Desertification in the Sahelian and Sudanian Zones of West Africa

Jean Eugene Gorse and David R. Steeds
<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Increasing Agricultural Productivity</td>
</tr>
<tr>
<td>3.</td>
<td>Ventilated Improved Pit Latrines: Recent Developments in Zimbabwe</td>
</tr>
<tr>
<td>4.</td>
<td>The African Trypanosomiases: Methods and Concepts of Control and Eradication in Relation to Development</td>
</tr>
<tr>
<td>5.</td>
<td>Structural Changes in World Industry: A Quantitative Analysis of Recent Developments</td>
</tr>
<tr>
<td>6.</td>
<td>Laboratory Evaluation of Hand-Operated Water Pumps for Use in Developing Countries</td>
</tr>
<tr>
<td>7.</td>
<td>Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries</td>
</tr>
<tr>
<td>8.</td>
<td>Institution Building for Traffic Management</td>
</tr>
<tr>
<td>9.</td>
<td>Meeting the Needs of the Poor for Water Supply and Waste Disposal</td>
</tr>
<tr>
<td>10.</td>
<td>Appraising Poultry Enterprises for Profitability: A Manual for Investors</td>
</tr>
<tr>
<td>11.</td>
<td>Opportunities for Biological Control of Agricultural Pests in Developing Countries</td>
</tr>
<tr>
<td>15.</td>
<td>Sheep and Goats in Developing Countries: Their Present and Potential Role</td>
</tr>
<tr>
<td>16.</td>
<td>Managing Elephant Depredation in Agricultural and Forestry Projects</td>
</tr>
<tr>
<td>17.</td>
<td>Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries</td>
</tr>
<tr>
<td>18.</td>
<td>Urban Sanitation Planning Manual Based on the Jakarta Case Study</td>
</tr>
<tr>
<td>19.</td>
<td>Laboratory Testing of Handpumps for Developing Countries: Final Technical Report</td>
</tr>
<tr>
<td>20.</td>
<td>Water Quality in Hydroelectric Projects: Considerations for Planning in Tropical Forest Regions</td>
</tr>
<tr>
<td>21.</td>
<td>Industrial Restructuring: Issues and Experiences in Selected Developed Economies</td>
</tr>
<tr>
<td>22.</td>
<td>Energy Efficiency in the Steel Industry with Emphasis on Developing Countries</td>
</tr>
<tr>
<td>23.</td>
<td>The Twinning of Institutions: Its Use as a Technical Assistance Delivery System</td>
</tr>
<tr>
<td>24.</td>
<td>World Sulphur Survey</td>
</tr>
<tr>
<td>25.</td>
<td>Industrialization in Sub-Saharan Africa: Strategies and Performance</td>
</tr>
<tr>
<td>26.</td>
<td>Small Enterprise Development: Economic Issues from African Experience</td>
</tr>
<tr>
<td>27.</td>
<td>Farming Systems in Africa: The Great Lakes Highlands of Zaire, Rwanda, and Burundi (Also in French, 27F)</td>
</tr>
<tr>
<td>28.</td>
<td>Technical Assistance and Aid Agency Staff: Alternative Techniques for Greater Effectiveness</td>
</tr>
<tr>
<td>31.</td>
<td>Remanufacturing: The Experience of the United States and Implications for Developing Countries</td>
</tr>
<tr>
<td>32.</td>
<td>World Refinery Industry: Need for Restructuring</td>
</tr>
</tbody>
</table>

(List continues on the inside back cover.)
Desertification in the Sahelian and Sudanian Zones of West Africa

