics are conventionally defined according to climatological criteria as those areas where precipitation exceeds potential evapotranspiration for between 2 to 7 months annually. Within West Africa, this corresponds to mean annual rainfall limits of between approximately 250 and 1300 mm, and includes all of Senegal, the Gambia, Burkina Faso, and Cape Verde; major southern portions of Mauritania, Mali and Niger; and the northern regions of the Ivory Coast, Togo, Benin, and Nigeria. With the exception of the Gambia and Nigeria which were former British colonies, all share a common colonial experience under French rule.

Table 1 presents basic structural data and several agricultural performance indicators for the nine countries which fall entirely within the WASAT as defined. With the exception of Senegal, all are classified by the World Bank (1981) as among the poorest third of the developing countries of the world with mean per capita incomes of $ 320 or less. Similarly, the populations of these countries are experiencing rapid growth (2.6% annual growth during the 1970's) and remain primarily rural and dependent on

Table 1. Selected characteristics of the Sahelian WASAT countries.

Country	Rainfall (mm)	Income per capita[a] (US $)	Population growth rate[a]	% Population in agriculture[b]	% Total land arable[b]	% Arable land irrigated[b]	Agricultural population per km^2 arable land	Cereal yields[c] (kg/ha)	Index of cereal production 1980[d] (1970=100)	Index of cereal production per capita[d]	Index of total food production per capita 1980[ab] (1970=100)
Senegal	390-1300	430	2.6	74	27	3	81	686	106	80	83
Gambia	900-1200	-	3.2	78	25	12	174	833	84	62	82
Cape Verde	500-600	-	2.0	56	9	5	479	289	-	-	-
Mauritania	0-550	320	2.7	82	e	6	705	381	59	45	75
Mali	0-1300	140	2.6	86	2	5	294	660	107	83	88
Burkina Faso	350-1300	180	1.6	91	9	e	220	582	120	94	93
Niger	0-850	270	2.8	87	3	1	140	422	128	96	89
Chad	0-1250	110	2.0	93	3	e	118	540	96	79	91
Total Sahel	-	-	2.6	63	3	6	156	538	112	87	-
Africa	-	-	3.1	63	6	5	183	964	117	86	90

a. Data for 1979 from World Bank, World Development Report, Washington D.C., 1981.

b. Data for 1980 from FAO Production Yearbook, 1981, Vol. 36, FAO/UN, Rome, 1982.

c. Mean yields for the period 1979-81 from FAO Production Yearbook, 1981.

d. Mean output for 1979-81 compared to 100 base for 1969-71 from FAO Production Yearbook, 1981.

e. Less than 1%.

agriculture with more than 80% of the workforce in the agricultural sector.

Compared to Africa as a whole aggregate agricultural pressure on the land appears to be low with only 3% of the total land area under cultivation in any given year. The average density of agricultural population in the region is 156 inhabitants/sq.km of cultivated land, compared to 183/sq.km for all of Africa (FAO, 1981). And inspite of the general aridity, investment in intensive irrigation is also less than in Africa as a whole with only 2% of all arable land under complete water control.

Conclusions as to the general absence of land shortage, however, must be closely qualified for several reasons. First, substantial portions of the WASAT are unsuitable for agriculture given existing technology due to desert conditions, large expanses of rock outcropping, periodic flooding etc. Second, the rural population is unevenly distributed in a manner which is not always positively associated with agricultural potential. This is due to tribal or colonial history (e.g. the Mossi Plateau in Burkina Faso) or due to disease infestation (e.g. onchosceriasis in many of the major river valleys). Third, due to micro-relief soil quality can vary widely in the WASAT even within small areas. Thus even in zones of only moderate population density (30-50 persons/sq. km) often the better soils are already under cultivation and expansion of cropped area means declining potential given current production technologies. And fourth, as is discussed later, soils in the WASAT tend to be unstable with rapidly declining productivity occurring with continuous cultivation. The traditional means of soil fertility management has been the bush fallow system which can require a 5 to 1 or higher ratio of fallow to cultivated land to maintain soil quality. These factors together are reflected in the variable and often high national averages of agricultural population per sq. km of cultivated area.

Cereals, particularly sorghum and millet, constitute the food staples in the WASAT, occupying nearly 70% of total cultivated area (Table 2). Cereal yields are low, less than half of the yield levels obtained for African cereals outside of the WASAT. Moreover, during the 1970's cereal output grew at a rate of only about 1% annually - the growth due primarily to area expansion - which has meant declining cereal output per capita in each WASAT country.

CLIMATIC DETERMINANTS OF AGRICULTURAL POTENTIAL

We have defined the WASAT to include areas receiving between approximately 250mm and 1300 mm annual rainfall. East-west isohyets further subdivide the WASAT into a continuum of agro-climatic and vegetative zones associated with distinct agricultural systems and development potential [1].

Table 2. Per cent of cultivated areas sown to major crop groups in Sahelian WASAT countries[a] (1980).

Country	Millet/ sorghum	Other cereals	Pulses	Roots/ tubers	Veg- etables	Ground- nut	Cotton	Other
Senegal	44	6	2	b	4	43	b	b
Gambia	16	24	6	b	9	45	b	b
Cape Verde	0	58	4	12	23	b	b	b
Mauritania	52	6	33	3	3	3	b	b
Mali	66	12	2	1	6	9	3	b
Burkina Faso	65	5	18	1	3	7	1	b
Niger	72	1	21	1	2	3	b	b
Chad	67	5	8	5	3	10	2	b
Total	63	5	13	1	3	13	1	b

a. Data for 1981 from FAO Production Yearbook, 1981.

b. Less than 1%.

Agro-climatic Zones

The Sahel zone is located in a belt between 250 mm and 750 mm with a rainy season of between 60 and 120 days. This includes all farmed areas of Cape Verde, Niger and Mauritania, between one third to one-half of the cultivated areas of Senegal, Mali, Burkina Faso, and Chad, and smaller portions of northern Nigeria (Norman et al., 1981). The shortness of the growing season, low and variable rainfall (especially during planting and grain filling periods), and soils of particularly low fertility are the principal environmental constraints in this zone.

The Sudan zone occupies a belt between 750 mm in the north to between 1000 to 1300 mm in the south. Included in this zone are the Gambia, the southern portions of Senegal, Mali, Burkina Faso and Chad, most of northern Nigeria and portions of northern Benin, Togo, and Ghana. With greater and less variable rainfall, a longer growing season - up to 150 days on its southern extreme - and generally better soils, the range of crops grown in the Sudan zone is greater, yields are generally higher, and the development potential more promising than in the Sahel.

South of the Sudan zone is the Guinea agro-climatic zone which is characterized by an even more favorable agricultural environment. Emphasis in this paper is centered on the two more northern zones, the Sahel and Sudan.

Throughout both zones, rainfall begins gradually during the late spring or early summer, reaches a maximum in August, and then ends abruptly in September [2]. Thus the cropping season extends roughly from early May to October in the extreme south, whereas in the northern Sahel the cropping season extends only from early July to September. In response to the changing rainfall patterns, from south to north one observes a shift from long to shorter cycle crop varieties, and from relatively drought sensitive crops (maize, upland rice, sorghum) to more drought tolerant crops (millet, cowpea, fonio).

Additional Climatic Constraints

In addition to the generally low rainfall there are several other climatic characteristics which pose important constraints to the region's agricultural potential:

1. Compared to other SAT areas of the world with similar mean annual rainfall levels, the WASAT is characterized by a significantly shorter crop growing season. Data summarized by Oram (1977) comparing the Indian and West African SAT, for example, indicate that the growing season is between 20 and 30 days shorter in the latter. Thus the direct transfer of certain technologies from India,

such as pre-planting plowing or long-duration crop varieties, may be more limited in the WASAT by an insufficient period of rainfall.

2. While high temperatures and solar radiation during the rainy season are conducive to rapid plant growth, these also result in high water requirements for crops and high evaporation which reduces available soil water. Annual potential evapotranspiration varies between 2 to 4 times the average annual rainfall. Moreover, evaporative demands are highest in May and September, during planting and grain filling, respectively, thus increasing risk of early and late season water stress [3].

3. Since most of the rains occur in convective storms rainfall intensities are between 2 to 4 times greater than in temperate climates. The result is a high risk of erosion of top soil and organic matter, and loss of up to 60% of rainfall through run-off.

4. Even in years of "normal" total rainfall, the distribution of rainfall tends to be erratic with drought periods of two weeks or longer common in the Sahel. Monthly rainfall variability is particularly high during early season planting periods (often forcing multiple replantings)and in the more northern and extreme western areas of the region.

5. Due to the randomness of convective rainfall, variability of precipitation over locations within a given season is also substantially greater than in more temperate climates. As a result crop yields reflect not only a systematic south to north decline, but also high variability laterally within belts (Nicholson, 1982).

6. In addition to high within season variability, variation in annual totals is also high. For example, the annual coefficient of variation increases from 20 to 30% in the Sudan zone to 30-50% in the Sahel zone. Moreover because inter-annual rainfall distributions tend to be positively skewed the number of below average years generally exceeds those where average or above average rainfall is experienced (Nicholson, 1982).

7. Although analyses of long-term rainfall data do not generally support hypotheses of long-term rainfall trends or well defined rainfall cycles, the data do reflect the tendency for abnormal years to occur in more or less uninterrupted succession for as many as 13 years (Nicholson, 1982). Most recently, the 1950's saw a period of nearly 10 years during which rainfall exceeded long-term averages by 10 to 20% in the Sudan zone and by 20 to 30% in the Sahel. Reversal occurred around 1960 after which rainfall declined through the early 1970's when annual totals were roughly 40 and 30%below long-term average in the Sahel and Sudan zones,

respectively [4]. The implication of such extended climatic reversals is that systems of storage, production, and exchange cannot be based exclusively on a given climatic situation. Rather they should be sufficiently flexible to reduce the welfare impact of a series of bad years while permitting the reasonable exploitation of resources during good years [5].

SOILS OF THE WASAT

Charreau (1977) has defined two broad soil groups in the WASAT which correspond roughly to the rainfall belts described above. Between the 200 and 500 mm isohyets modal brown and reddish brown soils (Camborthids) predominate. Further south between the 500 to 900 mm isohyets the most common soils are red to grey ferruginous leached soils (Ustalfs). High potential alluvial soils and black clay soils (Vertisols) which occupy large areas of the Asian SAT are far less common in the WASAT and tend to occur in isolated patches only in the more southern belts.

Soil texture varies from loamy sands in the northern Sahel to sandy loams in the southern Sudan areas. With the exception of the limited Vertisol pockets clay content is uniformly low, below 20%, and the soils are classed as structurally inert. Compared to red soils of the Indian SAT the clay content of typical WASAT red soils is approximately one half (Stoop et al., 1981). Soil depth is generally shallow except in the extreme north where eolian deposits result in deep sands merging into dune conditions.

Both of these soil groups have low to very low natural soil fertility. Due to low clay and organic matter contents (generally less than one percent), cation exchange capacities tend to be less than 5 me/100 g soil, and as a result the soils are highly fragile. Thus, though nitrogen and phosphorus are commonly the most limiting nutrients, other deficiencies (potassium, trace elements, and acidication) are readily induced with intensified continuous cropping (Pichot et al., 1981).

Additional Soil Constraints

In addition to low natural fertility, the major physical properties of WASAT soils which limit crop production potential include (Charreau, 1977):

1. Very low structural porosity and consequently a high bulk density (1.5 to 1.7) which reduces root penetration and water circulation.

2. A tendency for compaction and hardening during the dry season which results in high early season run-off and which severely restricts pre and post-season cultivation.

3. Generally poor infiltration, except on eolian sandy soils, due to rapid surface crusting of soils even after cultivation.

4. Substantial wind erosion on northern sandy soils leading to top soil loss and burying of seedlings.

5. Low values of available water. Available soil moisture content varies from 80 to 110 mm for eolian soils and from 120 to 150 for deep leached ferruginous soils. Depth of water storage on the latter soils is further limited due to concretions and iron pans. Comparable values for typical Indian SAT soils are substantially more favorable, between 150 to 300 mm for deep red soils and deep black soils, respectively (Virmani et al, 1978).

6. Increasing susceptibility to erosion with continuous cultivation.

Combined with the climatic conditions described in the previous section these characteristics result in a general fragility which can result in a rapid deterioration of soil productivity under some forms of intensification. This is discussed further below under the review of available technologies.