Jean Eugene Gorse and David R. Steeds
Desertification is defined as the sustained decline of the biological productivity of arid and semi-arid land. It is the result of pressures both human (increased population) and climatic (variable rainfall and long-term changes in climate). Three traditional production systems exist in the SSZ: agrosylvicultural, agrosylvopastoral, and sylvopastoral. Development activities have been tried in the past in the agriculture, livestock, and forestry sectors. Strategies for better resource management depend on the balance between the rural population and the carrying capacity of the land. Such strategies include increasing research on production systems, training staff and farmers, reducing the population through child spacing and resettlement, increasing the stock of fuelwood, reforming land laws, and providing incentives for increased agricultural and forestry production.
PREFACE

This paper was undertaken in response to growing concern, both inside and outside the Bank, that not enough was being done to tackle the desertification problem in West Africa. An informal working group was set up under the leadership of Jean Gorse (WAPAC). Since the subject matter is necessarily multidisciplinary, contributions were sought from many specialists; particularly notable contributions were made by James Thomson and Yves Dommergues (Consultants), Robert Fishwick (WAPAD), and Willem Floor (EGYEA). The present paper was written by David Steeds (WAPAC) and incorporates comments made at internal Bank reviews, reviews with external specialists, a meeting of national Directors of Agriculture, Livestock and Forestry convened by CILSS, and comments received from many individuals. It was not possible, of course, to satisfy all commentators on all points.

The editing of various drafts of the paper was done by Michèle Moriarty, and the word processing on this latest version by Alexandra Gripari.
CURRENCY EQUIVALENTS

Currency Unit = CFA franc (CFAF)
US$1.00 = CFAF 460
CFAF 1,000 = US$2.17

WEIGHTS AND MEASURES

Metric System

ABBREVIATIONS

AGRHYMET Centre Régional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle (Regional Center for Agrometeorology and Applied Hydrology), located in Niamey, Niger

CC Carrying Capacity

CILSS Comité Permanent Inter-États de Lutte contre la Sécheresse dans le Sahel (Permanent Inter-Government Committee against Drought in the Sahel); secretariat located in Ouagadougou, Burkina Faso

NAS National Academy of Sciences (Washington, D.C.)

NLC Northern Limit of Cultivation

RP Actual (1980) Rural Population

SSZ West African Sahelian and Sudanian Zones

TPS Traditional Production System

Note: The six climatic zones that can be distinguished within the broader SSZ are defined at Table 1, page 2.
# TABLE OF CONTENTS

Preface

Summary and Conclusions .......................................................... ix - xi

I. THE DESERTIFICATION PROBLEM.......................................................... 1
   The West African Sahelian and Sudanian Zones........................................ 1
      General Features .............................................................................. 1
      Climate ............................................................................................ 1
      Physical Features .............................................................................. 2
   Drought, Resource Degradation and Desertification .................................. 4
   Desertification: Drought or Resource Abuse? ......................................... 5
   A Complex and Multifaceted Problem ..................................................... 6
   Population ............................................................................................ 7

II. TRADITIONAL PRODUCTION SYSTEMS AND PRESSURES UPON THEM ............. 9
   The Three Basic Traditional Production Systems .................................... 9
      The Agrosylvicultural System ............................................................. 9
      The Agrosylvopastoral System ............................................................ 9
      The Sylvopastoral System .................................................................. 10
      Common Features .............................................................................. 11
   Carrying Capacities of Traditional Production Systems ......................... 11
   Pressures Upon Traditional Production Systems ....................................... 14

III. REVIEW OF PAST DEVELOPMENT ACTIVITIES .................................... 17
    Agricultural Sector Activities ............................................................. 17
    Livestock Sector Activities .................................................................. 18
    Forestry Sector Activities .................................................................... 18
    Common Weaknesses of Development Activities ..................................... 19

IV. ELEMENTS OF A STRATEGY FOR BETTER RESOURCE MANAGEMENT ........... 21
    General Observations .......................................................................... 21
    Actions Defined with Respect to Pressure on Carrying Capacity ................. 22
       Areas Where RP Does Not Exceed CC ............................................. 22
       Areas Where RP Slightly Exceeds CC ............................................. 23
       Areas Where RP Greatly Exceeds CC .............................................. 24
    Increased Carrying Capacity via Irrigation? .......................................... 25
    Upgrading Competence ........................................................................ 26
       Research ......................................................................................... 26
       Training ......................................................................................... 27
    Reducing Demand ............................................................................... 27
       Population ....................................................................................... 27
       Wood ............................................................................................... 29
    The Policy Environment ........................................................................ 30
       Land Law ......................................................................................... 30
       Incentives ......................................................................................... 31
V. IMPLICATIONS FOR ACTION .................................................. 34
   For CILSS ................................................................. 34
   For Governments ....................................................... 34
   For Financiers in General ........................................... 36
   For the Bank Group in Particular ................................. 37

ANNEXES
1. Statistical Appendix .................................................. 39
   A-1: Land Distribution by Climatic Zone .......................... 39
   A-2: Land Distribution by Soil Suitability ....................... 40
   A-3: Soil Suitability by Climatic Zone ............................ 41
   A-4: Current and Projected Population in the SSZ ............. 42
   A-5: Distribution of 1980 Population as a Function of
       Rainfall, Forestry Potential and Population Density ....... 43
   A-6: Adjusted Distribution of 1980 Population .................. 45
   A-7: Carrying Capacity with Traditional Rainfed
       Cropping Practices .................................................. 46
   A-8: Carrying Capacity with Traditional Livestock Practices 47
   A-9: Carrying Capacity of Natural Forest Cover ................ 48
2. Elementary Anti-Erosion Techniques ................................ 49
3. Research Orientations .................................................. 52

BIBLIOGRAPHY ................................................................. 57

TEXT TABLES
1. Climatic Zones .......................................................... 2
2. Land Distribution by Suitability of Soils ......................... 3
3. Sustainable and Actual Population Densities ..................... 13
4. Actual and Sustainable Numbers of People ....................... 28

MAP: IBRD 18441 - Climatic Zones
1. Desertification is a process of sustained decline of the biological productivity of arid and semi-arid land; the end-result is desert, or skeletal soil that is irrecoverable. This process is now at work in many parts of the West African Sahelian and Sudanian Zones (SSZ). Whether desertification is caused mainly by droughts and increasing aridity, or by resource abuse by the resident population, is hotly debated. But this debate has little operational consequence, since rainfall patterns cannot as yet be modified nor even predicted, whereas human behavior can be changed. The desertification problem is nonetheless severe, since it is an example of conflict between the public interest in long-term resource use, and private short-term resource abuse. If there is no effective reconciliation between these two interests, the desertification process will continue; while the process can be arrested, the end-result is irreversible.

2. Behavior in the SSZ is conditioned by two fundamental environmental features: rainfall is variable, and decreases in amount and predictability from south to north across the SSZ; and soils are of low fertility, particularly in phosphates and nitrogen, and structurally fragile. The traditional production systems described in Chapter II developed as responses to these conditions and included techniques, as well as enforceable rules, for assuring sustained-yield use of the modest and fragile resource base. The traditional production techniques employed in these systems imply limited carrying capacities, but varying by climatic zone. In all zones, however, the carrying capacity of the natural forest cover is lower than that for crops and livestock: the natural forest cover is therefore the most vulnerable part of the ecosystem. The traditional production systems have increasingly been disrupted, above all by rapid population growth; other pressures include changing social institutions, centralized political authority, and urban-biased economic policies.

3. As measured by the comparison between actual populations and carrying capacities (with traditional production techniques), it is in the Sahelo-Sudanian zone (350-600 mm per year) that resources are being most seriously over-exploited. This is also a zone where the available intensive production techniques – that could increase the carrying capacity – have not proven sufficiently remunerative for wide adoption, despite the pressure on the land. Desertification has set in, and crop yields are falling in many areas. Instead of a phenomenon of desert spread originating in the Saharan and Sahelo-Saharan zones, desertification is most threatening in the central Sahelo-Sudanian zone and the adjacent Sudanian and Sahelian zones, or the SSZ heartland. The principal task is not simply one of "stopping the desert", except where specific infrastructure is to be protected, but the more subtle one of arresting and if possible reversing the desertification process in the SSZ heartland.