Soil Micro-Variability

Overlaid on these regional soil characteristics are micro-variations linked to toposequence position which importantly determine a particular fields' production potential. Lacking means of importantly modifying soil quality, farmers have developed highly flexible systems to adapt management practices and even crop selection to these micro-variations. For example, shallow gravelly soils which are generally located on the plateau and upland portions of the catena tend to be droughty, rapidly exhausted, and subject to high risk of erosion. Millet is predominantly cultivated on these soils. Deeper soils (sandy loams or silt loams in the Sudan zone) often occur in depressions and became more frequent towards the mid-slope and lowlands. Less drought tolerant crops including sorghum, maize and rice are sown in these areas. The most preferred soils with respect to both physical and chemical properties and available soil moisture, are limited to the lower slope margins around the temporarily inundated lowlands. One result of the catena linked micro-variability is the highly fragmented cropping patterns of traditional cropping systems and the often uneven adoption of components of improved technology.

AN OVERVIEW OF FARMING SYSTEMS IN THE WASAT

This section briefly characterizes the principal aspects of the region's farming systems. We examine the crops produced and the nature of the production units - their resources, economic alternatives and principal constraints - in an effort to provide a backdrop for the discussion of technological alternatives which follows. The section concludes with a summary of the more important trends in the evolution of the region's farming systems, and their consequences for technical change.

As a result of rainfall similarities, cropping patterns in the WASAT reflect a general east-west uniformity within agro-climatic belts, but a systematic change as one moves across belts in a north-south transect. This is particularly true for the staple cereals - millet, sorghum, and maize. In comparison cash cropping densities, while determined in part by the necessary conditions of soil and climate, are more influenced than the food staples by institutional factors which vary across countries and within countries across administrative or "project" boundaries.

Principal Crops

Millet is grown throughout the WASAT from the Sahel to the southern Guinea savana zones, and is the dominant cereal between the isohyets of 250 to 700 mm. Zones of concentrated millet production south of this belt are due to first, localized presence of shallow and/or lighter soils which cannot support sorghum cultivation; second, the use of millet in rotation with sorghum; or third, the presence of short-cycle non-photosensitive millets such as gero which can be grown as an early harvested crop in relay cropping systems in the more humid Guinean zones (Kassam, 1976). Average yields on farmers' fields vary from 350 kg/ha in northern extremes to roughly 1000 kg/ha in the south.

Sorghum production is generally concentrated in areas of 600 to 1000 mm where it is the dominant foodgrain. Small amounts of short cycle sorghum are also grown in more northernly Sahelian areas under restricted lowland conditions where yields exceeding upland millets can be achieved. Sorghum is less drought tolerant than millet and prefers heavier soils. Average farmers' yields vary by region and soil type between 400 kg/ha to 1500 kg/ha. Like millet, local varieties are generally full-season, photosensitive types.

Maize is generally a minor crop except for the southern and more humid margins of the WASAT. In traditional systems in the Sahel and central Sudan zones maize tends to be grown only on heavily fertilized soils adjacent to compounds and on the margin of swamps, where it rarely exceeds three percent of total cereal area. In southern Sudanian areas where rainfall is more dependable, maize occupies between 5 and 15% of total area, and is commonly grown as an intercrop or in rotation with cash crops, such as cotton, where it benefits from applications of chemical fertilizers.

Experiments conducted by IRAT (Bono, 1981) and by IAR (Kassam, 1976) demonstrate that the yield potential of maize in the Sudan and Guinea savana considerably exceeds that of either sorghum or millet. Maximum yields greater than 8 tons/ha are reported for maize compared to maximum yields of 4-5 tons/ha for either millet or sorghum under very high management. In contrast, maize yields under farmers' conditions generally vary between 200 and 1500 kg/ha.

Rice is a minor crop throughout the WASAT with upland varieties generally sown on the margin of swamps and paddy varieties in swamps and on recession flood plains. Outside of localized projects, rice area represents less than two percent of cultivated cereal area throughout the WASAT. Yields of upland rice are highly variable between years, with average yields of around 500 kg/ha when grown sole cropped (Norman, 1972). Average paddy rice yields are higher and somewhat less variable ranging between 800 and 1700 kg/ha. Under experimental conditions in southern Burkina Faso, three crops per year of paddy rice have achieved annual yields of greater than 12 tons/ha (Kassam, 1976). Adequate water control and the presence of prefered heavy alluvial soils are the major constraints to increased production.

Wheat is not a major crop in the WASAT. However, because it represents a major component of cereal imports it is attracting considerable interest in several WASAT countries, in particular in Nigeria and Senegal. Wheat production has been shown in both countries to be technically feasible under irrigated conditions but due to capital development and mechanization, production costs are competitive with imported wheat only when cropping intensity is increased to double or triple cropping (Byerlee and Varughese, 1981). Due to management as well as technical problems, this is rarely achieved (see later section on irrigation).

Cowpea is the major grain legume in the WASAT. Grown usually as an intercrop at low density (1,000-6,000 pl/ha) with millet or sorghum, it is produced either for forage or for its grain which is consumed and/or sold as a cash crop. As an intercrop, cowpea not only provides grain and forage, but serves as a means of soil cover, and fixes nitrogen. Sole cropped cowpea is rare due to insect damage when densities approach or exceed 10,000 pl/ha. Yields as an intercrop are low and highly variable, ranging between 50 kg/ha to 250 kg/ha. Sole cropped yields of 500-700 kg/ha can be realized with local varieties if sprayed. Experimental varieties grown under high management can approach 3 tons/ha (IITA, 1982) (Kassam, 1976).

Groundnut has traditionally been the major cash crop of the WASAT south of the Sahel belt. Groundnut haulms also serve as an important source of forage and have considerable commercial value in some areas such as northern Nigeria and Senegal. Groundnut is sown both pure and in crop mixtures with millet and sorghum and is the most common legume in cereal/legume rotations. Formerly a major crop in northern Nigeria, diseases and unfavorable prices have substantially reduced planting since the early 1970's. Groundnut remains a major export crop only in Senegal. Average farmers' yields are roughly 500 kg/ha compared to experimental yields of improved cultivars under high management of up to 5 tons/ha (Kassam, 1976).

Cotton is a major cash crop in large areas of the Sudan and northern Guinea savanna. Within the francophone countries, production under relatively high management conditions has been successfully promoted formerly by the CFDT and more recently by a set of national prarastatals which have inherited the vertically integrated production and marketing structure. Within such zones of concetration (as in southern Mali and southwestern Burkina Faso), cotton cultivation is closely associated with high use of chemical fertilizers, pesticides, and animal traction, all provided on credit. Farmers' yields average between 500 kg/ha to 1200 kg/ha compared to experimental results of up to 3 tons/ha.

Diversification and Mixed Cropping

A high degree of crop diversification has traditionally characterized farm units throughout the WASAT. Diversification is a means by which farmers reduce aggregate production variability, produce nearly all foods required in their diets, satisfy part of their cash needs, and exploit micro-variability of soil types. Due to a greater range of technical possibilities (a longer rainy season, better soils) the number of crops cultivated is greatest in the Guinean savanna and systematically declines towards the north (Kabore, et al. 1983).

The most common and efficient means of diversifying is the growing of crops in mixtures. This has been shown to reduce risk of crop loss while increasing returns to scarce factors (Norman, 1974) (Abalu, 1976). The range of mixtures can be extremely wide with the greatest diversity again found in the southern portion of the WASAT. The longer season and higher rainfall of the southern Sudan and northern Guinean zone permits not only a wider range of crops but also the fitting together of crops with complementary growth cycles.

The Structure of Production Units

The vast majority of agricultural production in the WASAT is derived from small family-based farms. These units vary from relatively small nuclear families to large extended or compound family structures which can include 30 persons or more. A trend observed throughout the WASAT, however, is a progressive decline in the size and number of compound units due in part to increased economic opportunities and associated changes in community norms (Norman, et al. 1981).

Land: The cultivated area per household is a function of family size and population density with regional averages generally ranging between 2 and 6 hectares. The distribution of land among households tends to be highly equitable, with some exception in areas of high population density (Matlon, 1981). Furthermore, there is evidence that over time land control is becoming more concentrated. Unlike the Asian SAT, however, a landless class of workers has not yet emerged.

The principal reason for the relatively equal control of land is that under low population pressure, usufructuary rights to land have been determined by customary or Maliki law. This appears to be entering a period of transition in many areas, where pressure on the land is increasing and as the rural economy becomes increasingly monetized. In a study of six villages in three agro-climatic zones in Burkina Faso, Vierich (ICRISAT, 1982) found that conventional forms of usufruct have already yielded to rights of possession and transmission of ownership through inheritance. One reflection of this trend is increased fragmentation of holdings.

Labor: Labor input per unit area tends to range between 350-1200 hours per hectare, but this differs between crops and varies positively with population density and length of cropping season. Periods of peak labor input generally correspond with planting and weeding when timeliness can critically affect potential yields (Matlon and Newman, 1978). Family members provide the bulk of the labor input, but this also declines as a function of population density, degree of monetization, and family income status. Thus in an area of Burkina Faso with moderate population pressure and a low degree of monetization, McIntire (1981) observed that non-family labor provided less than 10% of total farm labor. In contrast, in northern Nigeria in an area of high population density and 60% monetized income, non-family labor was observed to provide 42% of total farm labor (Matlon, 1977) [6].

Capital: Capital in traditional production systems consists primarily of hand tools (often produced in part by family labor), seed (generally retained from own stocks), and fertilizer. Non-labor cash expenditures in manual systems without chemical inputs are low, generally less than five dollars per hectare. In areas where hired labor is common cash expenditures however, can vary as high as 20 to 60 dollars per hectare (Matlon, 1977).

Expenditures in systems employing improved mechanical and chemical inputs substantially increase cash requirements. Moreover, because such expenditures occur when cash resources are lowest these can often create a significant cash flow problem (Barrett et al. 1982).

In spite of efforts to extend animal traction dating to the early part of the century, a small proportion of farmers in the WASAT - probably less than 10% - employ animals as a power source. Aspects of animal traction use and factors constraining its adoption are discussed in a later section.

Production Efficiency and Distributional Trends

Farm management studies of WASAT farmers have generally concluded that on average allocative efficiency is high (Norman et al. 1981). This indicates that insignificant production gains could be achieved by reallocating available levels of land, labor, and capital given the quality of inputs and current technology. In contrast, considerable variation has been measured with respect to the technical efficiency of individual households. Such differentials, however, don't necessarily reflect a production gap which can be closed through improved management alone since these are also due to differences in factor quality (e.g. control of different soil types) and to positions of wealth and liquidity which largely determine production and employment strategies of individual families (Matlon and Newman, 1978). [7].

Farmer Objectives

It is generally held that within the limits of their available resources, technologies, and subsistance needs, WASAT farmers are responsive to economic incentives. Many researchers have proposed models whereby agricultural production goals are set first to meet household consumption requirements with any available surplus resources allocated to maximize profit through commercial exchanges. As a result, due to low productivity in cereal production, cropping patterns are generally cereal based.

In addition to simply meeting domestic consumption needs, however, several other factors influence farmers to set annual cereal production goals in excess of their own expected consumption requirements. First, given wide interannual weather fluctuations, farmers attempt to accumulate and maintain food stocks which can carryover important supplies into at least one subsequent bad year. Second, it is believed that social obligations, in particular the obligation to provide assistance to others, increases cereal targets by an additional kin and community based margin (ICRISAT, 1982). These two factors which commit excess resources to non-market, subsistence objectives, are probably of greater importance in the more arid northern regions than in the south where a greater degree of market participation, and cash cropping, is encountered.

On average marketed surplus of cereals is believed to represent between 10 to 15% of total production (CILSS, 1977). However, this is substantially lower in the northern belt, following one or several years of poor rainfall, and among resource poor farmers.

A second related objective often attributed to WASAT farmers is that they are risk averse and generally conservative with respect to innovation. In fact as Norman et al. (1981) point out, little rigorous empirical research on farmers' risk attitudes and behavior has been done in the WASAT. The role of risk perception, risk aversion, and risk avoidance strategies - as a determinant of production and innovation is in particular need of additional research. Available evidence also challenges the notion that WASAT farmers are averse to changes in their traditional cultural practices. Rather the adaptability of local systems is reflected in the widespread adoption of groundnut and cotton when necessary price and institutional conditions have been met. This is also reflected in active traditional experimentation with new technologies and seeds, and in considerable flexibility in the adoption of new "local" varieties to better fit changing conditions (ICRISAT, 1983).

Alternative Economic Activities

Because of the extended dry season and the need to diversify income sources away from weather dependent crop production, members of WASAT farming households generally pursue a range of non-agricultural income earning activities. These include artisanal activities, salaried labor, crop and non-crop trading, and livestock raising. In the highly monetized rural economics of northern Nigeria, these activities can contribute up to one-third of total farm household income and more than one half of net cash revenues (Matlon, 1981). Although many of these activities are pursued throughout the year, the total time allocation is negatively correlated with cropping labor and thus does not normally compete with crop production. Returns to labor in non-agricultural employment are highly variable as well as being location and trade specific. In northern Nigeria average returns in more than twenty non-agricultural occupations were found to be roughly 50% greater than the farm wage rate which was approximately equal to the marginal value product of farm labor. But among the most capital intensive set of occupations, returns to labor were generally two to three times the farm wage rate (Matlon, 1977).

An important additional source of income in some Sahelian countries is the migration of young men to coastal countries for off-season or multi-year employment. Income earned during such migration-linked employment is an important source of investment capital in both farm and other non-farm activities.

Livestock: Nearly all farm households maintain a stock of fowl and small ruminants, and in some cases cattle. Livestock are typically maintained as an easily liquidated form of savings, insurance and income. The potential technical complementarities between livestock raising and cropping, however, are rarely achieved. Under extensive land use systems which have traditionally prevailed, adequate sources of forage existed away from the farm resulting in a loss of the majority of manure. Systems of entrustment whereby fulani herdsmen managed the livestock of cultivators were well adapted to this ecological setting (Delgado, 1977).

With increasing population pressure, however, two opposing forces are developing which point to the need for profound structural changes in current cropping-livestock systems. First, with a shift to less frequent fallows, low organic matter levels are becoming a serious constraint to current production and to long-term soil stability. Substantially larger amounts of manure are needed to stabilize the system than are currently being applied [8]. But second, growing land pressure is concurrently reducing the area previously allocated to wild forage production. This is true both in former bush areas, and around water points where increasingly intensive crop activities are being introduced. Identifying adapted methods of achieving integrated mixed-farming systems represents an urgent research priority.

Support Services

With the notable exception of parastatals (responsible for cash-crop based extension, input supply, and marketing programs) and externally financed Integrated Agricultural Development Projects, support services to small farmers are generally very poorly developed throughout the WASAT. Understaffing [9], a multiplicity of agent responsibilities, lack of transportation, inadequate supplies of inputs, and insufficient training characterize the extension services of most WASAT countries. The lack of appropriate improved technologies to extend further reduces extension agent morale and farmers' confidence.

Summary of Major Trends and Implications for Technical Change

The two dominant motor forces inducing rural change in the WASAT are (1) mounting population pressure leading to more intensive land use patterns, and (2) increasing market penetration and a consequent rise in the level of monetization. Several consequences for the region's long-term agricultural production potential and technical needs follow:

1. With population growth cultivation is being systematically intensified, expanded onto fields more distant from habitations, and introduced onto marginal soils which were formerly avoided due to lower fertility and/or greater drought proneness. Traditional bush-fallow methods of maintaining soil fertility are being abandoned with a consequent decline in soil fertility and increasing soil loss through erosion.

In order to reverse this downward trend, and ultimately to achieve a positive growth rate in yields, alternative methods of maintaining marginal soils under intensive cultivation are required. This points towards methods of reducing run-off and soil erosion, and towards the development of mixed farming systems to more efficiently produce, recover, and transport organic matter. Similarly local cereal varieties traditionally selected for cultivation on the most favorable soil types, may not be well adapted to more shallow, drought-prone soils onto which cultivation is expanding. This points towards the development of shorter-cycle varieties of sorghum and millet with improved drought and Striga resistance.

2. Parallel changes in land tenure systems are resulting in greater personal control over landholdings, and in the fragmentation of holdings into smaller and more dispersed plots. This trend runs counter to investment in mechanization and scale responsive land management. On the other hand with greater and more permanent control over the land, WASAT farmers are more likely to internalize the negative long-term consequences of continuous cultivation and thus to perceive incentives to invest in land improvement. Moreover, although a monetized land market has not yet emerged, demand for inputs complimentary to continuous land use (chemical and organic fertilizers) is increasing rapidly, in conjunction with more commercialized exchanges for traditionally non-monetized inputs such as manure.

Coincident with this evolution is a tendency for greater concentration of land control. This could lead to a less equitable distribution of resources and may lay the base for the possible emergence of exploitive socioeconomic relationships in the future.

3. Increased economic opportunities have resulted in a trend toward the breakdown of large family units and a greater individualization of decision-making. While this will increase incentives to produce for personal gain, it

also reduces the effectiveness of traditional communal support mechanizms which protected families against severe welfare loss in case of crop failure. Thus risk is increased. The dissolution of large units also reduces the feasibility of new technologies which require large, lumpy investments and which are characterized by economies of scale (e.g. watershed-based land management, and, perhaps, animal traction).

4. The growing importance of non-agricultural employment, in particular, offers individuals increasingly viable alternatives outside of farming. Investments of capital and labor in agriculture are increasingly weighed by farmers against opportunity costs in the non-farm sector. Some authors have claimed that this has acted as an important constraint to agricultural intensification. On the other hand, the amount of capital generated in non-farm employment is increasingly available for reinvestment in farming. The issue is whether currently available agricultural technologies present sufficiently profitable investment opportunities.

PART II:

TECHNOLOGICAL OPTIONS TO IMPROVE AGRICULTURAL PRODUCTIVITY

In this part, we examine the current stock of technologies in five principal areas: irrigation, other forms of land/water management, mechanization, crop improvement and soil fertility management.

IRRIGATION IN SEMI-ARID WEST AFRICA

Given the generally low and variable rainfall which characterizes the WASAT, irrigated agriculture has often been viewed as a means to increase agricultural productivity while substantially reducing the risks of drought and interannual production variability. In this section we assess the short and long-term potential of expanded irrigation by combining information on the extent of irrigable soils and on surface and ground water, with considerations of the economics of irrigation development. Primary emphasis is placed on the eight West African states generally grouped together as Sahelian where the potential impact of irrigated technology is considered greatest.

Current Levels of Irrigation

Several major water control and irrigation projects were begun by the French prior to independence [10] and areas under irrigation in the Sahel have increased at an annual rate of between 3 and 5% through the late 1970's. By 1979 among the eight Sahelian countries 75 thousand hectares were currently under total water control and 155 thousand hectares under partial though modern control (CILSS, 1980).

An additional 200 thousand hectares were estimated to be under traditional lowland and recession agriculture. This means that only 3% of total farmed area are currently being exploited by either traditional or modern irrigation.

Production is somewhat more important than cultivated area with irrigated farming producing nearly 5% of cereal output in the Sahel. Production has concentrated on crops with relatively high income elasticities and for which demand exceeds current and projected domestic supplies (rice, wheat, sugar, fruits and vegetables).

Due to the lack of complete water control and general absence of double cropping, however, yields in both modern and traditional sites are low and highly variable. Annual yields range between 1 and 3 tons per hectare, or substantially below the potential of up to 8 tons, for example, achieved, under rice double cropping in parts of Niger (CILSS, 1980).

Irrigation Potential and Constraints

Although data from different sources vary,the general magnitude of the natural parameters determining the technical potential of irrigation is clear and points toward a technical potential well beyond current levels. Soil quality does not appear to be a limiting factor. Overlaying information on topography with soil physical and chemical properties, an FAO study (FAO, 1975) has concluded that within the Sahel irrigable soils cover approximately 14 million hectares. This represents roughly 8% of total area, and 20% the total arable land.

Information on surface water resources is also relatively good. The amount of water drained by the major river systems in the Sahel [11] has been shown to exceed substantially the amounts required for the region's human and animal consumption (FAO, 1975). The seasonal flow patterns, however, reflect extreme variability between months of maximum and minimum flow which means that substantial investment in dam facilities is required if more complete water control and more intensive double cropping are to be achieved. Given the generally flat topography of the region, natural opportunities for large dam construction, however, are extremely rare.

Information on groundwater resources are less precise, but the magnitudes of available estimates suggest a substantial technical potential [12]. In contrast to technical potential, however, it is generally conceeded that costs of exploiting groundwater resources rule out their use on an important scale for crops production given foreseable input and output price relationships (CILSS, 1980).

Lacking comprehensive and detailed feasibility studies throughout the region, an accurate assessment of future "economic" irrigation levels is impossible. In what would appear to be an overly optimistic projection (which rules out exploitation of groundwater sources but which assumes full exploitation of surface water) CILSS (1980) projects the irrigated agricultural potential of the Sahel states which could be developed within 25 years to be 2.3 million hectares, or approximately 10 times existing levels. A recent USDA report (1981) projects a similar technical potential based primarily on large scale projects [13].

An economic assessment of the potential of large scale irrigation projects is less encouraging due to several factors:

1. Per hectare investment costs are substantial varying between \$ 5000 to \$ 20000 (CILSS, 1980) (World Bank, 1980).

2. Yields are not sufficiently superior to rainfed agriculture, due to:
- poor water control
- absence of double cropping
- inappropriate agronomic packages
- lack of complementary inputs.

3. Poor management and high recurrent costs result in inadequate maintenance of equipment and structures [14].

4. Little consideration has been given to farmer incentives and to the problems of incorporating traditional farmers into intensive and externally directed irrigation systems.

5. External costs including loss of grazing and farming land, and movements of displaced population, can be considerable.

In a review of the limited available literature on the economics of irrigation in the Sahel, Sparling (1981), cited in Eicher and Baker (1982), provisionally concludes that small-scale, labor-intensive irrigation projects tend to be substantially more profitable, privately and socially, than large scale projects. Investments which the evaluation literature finds to be economically more attractive include (Eicher and Baker, 1982):

- improved lowland and recession farming systems
- small-scale groundwater development
- land reclamation through drainage and improved water control
- small perimeters which are developed and maintained by family or communal labor.

Following this strategy, investments in large scale projects would be limited to rehabilitation and improving the efficiency of existing structures.

It should be underlined that tne data and analytical base on which irrigation programs are being developed, is extremely limited. Further research in these areas, with emphasis on ex post project evaluations rigorously comparing the scale and technologies of both irrigated and rainfed systems, is needed (Eicher and Baker, 1981).

LAND AND WATER MANAGEMENT [15]

As indicated in the discussion of climatic characteristics, water constitutes a primary limiting factor to rainfed agriculture in the WASAT. The peaked uni-modal monthly rainfall distribution, high rainfall intensity and high intraseasonal variability reduce and destabilize agricultural productivity in several ways:

1. During the crop growing season there are successive periods of deficit and excess water which damage plants' physiology and retard growth.

2. A substantial portion of total rainfall is lost to plant growth due to run-off.

3. Loss of top-soil can be substantial. These losses are exacerbated by continuous cultivation and, in some cases, mechanical cultivation.

The most common traditional method to maintain adequate soil moisture and to achieve soil conservation has been shifting cultivation in which short cropping cycles alternate with long bush-fallow cycles. Due to increasing population pressure, however, these systems are giving way to shorter grass fallows, and in some areas to continuous cultivation. Alternative methods are clearly required.

Technological Alternatives

The principal techniques currently available or under research which might be applied in the WASAT are: (1) soil tillage, including various methods of plowing (discussed in a latter section) and ridging; (2) mulching; (3) strip cropping; (4) contour bunding; (5) watershed-based management.

These techniques vary in scale, respectively, from plot and field scale to entire watershed coverage. Given the common fragmentation of field ownership, the later more comprehensive approaches raise important of ownership and group management problems.

Tied ridges: The technique of constructing ridges which are subsequently tied (at planting, with first weeding, or at flowering) has been shown in east Africa to significantly increase water infiltration and enhance yields (Ruthenberg, 1980). Because of its often dramatic yield effects trials to determine the adaptibility and potential of this technique in the WASAT have been conducted by a number of institutes. We review here results from Burkina Faso.

Experiment station results indicate that yield response is greatest under conditions of soil-moisture stress (on plateau and mid-slope fields and on soils where water infiltration is limited due, for example, to excessive crusting) and where soil fertility is not limiting. Average yield increments of between 1 to 2 tons/ha for maize (Rodriguez, 1982, 1983), 950 kg/ha for sorghum, and 600 kg/ha for millet (ICRISAT, 1981) have been observed on research stations where medium to high doses of NPK fertilizer have been applied [16].