4. Past development efforts (Chapter III) have largely focussed on promoting productivity improvements in a single sector – crops or livestock or forestry – without paying much attention to the contexts in which traditional production systems developed. While this cutting-edge approach has produced results in wetter, more fertile areas, it has proven inadequate in the SSZ. The new techniques were not much more productive than existing practices, nor were they designed to fit into production systems based on local rainfall and
soils. While some successes have been achieved, overall results have been disappointing. In irrigation, where there is tremendous physical potential that could dramatically change the carrying capacity of parts of the Sahelo-Sudanian zone, the record has also been disappointing.

5. In order to address the desertification problem, certain elements of a strategy are clear (Chapter IV):

(a) in general, the design approach should be holistic, based on probable instead of average outcomes, and based on popular participation. These observations may appear elementary but in practice it is their neglect, not their application, that is striking;

(b) actions should be determined on the basis of the ratio of actual population to carrying capacity in any given area, although action programs will have to be site-specific: people's interests, aspirations and readiness for collective action are not identical and the physical conditions, even in apparently homogeneous areas, are not uniform. Three types of relation are examined in Chapter IV: those where population does not exceed carrying capacity, those where it slightly exceeds it, and those where it greatly exceeds it. Promising actions can be envisaged in all three types of areas to avoid further deterioration in land productivity. There is not yet sufficient evidence, however, to suggest that any set of actions can do much to increase carrying capacity without a major technological breakthrough. The one exception is the Sudano-Guinean zone, where actual population is far short of carrying capacity and proven intensive production techniques are available. People are already moving into this zone from the more densely-populated parts of the SSZ heartland, where on-site solutions have been lacking and will be long in coming. A key element in anti-desertification strategy must therefore be further to encourage resettlement from the SSZ heartland into the Sudanian-Guinean zone, but by taking into account the difficulties encountered in this zone, notably human and animal diseases unknown in the heartland. The challenge is to find answers to the questions: (i) what sorts of readily enforceable land-use regulations should be put in place to promote sustainable settlement, and (ii) what further role, if any, can the public sector play in encouraging settlement?

(c) research should be focussed on more drought-resistant, high-yielding millet and sorghum and on more fast-growing, drought-resistant multipurpose tree/shrub/bush species. Research of a multi-disciplinary nature and training should focus on site-specific anti-desertification action programs. For this relatively new work, institutional changes are warranted and an agrosylvopastoral unit and a forestry unit with regional mandates should be set up in the SSZ;

(d) demand will have to be reduced, in general, by starting to reduce population growth rates; in the short term, demand for wood must be reduced by increasing permit fees. Although there
is some, but not yet conclusive, scope for increasing the efficiency of fuelwood use, there is little scope for rapid substitution by other fuels, except perhaps kerosene and gas in urban areas;

(e) the policy environment can be improved, but not as much as often supposed. The main area for improvement is legal, where present land law does not sufficiently promote conservation. With the notable exception of wood permit fees, where substantial increases are warranted, the link between pricing policy and desertification is indirect; it works through the incentive to intensify production methods. Over the last decade, the trend in input and output prices has clearly been in favor of intensification. This trend will have to be sustained and the market displacement effects of food aid will have to be even further reduced.

6. The implications for action of the foregoing elements of a strategy are listed in Chapter V, for CILSS, governments, financiers in general, and the Bank Group in particular. The listings are succinct and not repeated here. One point deserves emphasis, however: desertification has not only demographic, social, technical and economic dimensions, it also has a political dimension. Since solutions will have to be sought principally by a participatory approach to better resource management, this will require the political will to: (a) delegate authority from central government to local decision-making bodies, and (b) change laws, regulations, policies and prices to increase the incentives for better resource management.

7. In conclusion, within the SSZ heartland, no significant change in carrying capacities is possible without a technological breakthrough. Locally, however, the desertification threat may be arrested by selecting appropriate anti-desertification actions and working with communities that are interested, and empowered, to use their land in a sustained-yield manner. Reducing the continued rapid growth of population is crucial, and current population pressures in the heartland need to be alleviated by further encouraging the existing spontaneous movement of people to the under-populated, high-potential Sudano-Guinean zone.
I. THE DESERTIFICATION PROBLEM

The West African Sahelian and Sudanian Zones

General Features

1.01 The Sahel is often viewed as an area isolated from the surrounding region, and with its own special problems. But on ecological grounds, as well as for historical and contemporary political and economic reasons, the Sahel should instead be seen as the northern part of a larger regional whole which includes the more humid Sudanian zone. The focus of this paper is, therefore, on the West African Sahelian and Sudanian Zones (SSZ).

1.02 Within the SSZ, this paper concentrates on seven countries: Burkina, Chad, Gambia, Mali, Mauritania, Niger and Senegal (see Map). These countries are grouped around the 14° parallel; all are members of the Comité Inter-États de Lutte contre la Sècheresse dans le Sahel (CILSS). While the northern areas of Cameroon, Nigeria, Togo, Benin, Ghana and Ivory Coast lie within the SSZ, they are not treated explicitly in this paper for reasons of comparability of statistics. Cape Verde, the eighth member of CILSS, has been excluded from this analysis because its island situation gives it an environmental character quite different from that of the SSZ.

Climate

1.03 The seven continental CILSS states cover 5.3 million square kilometers, of which two-thirds are north of the northern limit of rainfed cultivation (NLC) (Table 1 overleaf). Throughout the remaining area too, evapotranspiration exceeds rainfall during most months of the year. Only one rainfed crop per year is possible without irrigation. The climate is harsh indeed: a short rainy season characterized by often violent and unpredictable showers, followed by a long dry season. The dry season is hot, but the first few months following the rains are a little, though perceptibly, cooler. This "cool dry season" creates problems for irrigated crops: rice must be planted so that germination has occurred before the temperature drops, but the season is not cool enough to guarantee a wheat crop except in special circumstances.

1.04 This region has not been the object of extensive meteorological research, except in the last few years (AGRHYMET). Nicholson (1982:28-29) characterizes the climate regime as follows: "rainfall is low, spotty and highly variable, drought is inherent, and dry years are more prevalent than wet ones." In this context, "climate must be treated as a variable, not a constant"; indeed, the period since 1968 has been "dry", and in marked contrast to the preceding 20 "wet" years. While drought cycles cannot be precisely predicted, and evidence is not yet conclusive that human modification of landscapes can reinforce wet or dry tendencies, the increasing aridity observed over the last 20 years is most worrying. With population

1/ A working definition of drought is suggested at para. 1.10.
growing much faster than ever before, the proposition that there is now a trend towards increasing aridity deserves a special research effort.

Table 1: Climatic Zones

<table>
<thead>
<tr>
<th>Zone</th>
<th>Rainfall Description</th>
<th>Area (m.ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saharan</td>
<td>less than 200 mm</td>
<td>296</td>
<td>56</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>200 mm up to northern limit of rainfed cultivation (NLC)</td>
<td>56</td>
<td>11</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td><strong>352</strong></td>
<td><strong>67</strong></td>
</tr>
<tr>
<td>Sahelian</td>
<td>northern limit of rainfed cultivation up to 350 mm</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>350-600 mm</td>
<td>55</td>
<td>10</td>
</tr>
<tr>
<td>Sudanian</td>
<td>600-800 mm</td>
<td>38</td>
<td>7</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>more than 800 mm</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td><strong>178</strong></td>
<td><strong>33</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>530</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

a/ It would be highly desirable to show the comparison between isohyets based on averages and the 0.9 probability isohyets used here, but the sources do not permit it. As rough orders of magnitude, inferred from isohyet maps, the 0.9 probability isohyet is 60% of the average isohyet where the former is at 200 mm, 70% at 350 mm, 80% at 600 mm, and 90% at 800 mm. These data are all for the period 1931-60; if the data base were 1951-80, the isohyets would move further south.