Despite this technical potential, tied ridging is not practiced by WASAT farmers. The major questions surrounding tied ridges as a technique to be extended to farmers are: (1) whether labor required for the construction and tieing of ridges may be excessively costly if it occurs during the labor bottleneck period [17]; (2) whether adequate response can be achieved under low fertility levels more typical of farmers' conditions; and (3) whether an important off-station yield gap emerges even under high fertility levels. Limited test results under farmers' conditions indicate that substantial yield reductions do occur at both high and low fertility levels. Farmers' tests conducted by IITA over two years showed that tied-ridges increased maize yields by an average of only 55 kg/ha and 370 kg/ha on zero fertility and high fertility treatments, respectively. This was substantially below the cut-off increment of 430 kg/ha calculated as required to compensate for the opportunity cost of additional labor (Rodriguez, 1982). Similarly, two-year farmer tests on millet fields in Burkina Faso observed mean yield increments of 30 kg/ha on non-fertilized plots, and 85 kg/ha on the most highly fertilized plots (FSU, 1982, 1983). Although farmer tests show that sorghum responds better to tied ridging with yield increments of 90 and 140 kg/ha under low and high fertility conditions, these are still below breakeven levels (FSU, 1983). Additional farm level research is required to identify the factors contributing to these substantial yield gaps before this technique can be considered for extension on a wide scale.

Modified forms of tied ridges, such as the use of holes to collect and concentrate water on plant hills, require substantially less labor and have given significant yield effects under high fertility on-station trials (Rodriguez, 1983). Moreover, such methods are in fact practiced by farmers in zones of highest population pressure in Burkina Faso. Additional on-farm research is required to determine performance levels under low fertility farmer management and transferability to other agroclimatic zones.

Mulching: The major effects of applying crop residues or free-cut straw as a soil cover are to increase infiltration, to reduce erosion, to control weeds, to improve soil structure, and to reduce soil temperature. Contradictory results are available demonstrating the yield effects of mulching under experimental conditions, however, differences which may be explained by variation in soil types, topography, and seasonal rainfall patterns. Charreau and Nicou (1971) in a general review of West African research results, for example, found no clear superiority of yields under mulching, whereas in two years of trials Perrier observed yield increases varying between 50% and 200% for both local and improved sorghum varieties in central Burkina Faso (ICRISAT, 1981, 1983).

Although mulching is a technique known by WASAT farmers, it is generally applied on small areas and in special circumstances, such as on termite mounds and to particularly shallow portions of fields where water infiltration or retention is limited. A major constraint to expanded use is the availability of straw since much of the available material is diverted to other economic ends. These include feed for livestock, construction, mat making, and as a firewood substitute for domestic and small industrial purposes. Straw is particularly limited in the northern zones of the WASAT due to the lower rainfall combined with the greater importance of livestock raising. Moreover, the increasing demand for straw as a fuel source in many areas of the WASAT as population densities increase and deforestation becomes more severe seriously challenges this as a generalized approach for the future.

Strip cropping: A less demanding method of reducing erosion on gentle slopes is the contour placement of narrow bands of permanent vegetation between cultivated fields. The technique generally occupies less than 10% of the potential cultivated area, but has been shown in the Ivory Coast and in Niger to reduce soil erosion up to one tenth and run-off to one third under experimental conditions (Roose, 1975). Use under farmers' conditions has not been reported, although the practice of planting bands of perenial economic shrubs, such as andropogun, to reduce erosion while producing artisanal material, is common in many WASAT areas.

Contour bunds: Anti-erosion dikes constructed across the slopes of cultivated fields are common in the Indian SAT. The Indian experience shows that if properly laid out and maintained, soil erosion can be substantially reduced. Although bunding initially tends to increase water infiltration in a relatively narrow band above the bund (where it can create serious drainage problems leading to waterlogging on certain soil types [18]) overtime erosion within the bunds can result in a terraced effect which increases the area benefitting from improved water infiltration.

The traditional use of bunds in the WASAT is rare and on a generally small scale. In zones of high population pressure, for example, farmers occassionally construct small rock dikes across water courses to reduces run-off velocity and gully erosion. Similarly, low dirt dikes are sometimes built around small heavily manured household plots to avoid loss of fertilizer.

Although early large scale projects in the WASAT which used unstable dirt contour bunds were not successful [19], evaluations of more recent projects suggest considerable potential. In addition to the long-term benefits of reduced top soil loss, farmers' tests conducted by ICRISAT in Burkina Faso have measured highly significant 20 to 80% yield increases in the short-term (ICRISAT, 1983). Yield increments of these magnitudes are probably essential to motivate faremrs to maintain the fragile bunds [20]. More stable rock-based small-scale water harvesting bund systems have also been developed and extended in the most densely populated and environmentally degraded portions of Burkina Faso (Wright, 1983). Although this method has been shown to be successful in bringing highly eroded, abandonned fields back into production, its potential in increasing yields on currently cultivated fields has not yet been determined. A combination of such small and large scale bund systems, as appropriate for specific locations, represents one of the most promising sets of technologies now available for areas of relatively high population density.

Watershed-Based Approaches: A technique which has been developed and successfully tested by ICRISAT in the Indian SAT has been the comprehensive development of entire elementary watersheds with the goal of increasing the use efficiency of watershed precipitation [21]. The approach has been shown to be an effective means of erosion control on black soils with both run-off and erosion reduced by approximately 80% compared to control treatments. Economic analyses of the Indian systems however, have shown them to be profitable only on deep Vertisols, not on medium or shallow Vertisols, nor on Alfisols (Binswanger et al. 1980).

Although ICRISAT has considered initiating an experimental program of watershed development in Burkina Faso, no research has as yet been undertaken in West Africa. Moreover, differences in the physical and social environments of the Indian and West African SAT areas suggest that the potential area on which watershed-based development is appropriate is more limited in the WASAT and that the direct transfer of existing methods is probably not possible (Charreau, 1977).

As noted earlier, deep black Vertisols are extremely rare in the WASAT, and yet it is on soils of this type in India that the watershed approached has been shown to be most promising. In addition, because the red soils of the WASAT are generally shallower than those in the Indian SAT and have lower waterholding capacity, the potential technical impact would be importantly reduced. Finally, iron-pan outcroppings which are more common in the WASAT can create serious downslope erosion problems not typically found in Indian watersheds.

A second important difference concerns topography and the required scale of watersheds. In India, due to greater micro-relief, elementary watersheds are generally small, between 5 and 15 hectares; whereas the flatter WASAT topography results in elementary watersheds which tend to exceed 100 hectares. This points to substantially larger investment requirements as well as greater institutional problems since a larger number of households would be involved. The general flatness of the WASAT terrain also means that water storage facilities would be less efficient and would cover substantially larger areas of often the best and most intensively cultivated soils.

Third, due to historic high population density Indian farmers are more accustomed to intensive cultivation methods and to irrigation both of which require substantial investment in the land. Neither situation is true for the vast majority of WASAT farmers. Consequently a considerably greater adjustment time would have to be anticipated before potential benefits could be realized in the WASAT. Finally, bullock traction, which is required to construct and fully exploit the potential of the broad-bed and furrow system, is an integral part of Indian SAT farming, whereas it represents the exception in the WASAT.

MECHANIZATION

The history of agricultural development in Asia, Europe, and the Americas shows that over time specific farm operations become increasingly mechanized when power employed in those operations is a limiting production constraint and when the cost of the principal alternative power source -- human labor -- increases relative to the cost of capital. Based on such experiences elsewhere, major efforts have been made since the early 1900s to introduce draft animal technology to WASAT farmers. Moreover, the pace of such efforts is increasing with more than 50 projects involving a draft animal component funded in francophone West Africa alone since 1970 (Sargeant et al. 1981). Large investments in tractorization have also been made, particularly during the 1950s and 1960s in several WASAT countries. Despite these programs it is estimated that less than 20% of total farmed area in the WASAT is currently mechanically cultivated.

In this section we briefly present the results of technical research showing the potential benefits of mechanized farming, followed by impacts observed under farmers' conditions. We conclude with policy implications for planning mechanized farm production projects. Emphasis is placed on draft animal systems.

Potential Technical Benefits of Animal Traction

The potential benefits of animal traction cultivation are: (1) area expansion (through labor savings in bottleneck operations); (2) increased yields per unit area; (3) freeing labor to non-farm employment and leisure; or a combination of all three effects for different crops, land types, population densities, or farm types.

The principal means of increasing yields which can be derived from mechanized operations are through land preparation (plowing, scarifying, ridging), and through more timely and uniform seeding and weeding.

Plowing: For the coarse loamy "inert" soils which dominate in the WASAT deep plowing can improve yields through at least four mechanisms: (1) increased soil porosity which improves root density and depth; (2) improved water regime by reducing run-off, increasing infiltration, and increasing soil waterholding capacity; (3) increased organic matter levels and microbial activity through incorporation of added amounts of crop residues and manure; and (4) improved weed control.

Research station experiments have verified the yield effects of deep plowing in several WASAT countries. Charreau and Nicou (1971), for example, report on trials in Senegal showing yield increases of between 20 and 30% for millet, sorghum, maize, cotton, and groundnut. Results from the Gambia show 40% increases for millet and groundnuts (Kline et al. 1969) and ICRISAT in Burkina Faso (1978) has observed yield increases of 45% for sorghum [22]. In addition to the main effect of deep plowing the positive interaction between plowing and fertilizer is usually highly significant due to plowing's effects on soil moisture and incorporation of organic matter. However, it is important to note that by breaking the soil crust, plowing can accelerate organic matter decomposition. This can seriously reduce soil organic matter levels over time unless substantial amounts of manure are returned (W. Stoop-personal communication).

Seeding: The short rainy season combined with the intermittant pattern of rainfal makes it necessary for rapid planting of full-cycle photosensitive cereal varieties following each early season rainfall in order to realize full yield potential. Planting with mechanical seeders can reduce labor requirements by roughly 60% thus potentially doubling the area planted after each planting rain. Yield benefits to early planting have been observed to be on the order of 10% for cotton, 30% for groundnuts, and between 40 to 60% for sorghum when compared to 2-3 week delays (Andrews, 1975) (ICRISAT/Burkina Faso, 1978, 1982).

Weeding: Thorough and timely weeding has been identified as the most limiting constraint on production in the WASAT given traditional inputs (Norman et al. 1981). Theoretical labor savings of greater than 75% for mechanized weeding compared to hand labor permit more timely execution or a proportional expansion of cultivated area [23].

Adoption Patterns and Major Constraints

A range of animal traction packages have been adopted under widely differing agroclimatic and institutional conditions. A review of more than one hundred development projects in francophone Africa which include animal traction as a major component observed the following common patterns and constraints limiting attainment of the potentials just described (Sargent et al. 1981):

1. Adoption of traction systems tends to center in pockets which are areas of cash cropping concentration. This is reflected in high rates of adoption in the Sine-Saloum region in Senegal (groundnut) as well as in southern Mali and south-western Burkina Faso (cotton). The high correlation between traction adoption and cash cropping is probably better explained by institutional than technical factors. Supplies of complementary inputs provided on short-term credit, medium-term credit for equipment and animals, intensive extension and veterinary support, and assured output markets are typically provided by vertically integrated cash crop marketing institutions. Where such support services are lacking, adoption rates tend to remain low.

2. The range of operations performed is also commonly less than that required to obtain the full benefits of an integrated traction system. Land preparation equipment - scarifiers and shallow plows in the sandy soils of the northern belt and deeper plows for the heavier soils further south - are often the first and only cultivation equipment adopted. Weeding equipment is less common with fewer than 25% of Sahelian farmer with traction equipment weeding mechanically. Seeders have been adopted to an important extent only in Senegal and the Gambia. The general absence of weeding, in particular, poses a major constraint to area expansion in zones where manual plowing operations have been mechanized. As a result of the limited range of operations performed, animals tend to be grossly underutilized unless transportation is also mechanized [24].

3. The short rainy season creates important labor conflicts between plowing and timely planting particularly in more northern and extreme western portions of the WASAT where land preparation is not manually performed [25]. Because oxen plowing requires about five days per hectare and since soils remain sufficiently soft to permit plowing only for three to four days after an adequate rainfall, the proportion of total area plowed for traction farmers is often small in the central and northern belts. The timing problem also helps explain the lack of an important equipment rental market for plowing and first weeding in all but the most southern zones where the cropping season and preparatory rainfall phase are longer. Thus the full burden of the fixed costs for animals and equipment must generally be amortized over the cultivated area of a single equipped farm unit.