Source: Table A-1.

Physical Features

1.05 Of the 530 million ha under discussion, soils are suitable for cultivation on only about 60 million ha, of which about 20% was being farmed in the 1970s. About 150 million ha are classified as rangeland. The distribution of land by climatic zone and soil suitability is shown in Table 2 (opposite), which reveals an important point. About 13 million ha, or fully 20% of the 62 million ha of cultivable land, lies within the Sahelian climatic zone, i.e., between the northern limit of cultivation and the 350 mm isohyet.
Table 2: Land Distribution by Suitability of Soils

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total Area (m.ha)</th>
<th>Soils Suitable for Cultivation (m.ha)</th>
<th>Pasture (m.ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saharan</td>
<td>296</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>56</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>Sahelian</td>
<td>45</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>55</td>
<td>18</td>
<td>34</td>
</tr>
<tr>
<td>Sudanian</td>
<td>38</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>40</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>530</strong></td>
<td><strong>62</strong></td>
<td><strong>150</strong></td>
</tr>
</tbody>
</table>

Source: Tables A-2 and A-3.

When rainfall is less than average, and indeed the mode is always less than the mean, cultivation becomes an unproductive activity, and pastoralism the most appropriate use. This is therefore an area of shifting use, and of conflict between herders and farmers as changing climate modifies appropriate uses, although herders may also take up farming as one adaptive response.

1.06 Most SSZ soils are of low fertility, particularly poor in phosphates and nitrogen, and structurally fragile with low humus content and water retention capacity. Hydromorphy, hard clay pans, laterization, and wind and water erosion are all common problems. Research and experience over the past 20 years in SSZ agriculture and forestry tend to confirm that the low fertility and vulnerability to erosion of SSZ soils are as important a constraint on plant productivity as drought (Breman and de Wit, 1983; Gorse, IDA/PCR Niger Forestry I, 1982).

1.07 Water for perennial or seasonal irrigation is available in abundance from major streams and rivers (Senegal, Niger and Chari-Logone). Uncontrolled irrigation and flood recession cropping is widely practiced, but the area equipped for partially or fully controlled irrigation is still scarcely 100,000 ha. Bottomlands, small streams, lakes and shallow groundwater tables provide locally-important sources for dry season cropping. The shallow aquifers, which are also the principal source of village water supply, depend for recharge both on rainfall and sound resource management, particularly of the natural vegetative cover in order to reduce surface water runoff and promote infiltration. No systematic work is known to have been conducted on the effects of the current dry period on groundwater reserves, but all recent
indications, however patchy, show that shallow aquifer levels are falling perceptibly.

1.08 The natural vegetative cover - forests, woodlands, tree/shrub/grass savannas and steppes - is relatively drought-resistant and well-adapted to the ecological conditions of the SSZ. In the context of traditional production systems (TPSs) 1/ people have selected and developed multipurpose plant and tree species, and productive, anti-erosive vegetative associations such as bush fallows, forest parks and live fences. Much of the tree and shrub cover is composed of slow-growing species. These are often difficult to regenerate where mature stands now exist because local conditions have deteriorated. Prolonged dry periods, combined with increasing human and livestock population pressure, further retard already slow natural regeneration and thus trigger new phases of the desertification process. The natural forest cover still provides the overwhelming source - 84% (CILSS, 1983c:11) - of domestic energy, in addition to building poles, timber, and secondary forest products and foods, but access to these products is fast becoming more difficult.