Finally, end of season plowing is rarely performed by farmers due to conflict with harvesting operations and due to the rapid drying and hardening of the top soil immediately at the end of the rains. As a result full incorporation of crop residues is rarely achieved.

Yield and Area Expansion Effects Under Farmer Conditions

For the reasons described the transfer of draft animal technologies to farmer conditions generally results in a substantial shortfall from the levels of potential benefits observed on research stations. The number of sufficiently detailed farm level studies is limited, and the results are often inconsistent. Most generally these studies report insignificant yield effects but measurable area effects of between 10 and 40% in Gambia (Mettrick, 1978), southeastern Mali (Whitney, 1981), and Burkina Faso (Barrett et al. 1982) (McIntire, 1981) (Jaegar, 1984). In one of the largest and most detailed farm level studies of animal traction available, Barrett (1982) observed an insignificant 4% increase in area per worker among Burkinabe farmers cultivating with oxen equipment but a significant 18% increase for farmers using donkeys as a source of power. No significant yield effects were observed for either sorghum or millet which occupy greater than 80% of total area. Moreover, labor use per hectare was reduced by nearly 25% with the freed labor diverted to area expansion, animal care, agricultural trading, and leisure.

Economic Effects

Economic analyses of draft animal systems reflect this low technical efficiency at the farm level. In Burkina Faso Barrett observed that plowing alone does not achieve a competitive internal rate of return when calculated over a ten year period (4 and 14%, respectively, for donkey and oxen plowing). The returns to mechanical weeding in addition to plowing however, substantially increased the internal rates of return, to 24 and 28%, respectively, for donkey and oxen [26]. It should be noted that a large portion of the net benefit from oxen traction is due to the appreciation and resale of the animals for meat.

Several studies also show that adoption is a dynamic process which can require at least six to eight years to achieve full farm level benefits [27]. The slow learning process combined with repayment of credit (provided in most projects for the purchase of equipment and animals) can result in severe cash flow problems during the first several years of adoption when net incremental benefits tend to be negative [28]. The risk of animal loss due to sickness or death, and the risk of production shortfall due to climatic variability - particularly if climatic problems persist for more than one year - underline the magnitude of potential cash flow problems.

Implications for Animal Traction Programs

These results placed within the context of the region's demographic and ecological trends discussed earlier, have important implications for future animal traction programs and research.

1. Despite increasing population pressure which is being accompanied by shortened fallow periods, expansion onto marginal soils, and growing areas of declining soil quality, current patterns of animal traction adoption reflect a tendency towards further though limited area expansion. This application of animal traction alone has little potential to increase production over the long term.

The development and promotion of traction implements and packages which provide only area expansion benefits should be limited to areas with ample land resources. Alternative packages and recommendations should be developed to achieve successful intensification in areas of more limited land resources. Since farmers probably tend toward more extensive systems as a means of risk reduction, new intensive systems must give equal weight to short-term profitability, interannual stability, and long-term soil conservation.

2. The development of intensive animal traction cereal systems must incorporate complementary bio-chemical components. Cereal varieties which are more responsive than locals to plowing and which permit later and more flexible planting - thereby reducing the conflict with plowing - would increase returns to traction adoption while simultaneously reducing weather induced risks.

3. Intensive traction systems must provide for greater integration of crop and livestock activities in order to more effectively manage and recycle biomass production on

the entire farm system. This is necessary to improve animal health and nutrition while returning greater amounts of organic matter to the soil [29].

4. Because increased cash crop production may be necessary to assure the financial viability of animal traction, agronomic research should focus on the development of cropping systems incorporating cash crops as complementary elements in cereal based systems. Groundnuts, cotton, or cowpea in rotation or intercropped with sorghum, maize, or millet may have important complementarities due to different nutrient demands, different crop cycles and due to the residual effects of fertilizer and plowing applied to cash crops on subsequent or intercropped cereal crops.

5. Viable support services must be considered integral elements of animal traction projects. These should include farmer and animal training, credit, input and output marketing, veterinary care, and timely equipment sales and repair.

6. Credit programs in support of animal traction should establish repayment terms which reflect the profile of benefits accruing over time as farmers gain experience with the animal traction system [30]. The extreme variability and risk of loss in semi-arid agriculture should be reflected in animal and equipment insurance. The economics of crop insurance programs or the inclusion of flexible grace period conditions should also be examined.

Tractorization

Tractors as a source of draft power have attracted both governments and donors during the 1950s and 1960s as a means of rapidly modernizing African agriculture. Within the WASAT, tractorization has been limited to the guinnean zones, including the northern portions of Benin, Ghana, Nigeria and southern Mali where it has been introduced in the context of large-scale farms and tractor hire schemes.

In comparison with animal power, tractors have the advantage of permitting deeper plowing and substantially reducing the time necessary for land preparation, seeding, and weeding. The disadvantages however, are considerable and include:

1. Loss of the biomass recycling complementarities of mixed farming systems.

2. High foreign exchange costs for both capital and recurrent expenditures.

3. Maintenance problems resulting in underutilization and rapid depreciation.

Economic studies of tractor schemes have generally shown that at high rates of subsidy [31] rental of a large tractor services can be financially profitable, but nearly always represents a net economic loss to society. Moreover, benefits tend to be concentrated primarily on large landholders by-passing smaller farmers on whose dispersed and fragmented fields per hectare tractor operation costs are considerably higher (Shepherd, 1981).

Given the increase in fuel prices and increasing foreign exchange constraints of most countries in the WASAT, it cannot be foreseen that large tractors will play an important role in WASAT food production in the near future. Only substantial increases in labor costs and/or in animals and animal traction equipment could change this conclusion. Work on small or intermediate sized tractors as has been carried on in Senegal, Nigeria, Mali, and Burkina Faso, however, may have greater promise if issues of fit to fermers technical, economic, and social conditions are addressed early-on in on-farm adaptive research.

CROP IMPROVEMENT

Breeding and varietal selection programs aimed at improving the productivity of both cash crops and foodgrains have existed in the WASAT for several decades [32]. However, in contrast to significant improvements in cash crop varieties which have been widely diffused to small farmers in the WASAT, little progress has been achieved with respect to foodgrains. The greatest advances in cereals have occurred in upland rice and in maize where a number of IRAT and IITA varieties have met with some success [33]. Both rice and maize, however, are minor crops with little leverage on total food production. Much less success has been achieved for the coarse foodgrains sorghum and millet which constitute the staple diet of the vast majority of the WASAT population.

In this section we examine briefly some of the reasons for the lack of progress to date in sorghum and millet, and suggest elements of improved crop selection and breeding strategies which are more likely to achieve success in the foreseeable future. We conclude that the general lack of improved varieties which are well adapted to farmers' conditions is due to a complex of factors which include:

- inappropriate crop improvement objectives in view of the region's soils, level of infrastructural development, and farm level capital;

- over-reliance on selecting varieties and hybrids solely under research station conditions which often poorly reflect the quality of farmers' resources;

- lack of systematic feed-back from the farm to the research station to assess reasons for performance differences and lack of adoption.

Crop Improvement Objectives

Most crop improvement programs in the WASAT have included several objectives to varying degrees, but priority has traditionally been given to identifying high yielding cultivars under high management [34]. Although this approach is generally consistent with the one which realized substantial production gains for wheat and rice in south-asia during the 1960s and 1970s, critical differences in the WASAT environment compared to Asian conditions have blocked progress to date.

First, the high yielding variety package approach generally requires increased plant density and high use of chemical fertilizers to obtain production potential. However, technical response rates to fertilizer and to increased plant densities are substantially lower and risk higher on soils with low water holding capacity or when water control is absent. As described in earlier sections, soils in the WASAT generally have lower water holding capacity than soils in areas with similar total rainfall in the Asian SAT. In addition, the density of irrigation is insignificant in the WASAT as compared to Asia [35].

Institutional and economic factors are also important. For example, the density of extension support is lower and the level of infrastructure to supply chemical inputs in a timely and assured basis is considerably less well developed in WASAT than in most Asian countries. Moreover, because there is substantially lower land pressure in the WASAT compared to the Asian SAT, there are less economic incentives to intensify land use at the expense of traditional risk reducing land extensive strategies which are associated with lower production costs per unit area.

Closely linked to the "high yield-high management" objective has been the effort to transfer high yielding cultivars from other SAT regions of the world as direct introductions into the WASAT. These efforts have not generally been successful. This was evident for example in ICRISAT's early attempts during the late 1970s to introduce into West Africa high yielding varieties and hybrids of both sorghum and millet which had been developed in India [36]. A systematic regional effort to evaluate local West African varieties of sorghum and millet is now being made with the cooperation of national, regional and international research institutes. Concurrently, greater efforts are being made to exploit the local genetic diversity of West African material through crosses within locals and between locals and exotics in order to combine the robustness and adaptability of local materials with the possibly higher yield potential of introduced materials [37]. Whether greater use of local materials results in important breakthroughs will not be clear until the mid to late 1980s.

Alternative Medium-Term Crop Improvement Objectives

More at issue than the relative use of local or exotic materials in cereal improvement programs, however, is the priority given to the objective of management-dependent high yields to the exclusion of other possible objectives. Varieties which require good soil moisture, high soil fertility, thorough soil preparation, and other aspects of advanced management in order to outyield local varieties may present farmers with unacceptable risk and are unlikely to be adopted on a wide scale in the near future. Rather what may be required for a general impact in the short and medium-term are stable varieties which yield as well or better than local varieties under current farmer conditions, but with sufficient plasticity and yield potential to respond more favorably than locals to improved conditions [38].

Potential for moderate yield increases and substantially greater stability also exists through breeding for resistance to the most common pests and diseases. This includes resistance to downy mildew in millet, to Striga in both sorghum and millet, and to aphids and midge in sorghum. Greater drought resistance and improved seedling vigor are at least equally important. The magnitudes of such potential gains are not easily defined however, as rigorous yield loss assessments are not generally available [39].

The development of varieties with a wider range of agronomic characteristics, such as plant structure or reduced crop cycle, could also increase farmers' management options; for example, by opening new intercrop or relay cropping possibilities, by permitting farmers to plant late without yield loss following failure of early rains or after soil preparation, and by permitting cropping on the most drought prone soil types where soil moisture limitations reduce the effective growing period. As with breeding for resistance, however, the impact of such a strategy would likely be marginal in terms of aggregate production though it would achieve greater production stability.

Over the longer-term it is clear that for major breakthroughs in cereal production development of more management responsive varieties or hybrids must be advanced. By increasing returns to complementary inputs, demand for such inputs will increase thus providing greater economic incentive for both public and private sectors to supply the needed materials and services. The shift to more intensive systems based on a high yielding variety package approach is inevitable, but it will take time and requires major investments outside of cereal breeding. An intermediate approach involving less dependence on purchased inputs would be to radically modify existing farming systems to provide the improved inputs (such as soil fertility) internally through improved methods of rotation and through a full integration of cropping and livestock rearing. The time required for such change as well should not be underestimated.

On-farm Research in Crop Improvement

Crop improvement research has traditionally been conducted exclusively on research stations where, with improved management, environmental variability can be reduced and genetic expression most effectively observed. Crossing programs and seed multiplication is also most efficiently carried out within the infrastructure of a modern research station.

Selection work conducted strictly under typical research station conditions, however, can bias results away from varieties which are well adapted to farmers' needs. Due to criteria used in choosing research station sites [40] and due to years of improved soil management, the micro-environment of most research stations fail to reflect representative farmers' conditions. As a result, when improved varieties are transfered off of the research station where they were selected or developed, they invariably experience yield gaps of up to 60% when grown by farmers even under improved management levels (ICRISAT, 1982, 1983). Associated problems of poor seedling establishment under low tillage and poor grain quality are also frequently observed.

We conclude that achieving success in both the medium and long-term goals suggested above urgently requires greater accent off the research station using a farming systems approach which has been lacking to date. Greater *a priori* understanding is needed of the physical and social environment within which breeders' output has to perform (Stoop et al., 1981) (Oram, 1977). Factors causing the yield gap between the research station and the farmer's field need to be identified and this information fed-back to modify on-station objectives and methods. Constraints and points of flexibility in current production systems need to be identified to understand to what degree management practices can be modified to incorporate new more responsive materials, and at what cost. The storage, processing, and consumption components of desired grain quality characteristics need to be understood from the farmers' and consumers' perspectives and incorporated as important elements in varietal selection.

This approach requires an interdisciplinary effort involving specialists in physiology, plant protection, agronomy, food science, economics and breeding. It also requires greater work with farmers at several stages of the breeding effort, not simply, as is conventionally done, at the final stage of pre-extension screening. A continuing, interactive relationship with farmers to define appropriate breeding objectives and to test concepts and materials should reduce the time necessary to arrive at truly adapted improved materials.

CHEMICAL FERTILIZER

Patterns of Fertilizer Use in the WASAT

Despite an annual rate of growth of approximately 15% since the mid 1960s, the use of chemical fertilizer in the WASAT remains the lowest of any developing region in the world. Excluding Senegal, which consumes approximately 80% of the total NPK fertilizers in the Sahel, the average units of NPK applied to food crops is less than 1 kg/ha among the Sahelian states. This compares with 1.4 for West Africa as a whole; 3.6 for East Africa; 29 for North Africa and the Middle East; 23 for Asia; and 33 for South America [41]. Including both food and cash crops, only about 10% of total cultivated area receives chemical fertilizer, again with the exception of Senegal where this approaches 30% and where the majority is applied to the export crop groundnut.

The major factors explaining the historically low use rates include: (1) costs of foreign exchange [42]; (2) high transport costs to and within the land-locked countries [43]; (3) low and highly variable response rates to local cereal varieties, particularly in areas of less than 700 mm annual rainfall; (4) poorly developed extension and distribution systems; and (5) inadequate farm level capital.

The intervention of parastatal agencies responsible for cash crop production and marketing in several WASAT countries have greatly relaxed constraints imposed by the latter three factors by providing both high quality seed of improved management responsive varieties and fertilizer (generally subsidized) on credit to small producers. As a result rates of application are substantially higher on cash crops, such as groundnut and cotton, than on cereals [44].

An additional effect of the cash crop parastatals in several WASAT countries is that often only fertilizer formulas developed for the cash crops are available for cereal production. In Burkina Faso, for example, extension recommendations for sorghum and millet are based on the available cotton complex fertilizer despite evidence that in the absence of large applications of organic matter, after several years of continuous application that formula leads to a serious decline in soil quality with declining cereal yields (Pichot et al. 1981). Indeed, little research has been done to determine optimal formula for different cereals by soil type and agroclimatic zone.

Economics of Fertilizer Use

Economic analyses of the response to chemical fertilizer in the WASAT are limited in number and are often biased by research station conditions which interact positively with fertilizer (deep plowing, complete weed control, high applications of organic matter, high plant populations, etc). Nevertheless, these studies demonstrate the maximum technical response and financial returns of recommended doses across a range of crops. A synthesis of experimental results obtained by IRAT during 1978-82 in two experimental research stations in Burkina Faso, for example, concluded that the technical response as measured by the yield increment per kilogram of NPK nutrient was highest for maize (a ratio 13.5), followed by sorghum (10.3), soybeans (8.6), cotton (4.3), millet (3.1), and groundnut (2.3). At financial prices (with a nearly 50% subsidy in effect) and costing only the direct costs of fertilizer, the ranking of crops was almost identical with maize and sorghum highest, at rates of return of 450 and 330%, respectively. Millet was lowest with a return of only 37% [45]. However, after eliminating the effect of the fertilizer subsidy only maize, sorghum, and soybeans gave profitable responses under experiment station conditions (Bonnal, 1983).

Substantially lower responses are observed for farmer demonstrations, where average returns are roughly one half to two thirds of those recorded on experiment stations. In five years of FAO farmer demonstrations in Burkina Faso financial returns to recommended fertilizer levels applied to sorghum varied between 70 and 150% with returns consistently higher for improved varieties, on plowed (compared to unplowed) fields, and in locations with higher and more assured rainfall [46].

Response gaps are even wider when fertilized crops are managed entirely by farmers [ICRISAT 1982, 1983]. Two years of farmers' tests conducted in three agroclimatic zones in Burkina Faso (approximately 900, 700, and 500 mm annual rainfall) demonstrated that using the unsubsidized cost of fertilizer an average 2:1 benefit : cost ratio was obtained to the recommended cotton complex fertilizer (14:23:15) applied to local sorghum varieties only in the medium and high rainfall zones when applied at one-half of the recommended dose [47]. Average negative economic returns were recorded both years in low rainfall Sahelian sites. Returns were consistently higher for improved sorghum varieties in all three zones.

The farmer test results also showed the high variability and risk to fertilizer use on local varieties. For example, during a year of somewhat below average rainfall when average financial returns of 80 and 40% were obtained to recommended doses in the high and middle rainfall zones, respectively, the proportion of fields where incremental yields did not cover subsidized fertilizer costs was nevertheless 44 and 70% in the respective zones.

In addition to the questionable short-term economics of available fertilizers when applied to local cereal varieties in the WASAT, there is increasing evidence that continuous applications of nitrogenous fertilizers in cereal production can result in a long-term reduction in soil fertility. In trials conducted over 18 years in Burkina Faso, for example, IRAT observed that following seven years of chemical fertilizer application sorghum yields steadily declined due to soil acidification, potasium deficiencies, and aluminum toxicity. Only large applications of animal manure in conjunction with chemical fertilizer was found to counteract the negative effects by maintaining or improving soil fertility (Pichot, et al. 1981) [48].

Because of large local deposits of rock phosphate in several WASAT countries considerable emphasis is currently being given to accelerate its production and distribution. Although trials have confirmed residual yield effects of a basal dose of granulated rock phosphate, when compared to imported soluble phosphates it is a generally less economical source of phosphorus (Bonnal, 1983). When used in combination with nitrogenous fertilizer, and when incorporated into the soil by animal traction plowing, it is nearly as profitable as soluble phosphates financially, but in economic terms is marginal except on maize and sorghum in the more humid WASAT areas. Additional constraints to increased farm level use are difficulties encountered in applying and incorporating the finely granulated phosphates, and the multi-year delay in realizing the full yield benefits. Recent results with partially acidulated forms of rock phosphate show promise in overcoming some of these problems.

Key Issues Regarding Fertilizer Use

We conclude that the increased use of presently available chemical fertilizers alone does not offer a viable economic technology for sustained agricultural growth in the WASAT. Low response, high risk, and negative long-term impact on soil quality combined with infrastructural and foreign exchange cost questions underlie this conclusion. Several key issues must be addressed by both researchers and policy-makers if chemical fertilizer is to play a more important role in WASAT agriculture in the future:

1. Specific cereal based fertilizer formulas need to be developed which more efficiently provide the balance of nutrients required for different cereals, as well as for different soil and climatic conditions.

2. Far greater applied research is required at the farmer level to better determine optimum dose levels taking into consideration financial and economic profitability as well as risk. It should be recognized that optimum doses probably vary by agroclimatic zone as well as by farm type (capital position and ability to absorb risk).

3. Major infrastructural investments are required in the production and distribution of fertilizer as well is in the promotion of complementary inputs - in particular improved varieties - if the potential leverage of fertilizer is to be exploited.

4. Greater basic and applied research must be directed to managing the long-term effects of fertilizer use on WASAT soils. Preliminary evidence suggests that mixed-farm (livestock-cropping) systems which recycle bio-mass through animal manure may be an essential complement to sustained chemical fertilizer use.

5. Given the economics of currently available fertilizers, current price and subsidy policies must be given further consideration. Fertilizer subsidies at present levels would appear to be justified only at implicit cereal prices well above domestic market and import price levels.

PART III
SYNTHESIS AND RECOMMENDATIONS

THE CONTEXT AND EVOLVING NEEDS

Farming systems in the WASAT reflect a long process of adaptation to historical conditions of low and variable rainfall, generally poor and fragile soils, and readily available land. The extensive land use systems which have evolved are marked by low productivity per unit area and high inter-annual variability. Soil quality has traditionally been maintained by long bush fallow rotations requiring a ratio of fallow to cultivated land of five to one or greater.

In rapidly expanding areas of the WASAT, however, growing rural populations are upsetting this generalized ecological balance. Cultivation is being introduced on more marginal soils, and intensified with a shift towards shorter grass fallows and, in many zones, towards continuous cultivation. At the same time increased cash needs are inducing farmers in some areas to shift greater resources into cash crop production, often employing technologies which accelerate a decline in soil quality. The immediate result is nearly stagnant growth in yields of food crops and a general fall in aggregate farm output per rural habitant. A more pervasive long-term effect in areas of greatest population density is the steady decline of the natural resource base pointing toward reduced long-term production potential.

Because these processes have developed unevenly in varying parts of the WASAT, cropping intensitives often vary considerably from location to location. As a result the current production potential, as well as the short and medium-term technological needs, differ not only along the north-south axis, but also within climatic zones as a function of population pressure.

In the limited remaining areas of very low population density there is still scope in the short-run for labor augmenting technologies to permit more efficient area expansion. In contrast, for areas of highest land pressure immediate priority must be given to land augmenting technologies which will arrest declining land quality while increasing yields on a sustainable basis. Between these two extremes a mix of approaches may be appropriate, but each should be viewed as a stage along the evolution to more stable long-run intensification.

TECHNOLOGICAL OPTIONS

Within this framework, our review of currently available technologies has shown that marginally profitable animal traction systems exist to permit some expansion of cultivated area per worker. To succeed, however, these require a substantial and continued investment in support infrastructure and in the provision of complementary inputs. Moreover, generally lacking is a consistent approach through which these extensive systems can be directed to evolve toward more intensive, sustainable animal-based systems in the future.

Our review has also identified a range of technologies which under research station conditions in the southern and central Sudanian zones can achieve substantial short-run yield increases. Single component yield responses on the order of 20 to 40% are typically recorded for moderate fertilizer doses, for plowing, or for land management practices when applied separately. Due to significant interactions, package yield responses on the order of 100% are not unusual. Even greater increments can be attained by adding more management responsive varieties. However, due to a range of factors discussed in Part II, when these yield augmenting technologies are transfered to farmer conditions, only a very small proportion of farmers typically approach station performance levels. Average yield gaps of between 40 and 60% are normal, resulting in a high risk of financial loss and typically low adoption.

As important in the long-run is the need to develope farmer adapted systems to maintain soil quality under the high input management which is necessary to achieve these significant yield increases. Bund and water-catchment systems of various scales which reduce erosion while improving soil moisture show considerable potential under certain conditions and should be further developed. However, economic means to generate, recover, and recycle biomass at levels adequate to maintain soil organic matter are particularly lacking.

CONCLUDING RECOMMENDATIONS

Reversing this situation will require not only continued investment in research, but also important changes in concept and approach:

First, the objectives of both research and development programs should reflect greater balance between immediate production gains and resource base conservation. In the research domain, this implies a broader set of criteria and a multi-year time frame for the evaluation of new technologies. In the development domain, the existence of important physical externalities and differences between individual and societal time preference may justify greater investment in conservation-based infrastructure (such as stable anti-erosion systems) and increased subsidies for farm level inputs with important long-term benefits (such as rock phosphate).

Second, the presence of substantial complementarities between separate components of improved technologies - particularly those affecting soil moisture, soil fertility, and varietal change - argues for a package or systems approach in technology development and extension. We make this recommendation subject to two important qualifications. First, given limited farm level investment capacity and risks linked to poorly developed delivery systems, the separate components of such packages should themselves be profitable when used in isolation, and should to the extent possible employ resources already available or generated at the farm level. Second, because of differences in the quantity and quality of resources across production units, packages should be designed to vary from smaller, less costly, and less complex sets to larger, more costly and more complex systems which fit the needs and resources of distinct farm types.

Profound structural changes are especially required to move towards more efficient and stable mixed-farming systems which fully integrate cropping and livestock activities. Because such systems require radical changes in production objectives, in land and labor use patterns, and in socioeconomic relations between ethnic groups, research addressing this problem must have an evolutionary perspective which identifies alternative paths or sequences of development for separate areas and farm types.

Third, it follows that research and development programs should recognize a more disaggregated set of recommendation domains based on regional and farm type criteria. Zonification incorporating rainfall, soils, population density, and ethnic composition need to be further developed to permit greater relevance in defining research objectives and in extending interventions, and greater efficiency in applying results of regional and international research programs.

Fourth and finally, there is an urgent need for more emphasis on off-station reseach using well placed researcher-managed trials and farmer-managed tests. Greater farmer participation is required at various stages in the development and testing of technologies to ensure greater farm-level adptation. In particular, the principal factors causing yield shortfalls between the research station and farmers' fields need to be identified and fed-back to modify as necessary on-station objectives and methods.

FOOTNOTES

[1] Mean annual precipitation increases by about 100 mm for each 100 km as one moves in a southerly direction.

[2] On average between 20 and 40% of total annual rainfall occurs in August in the extreme southern and northern zones of the WASAT, respectively (Virmani, et al., 1980).

[3] In contrast, there is a single period of maximum potential evapotranspiration in the Indian SAT, during April-May (Charreau, 1977).

[4] Similar blocks of abnormal years are recorded in the periods 1870-1895 (wet) and 1913-1924 (dry), as well as earlier.

[5] In addition a number of authors claim that over-exploitation of resources during a succession of good years may deepen and prolong the effects of a subsequent period of bad years (Charney, 1975, 1977) (Otterman, 1977) (Walker and Rowntree, 1976) (Schnell, 1974). This is believed to have occurred with the expansion of cultivation and grazing in the Sahel zone during the 1950's and early 1960's followed by the 1968-73 drought. The mechanisms for this process are believed to involve an increase in surface albedo due to loss of vegetative cover.

[6] Moreover, in the latter area among households in the highest third of the income distribution, nearly 60% of total farm labor was drawn from other households.

[7] In northern Nigeria, for example, it has been observed that under conditions of a well developed labor market and a relatively monetized rural economy, liquidity constraints may force lower income households to pursue cropping strategies which increase their dependence on the market for food staples, and to pursue employment strategies which systematically reduce their own-farm productivity (Matlon and Newman, 1978). Overtime the evolution of these relationships point toward a less equal distribution of resources and income. Furthermore, cash intensive technologies which involve major lumpy investments or large cash outlays during liquidity constraint periods are likely to accelerate this process.

[8] Studies by ICRISAT in Burkina Faso have shown that given current methods of animal entrustment, temporary stabling, and manure recovery and transport, between 250-500 kg of manure are applied per hectare on average. Manuring is practised in a ring cultivation system whereby the intensity of manure is inversely correlated to distance from household (Bonkian, 1981) (Prudencio, 1983).

[9] Farmer to extension agent ratios vary as high as 3000 (USDA, 1981).

[10] These include the Office due Niger and Casier de Baquineda in Mali, the Casier Richard Toll in Senegal, and the Casier de Bongor and Polders in Chad.

[11] These include, in particular, the Senegal, Niger, and Logone - Chari rivers, as well as the Gambia, Casamance, and Volta river systems.

[12] A UN study (UN, 1973) estimates that the annual replenishment of the crystalline basement areas of Burkina Faso exceed by 10 to 100 times population needs. Similarly the three aquifer systems located in the sedimentary basins of Chad, Niger, Mali, and Senegal - Mauritania are believed to contain replinishable reserves of between several hundred billion to 1 trillion cu. m.

[13] The USDA study identifies at least eleven projects in the Sahel states which could increase total irrigated area to over 1.9 million hectares.

[14] CILSS (1980) reports that by 1979 more than 25,000 hectares of modern irrigated sites (11% of the total) have been abandoned and require substantial rehabilitation.

[15] This section draws considerably from the analysis of Charreau (1977).

[16] In contrast, IRAT observed a mean yield increment of only 50 kg/ha on five research station sites in Burkina Faso under fertilized conditions (IRAT, 1982).

[17] Late season ridging and tieing after peak labor periods may be more appropriate for northern Sudan and Sahel conditions where conflict with early season activities is more concentrated.

[18] Yield losses of between 25 and 60% have been reported on black soils in Indian experiments (Krantz, Kampen, and Associates, 1976) (ICAR, 1970).

[19] Perhaps the largest, constructed in the Yatenga region of Burkina Faso during 1960-62, has generally been judged a complete failure (Marchal, 1979). Project planners bypassed the farmers who, observing no immediate yield increase, failed to maintain the bunds. As a result potential longer-term benefits in soil quality improvement were lost as the bunds were breached and eroded away.

[20] This project distinguishes itself from earlier approaches by working through farmer groups in explaining both the objectives of the bunds and the importance of maintenance; and by promoting the use of complementary inputs including contour plowing and fertilizer.

[21] The technique consists of constructing broad (1.5 m) beds separated by furrows along the natural contour of the land at a grade less than the maximum slope. The furrows trap and direct water to run slowly across the slope, thereby reducing erosion and increasing the time for infiltration. Run-off is then fed into grassed waterways which direct the water into small storage facilities for eventual use in supplemental irrigation.

[22] The design of most of these experiments, however, confound several interacting factors including plowing, varieties, fertilizer, population densities, and timing. Results from Mali which separate out the plowing effect alone show significant yield increases of nearly 30% for maize and sorghum but only marginal 5% increments for groundnut, cotton, and millet (SRCVO, 1978).

[23] Up to 10% yield losses due to a one week delay in first weeding have been observed under farmers' conditions (Matlon and Newman, 1978).

[24] Barrett et al. (1981), for example, observed that 45% of farmers with traction equipment used their animals for less than 50 hours per year in field work.

[25] This is exacerbated by poor animal nutrition during the early portion of the rainy season (which reduces their strength and speed) and by the irregular and widely spaced early season rains which are required for both planting and plowing.

[26]. These results agree closely with those of Jaeger (1984). Analysing data from two villages in Burkina Faso he calculated internal rates of return of 35% and 25% for donkey and oxen systems, respectively.

[27] Thus in the Barrett et al. (1982) study cited the percent of oxen traction farmers who mechanically weeded and ridged increased from 10% among farmers with two or less years of experience, to nearly 55% with seven or more years of experience. A very similar and high significant correlation between experience and use rates was obsrved by Jaegar (1984).

[28] This implies that only households with diversified non-agricultural sources of income or cheap sources of informal credit could successfully adopt draft systems without substantial hardships or falling in arrears on credit payments.

[29] Systems developed in southeastern Mali and in the Sine-Saloum provide useful models in this regard.

[30] The AVV credit system in Burkina Faso is a useful example of such programming.

[31] Eighty-five percent in the case of Sierra Leone (Spencer and Byerlee, 1976).

[32] This includes the work of the various GERDAT institutes in most francophone countries, research undertaken within national research institutes and more recently programs directed by the international research institutes including ICRISAT (sorghum and millet), IITA (maize and cowpea) and WARDA (rice).

[33] Although maize is typically grown on extremely limited tracts of land located either next to family dwellings, and thus highly fertilized, or adjacent to swamps, the agronomic potential of maize under adequate soil fertility conditions has been shown to be considerable on a wide spectrum of soil types in the northern Sudan zone (Norman, Beeden, et al. 1976). Improved maize varieties have been successfully extended in several integrated agricultural development projects financed by the World Bank in northern Nigeria. However, these projects are characterized by extremely high investment in input and marketing infrastructure as well as in extension, and as such are not easily replicable.

[34] Other objectives include introducing improved resistances to yield loss factors (insects, diseases, drought, Striga, etc.) and changing agronomic characteristics other than yield to exploit underutilized resources in existing systems (plant structure or cycle length to permit new intercropping combinations, avoid labor conflict, or escape drought).

[35] It is significant that even in the Indian experience the highest rates of adoption of high yielding sorghum varieties and the greatest use of chemical fertilizer have tended to be concentrated in areas of more assured rainfall and in areas of greater irrigation density (Jha et al. 1981). Adoption of HYVs is lowest in areas of lower rainfall and where soils are characterized by poor water holding capacity. These two conditions describe much of the central and northern portions of the WASAT.

[36] It was observed that the Indian millet materials were highly susceptible to African races of mildew, smut, and ergot. Moreover, a set of physiological factors tended to accelerate the growth of the Indian varieties causing them to be spindly and partially sterile (Scheuring, 1980). Similarly, the high yielding sorghum hybrid CSH-5 which had substantial success in India, experienced unacceptable problems of charcoal rot and lodging in trials and farmers tests in several West African countries.

[37] In this context, it is not surprising that the improved sorghum and millet varieties which have experienced relatively more success - such as the IRAT sorghum varieties Ouedezoure and Gnofing in Burkina Faso and the millet

variety Souna 3 in Senegal - are improved locals derived from West African genetic stock.

[38] Even in the immediate future, however, there is likely to be demand for management dependent high yielding varieties in relatively limited situations such as in irrigated farming schemes or in integrated agricultural developments projects (e.g. northern Nigeria) where support services are concentrated. Leverage on regional production, however, will be limited.

[39] Scheuring (1980) observes a 40% loss in millet yields in one region in Mali due to downy mildew, and McIntire (1982) reports an economic loss of between 27 and 37% in millet yields under farmer conditions in Niger due to Raghuva and Chribras millets.

[40]. Stations are often located on atypically good soils or near lowland catchments to provide off-season irrigation capacity.

[41] These figures are for 1975 from (IFDC, 1977) and (Oram, 1981).

[42] NPK fertilizers (using in most cases imported raw materials) are produced only in Senegal and Nigeria among the WASAT countries. Rock phosphates, on the other hand, are currently being produced in Senegal, Niger, Mali, and in Burkina Faso.

[43] Representative costs for Burkina Faso in 1982 are 39 CFA/km ton by truck and 15 CFA by rail (Bonnal, 1983).

[44] It is estimated, for example, that in 1978 approximately 30 kg/ha was applied to groundnuts in Senegal; and in 1981 nearly 100 kg/ha was applied to cotton in Burkina Faso (Societe Africaine d'Edition, 1982) (SOFITEX, 1982).

[45] The FAO uses a rule of thumb of 100% as the minimum return required by farmers for adoption considering risk and indirect costs.

[46] Because such demonstrations are normally conducted using discreet combinations of chemical fertilizers rather than with continuous level variation, they do not permit an evaluation of economically optimal doses. Moreover, the distributions of responses are rarely examined to determine the probability of outcomes.

[47] Results of the farmers' tests indicated a 40 to 60% reduction in technical response for sorghum and millet compared to station results. Thus the yield increment per kilogram of NPK nutrient for local sorghum varieties in the 700 and 900 mm rainfall zones were 4.4 and 6.0 respectively.

A ratio of 1.5 was observed for millet in the 500 mm zone. The ratios for improved varieties were up to 45% greater.

[48]. Similar results have been obtained in cotton producing zones of Burkina Faso [Hien et al., 1984] and Senegal [Ange, 1984].

REFERENCES

Abalu, G.O.I. 1976. A note on crop mixtures under indigenous conditions in Northern Nigeria. Journal of Development Studies 12:213-220.

Andrews, D.J. 1975. Sorghum varieties for the late season in Nigeria. Tropical Agriculture 52(1):21-30.

Ange, A. 1984. Les contraintes de la culture cotonniere dans le systeme agraire de Haute Casamance au Senegal. Paris, France: Institut National Agronomique.

Barrett, V., Lassiter, D., Wilcock, D., Baker, D., and Crawford, E. 1982. Animal traction in Eastern Upper Volta : a technical, economic, and institutional analysis. Michigan State University, Department of Agricultural Economics, MSU International Development Paper 4, East Lansing, U.S.A.

Binswanger, H.P., Virmani, S.M., and kampen, J. 1980. Farming systems components for selected areas in India : evidence from ICRISAT. ICRISAT Research Bulletin 2, Patancheru 502 324, A.P., India.

Bonkian, A. 1981. Manure use in two villages of central Upper Volta. ICRISAT West Africa Economics Program Village Studies Report 5, Ouagadougou, Upper Volta.

Bonnal, J. 1983. Rapport de mission en Haute-Volta : aspects economiques du probleme de l'utilisation des volta-phosphates. Paris, France : IRAT-IVRAZ.

Bono, M. 1981. Amelioration varietale du mais en Haute-Volta : Bilan 1972-1980. Agronomie Tropicale 36-4:347-355.

Byerlee, D., and Varughese, G. 1981. The potential for commercial wheat production in Senegal : some issues. CIMMYT, Mimeo.

CILSS. 1977. Marketing, price policy and storage of foodgrains in the Sahel : A survey. CILSS, Club du Sahel, Working Group on Marketing, Price Policy, and Storage.

CILSS. 1980. The development of irrigated agriculture in the Sahel : review and perspectives. Club du Sahel.

Charney, J.G. 1975. Dynamics of deserts and drought in the Sahel. Quarterly Journal of the Royal Meteorological Society 102:59-64.

Charney, J.G. 1977. A comparative study of the effects of

of Atmospheric Science 34:1366-1384.

Charreau, C. 1977. Some controversial technical aspects of farming systems in semi-arid West Africa. In Proceedings, International Symposium on Rainfed Agriculture in Semi-Arid Regions, Consortium for Arid Lands Institute, 17-22 April 1977, Riverside, California, U.S.A.

Charreau, C., and Nicou, R. 1971. L'amelioration du profil cultural dans les sols sableaux et sablo argileux de la zone tropicale seche Ouest Africaine et ses incidences agronomiques. L'Agronomie Tropical 26(2):209-255, (5):565-631, (9):903-978, (11):1184-1247.

Delgado, C.L. 1977. Economic interactions between peasants and herders in the West African savannah : a case study from Tenkodogo, Upper Volta. Ann Arbor, U.S.A. University of Michigan. CRED.

Eicher, C.K., and Baker, D.C. 1982. Research on agricultural development in sub-Saharan Africa : a critical survey. Michigan State University, Department of Agricultural Economics, MSU International Development Paper 1, East Lansing, U.S.A.

FAO. 1975. Perspective study on agricultural development in the Sahelian countries 1975-1990. Vol.1:Main Report.

FAO. 1981. Production yearbook 1981. Rome, Italy: FAO.

FAO. 1982. Rapport annual saison culturale 1981. Ouagadougou, Upper-Volta : Programme Engrais de la FAO en Haute-Volta.

FDR. 1983. Rapport d'execution des operations conduites sur les zones-pilotes : campagne agricole 1982-83. Ouagadougou, Haute-Volta : Fonds de Developpment Rural.

FSU. 1982. Annual report 1982. Ouagadougou, Upper Volta : SAFGRAD, Farming Systems Unit.

FSU. 1983. Annual report, 1983. Ouagadougou, Upper Volta: SAFGRAD, Upper Volta: SAFGRAD, Farming Systems Unit.

Hien, V., Belem, P.C., Berger, M., and Richard, L. 1984. Aspect general de l'evolution de la fertilite des sols voltaiques en culture continue. Ouagadougou, Upper Volta: IVRAZ/IRCT.

ICAR. 1970. Soil and water conservation research 1956 to 1958. New Delhi, India : Council of Agricultural Research.

IFDC. 1976. Etude sur les engrais en Afrique de l'Quest. Muscle Shoals, USA : Volume 1.

ICRISAT. 1978. Annual report 1978. Ouagadougou, Upper Volta : ICRISAT Cooperative Program/Upper Volta.

ICRISAT. 1982. Rapport annuel, 1982. Ouagadougou, Haute-Volta : Programme Cooperatif ICRISAT/Haute-Volta.

ICRISAT. 1983. Annual report, 1983. Ouagadougou, Upper Volta: Cooperative Program ICRISAT/Upper Volta.

ICRISAT. 1984. Annual report, 1984. Ouagadougou, Burkina Faso: Cooperative Program ICRISAT/Burkina Faso.

IITA. 1983. Annual report, 1982. Ouagadougou, Haute-Volta : SAFGRAD, International Institute of Tropical Agriculture.

IRAT. 1983. Rapport de synthese, 1982. Ouagadougou, Haute-Volta : Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres.

Jaegar, W. 1984. Agricultural mechanization: the economics of animal traction in Upper Volta. Palo Alto, USA: Stanford University, Department of Agricultural Economics, Unpublished Ph.D. dissertation.

Jha, D., Raheja, S.K., Sarin, R., Mehrota, P.C. 1981. Fertilizer use in semi-arid tropical India : the case of high-yielding varieties of sorghum and pearl millet. ICRISAT Economics Program progress report 22, Patancheru 502 324, A.P., India.

Kabore, P.D., Lebene, Y. et Matlon, P.J. 1983. Modeles de cultures dans trois zones agro-climatiques de Haute-Volta. Ouagadougou, Haute-Volta : ICRISAT, Programme Econommique de l'ICRISAT, Etudes Villageoises - Rapport 9.

Kassam, A.H. 1976. Crops of the West African semi-arid tropics. ICRISAT, Patancheru 502 324, A.P., India.

Kline, C.K., Green, D.A.G., Donahue, R.L., and Stout, D.A. 1969. Agricultural mechanization in equatorial Africa. Michigan State University, Institute of International Agriculture research report 9, East Lansing, USA.

Krantz, B.A., Kampen, J., and Associates. 1976. Annual report of the farming systems research program. ICRISAT, Patantheru 502 324, A.P., India.

Marchal, J.Y. 1979. L'espace des techniciens et celui des paysans. Histoire d'un perimetre antierosif en Haute-Volta. Pages 245-252 in Maitrise de l'espace agraire et development en Afrique tropicale. Memoire ORSTOM No. 89. Paris, France: CNRST - ORSTOM.

Matlon, P.J. 1977. The size distribution, structure, and determinants of personal income among farmers in the north of Nigeria. Ph.D. unpublished dissertation, Cornell University, Department of Agricultural Economics, Ithaca, U.S.A.

Matlon, P.J. 1981. The structure of production and rural incomes in Northern Nigeria : results of three village case studies. Pages 261-310 in Inequality and Development in Nigeria, ed. H. Bienen and V.P. Diejomaoh. New York, USA : Holmes and Meier Publishers.

Matlon, P.J., and Newman, M. 1978. Production efficiency and income distribution among farmers in the north of Nigeria. Michigan State University, Department of Agricultural Economics, East Lansing, U.S.A.

McIntire, J. 1981. Crop production budgets in two villages of central Upper Volta. ICRISAT West Africa Economics Program village studies report 4, Ouagadougou, Upper Volta.

McIntire, J. 1981. Two aspects of farming in central Upper Volta. ICRISAT West Africa Economics Program village studies report 7, Ouagadougou, Upper Volta.

McIntire, J. 1982. Annual report of the ICRISAT/Niger Economics Program. Niamey, Niger : ICRISAT.

Mettrick, H. 1978. Oxenisation in the Gambia : an evaluation. London, UK : Ministry of Overseas Development.

Nicholson, S.E. 1982. The Sahel : a climatic perspective. CILSS/OECD. Club du Sahel. Consultant's report.

Norman, D.W. 1972. An economic study of three villages of Zaria province. 2. An input-output study. Vol.1, Text. Zaria, Nigeria : Ahmadu Bello University, IRA. Miscellaneous paper 37.

Norman, D.W. 1974. Rationalizing mixed cropping under indigenous conditions : the example of Northern Nigeria. Journal of Development Studies 11:3-21.

Norman, D.W., Beeden, P., Kroeker, W.J., Pryor, D.h., Huizings, B., and Hays, H.M. 1976. The production feasibility of improved sole crop maize production technology for the small-scale farmer in the Northern Guinea Sananna Zone of Nigeria. Samaru Miscellaneous paper 59. Zaria, Nigeria : Ahmadu Bello University, IAR.

Norman, D.W., Newman, M.D., and Ouedraogo, I. 1981. Farm and village production systems in the semi-arid tropics of West Africa. ICRISAT Research Bulletin 4, Volume 1, Patanchenru 502 324, A.P., India.

Oram, P.A. 1977. Agriculture in the semi-arid regions : problems and opportunities. In Proceedings, International Symposium on Rainfed Agriculture in Semi-Arid Region, Consortium for Arid Lands Institute, 17-22 April 1977, Riverside, California, USA.

Oram, P.A. 1981. Production potentials in Africa : issues and strategies. Pages 49-88 in Food policy issues and concerns in sub-saharan Africa, IFPRI, 9-11 February 1981. Ibadan, Nigeria.

Otterman, J. 1977. Anthropogenic impact on the albedo of the earth. Climatic Change 1:137-155.

Pichot, J., Sedogo, M.P., Poulain, J.F., and Arrivets, J. 1981. Evolution de la fertilite d'un sol ferrugineux topical sous l'influence de fumures minerales et organiques. Agronomie Tropicale 36-2:122-133.

Prodencio, Y.C. 1983. A village study of soil fertility management and food crop production in Upper Volta : technical and economic analysis. Tucson, USA : University of Arizona, Department of Agricultural Economics. Unpublished Ph.D. dissertation.

Rodriguez, M. 1982. Rapport annuel, 1982 : Programme d'agronomie du mais due SAFGRAD/IITA. Ouagadougou, Haute-Volta : SAFGRAD, International Institute for Tropical Agriculture.

Rodriguez, M. 1983. Rapport annual, 1982: Programme d'agronomie du mais du SAFGRAD/IITA. Ouagadougou, Haute-Volta: SAFGRAD, International Institute for Tropical Agriculture.

Roose, E.J. 1975. Erosion et ruissellement en Afrique de l'Ouest : Vingt annees de mesures en petites parcelles experimentales. Abidjan, Cote d'Ivoire : ORSTOM.

Ruthenberg, H. 1980. Farming systems in the tropics. London, UK : Oxford University Press. 3rd Edition.

SOFITEX. 1982. Rapport annuel. Ouagadougou, Haute Volta.

SRCVO. 1978. Rapport synthetique de la campagne, 1977-1978. Bamako, mali : Section de Recherches sur les Cultures Vivrieres et olegineuses.

Sargeant, M., Lichte, J., Matlon, P., and Bloom, R. 1981. An assessment of animal traction in francophone West Africa. Michigan State University, Department of Agricultural Economics, African Rural Economy working paper 34, East Lansing, U.S.A.

Scheuring, J.F. 1980. ICRISAT millet improvement in CILSS countries of West Africa. Presented at the CILSS meeting on Food Crop Improvement 8-10 December 1980. Ouagadougou, Upper Volta.

Schnell, R.C. 1974. Biogenic and inorganic sources for ice-nuclei in the drought stricken areas of the Sahel. New York, USA : Report to the Rockefeller Foundation.

Shepard, A.W. 1981. Agrarian change in Northern Ghana : public investment, capitalist farming and famine. In Rural development in tropical Africa, ed. Heyer, J., Roberts, P., and Williams. New york, USA : St. Martin's Press.

Societe Africaine d'Edition. 1983. Le Senegal en chiffres : Edition 1982-1983. Dakar : Senegal.

Sparling, E.W. 1981. A survey and analysis of ex-post cost-benefit studies of Sahelian irrigation projects, draft. Colorado State University, Department of Economics, Fort Collins, U.S.A.

Spencer, D.S.C., and Byerlee, D. 1976. Technical change, labor use, and small farmer development : evidence from Sierra Leone. American Journal of Agricultural Economics 58 :874-880.

Stoop, W.A., pattanayak, C.M., Matlon, P.J., Root, W.R. 1981. A strategy to raise the productivity of subsistence farming systems in the West African semi-arid tropics. Pages 519-526 in Proceedings, Sorghum in the Eighties ICRISAT 2-7 November 1981, Patancheru 502 324, A.P., India.

UN. 1973. Outline analysis of water management problem areas : Sudano-Sahelian zone. United Nations Secretariat, Special Sahelian office.

USDA. 1981. Food problems and prospects in sub-Saharan Africa : the decade of the 1980's. Washington, D.C., USA : Department of Agriculture, Economic Research Service, International Economics Division.

Virmani, S.M., Kampen, J., and Krantz, B.A. 1978.

Agricultural climate characterization to identify research priorities : a system analysis approach applied to the Hyderabad region. in Proceedings of the 11th International Soil Science Society Congress. Edmonton, Canada.

Virmani, S.M., Reddy, S.J., and Bose, M.N.S. 1980. Manuel de climatologique pluviale de l'Afrique occidentale : donnees pour des stations selectionnees. Hyderabad, Inde : International Crops Research Institute for the Semi-Arid Tropics.

Walker, J., and Rowntree, P.R. 1977. The effect of soil moisture on circulation and rainfall in a tropical model. Quarterly Journal of the Royal Meterological Society 103:29-46.

Whitney, T.R. 1981. Changing patterns of labor utilization, productivity and income : the effects of draft animal technology on small farms in south-eastern Mali. West Lafayette, USA : Purdue University, Department of Agricultural Economics. Unpublished M.Sc. Thesis.

World Bank. 1981. Accelerated development in sub-Saharan Africa : An agenda for action. Washington, D.C., USA.

World Bank. 1981. World Development Report. Washington, D.C., USA.

Wright, P. 1983. Project agro-forestier (Oxfam) : rapport de fin de campagne 1982 au Yatenga, Haute-Volta. Ouagadougou, Haute-Volta : OXFAM.