1.09 SSZ pasture lands are estimated at 150 million ha. Patchy, uncertain rainfall makes it difficult to predict locations of good pasture in a given year. In most of the rangeland in the Sahelian and Saharo-Sahelian zones, annual grasses now predominate, having replaced the more valuable, but less resistant perennials. Annuals may not appear for years in an area for lack of adequate moisture, and then produce a flush of good forage when the rains strike again. Perennial grasses mixed with shrubs and trees, particularly in the better-watered bottomlands, are still to be found in the Sahelo-Sudanian zone in relative abundance. Overall, however, the situation of the pasture lands is one of deteriorating quality, quite apart from localized problems of acute overgrazing.

Drought, Resource Degradation and Desertification

1.10 Drought will be defined here as a markedly sub-average amount of rainfall during a year or series of years. Precision in this regard - how much less precipitation - is difficult to provide for two reasons. First, averages are deceiving, particularly in the northern arid areas, where precipitation totals vary markedly from one year to the next. A few years of abundant precipitation often skew statistical averages well above realistic expectations for rainfall in a given place in, for instance, seven out of ten years. Second, gross amounts of rainfall only partly determine vegetative productivity. In addition to soil fertility and structure, timing and distribution of precipitation play a crucial role. "Below average" rainfall, if well distributed temporally and spatially, will produce quite adequate crop yields. On the other hand, "average" or even "above average" precipitation totals may not correlate with "average" or "better than average" crop yields if rainfall is spotty, and if dry periods are interspersed with over-abundant precipitation.

1/ Traditional in the sense of systems developed by local residents over long periods, in which governments do not play a major role.
"Drought" is a broad, somewhat misleading term. But it is useful because it underlines the vulnerability of SSZ lands and economies to the vagaries of the local climate. Drought is a constant menace, a fact of life with which rural dwellers must cope if they are to survive in the region. But drought alone does not, in the short run, produce resource degradation of the sort now found in the SSZ. Other factors are at work, including population growth, spread of extensive agriculture and thus deforestation, and rapid urbanization (which concentrates demand for fuelwood). In addition, changes in national and local political, economic and social institutions have on balance reduced local autonomy and capacity to organize joint undertakings. Together, these factors are making it increasingly difficult to manage the natural resource base upon which the economy of the region rests.

Desertification can be defined as: "the continuous and sustained decline in the amount and quality of the biological productivity of arid and semi-arid land. Such stresses, if continued or unchecked over the long term, lead to ecological degradation and ultimately desert-like conditions. Biological productivity refers to the naturally-occurring plant and animal life as well as to the agricultural productivity of a given area" (adapted from Sabadell, 1982:1). Common indicators of desertification include a reduction in the amount and diversity of plant and animal species, loss of water retention capacity, lessened soil fertility and increasing wind and water erosion. Eventually, plant and animal communities become so radically simplified that species formerly common in an area can no longer survive under the drastically altered circumstances, even if they are deliberately reintroduced.

Desertification takes two distinct forms: desert spread and induced desertification in more humid areas. Saharan encroachment into Sahelian lands may occur gradually through growing aridity and resource abuse, such as overgrazing, excessive tree lopping and woodcutting, and clearing of marginal lands. Of more immediate concern here is man-induced, accelerated degradation of areas well south of the Saharan fringe. Deteriorated patches occur now with alarming regularity around centers of human activity, even well south into the Sudanian zone. In their struggle to survive, populations further over-exploit resources in these focal points of desertification, and gradually encourage their spread. The challenge is not "stopping the desert's advance from the north", but effectively managing renewable resources south of the desert. 1/

Desertification: Drought or Resource Abuse?

The answer to this fundamental question depends upon perceptions of drought and the destruction of resources with which it is often associated.

1/ At some point south of the desert, it would be more appropriate to speak of resource degradation rather than desertification; indeed, the latter is a particular case of the former. The term desertification is retained in the following discussion, however, since that was the starting point for this paper.
Three general explanations are advanced:

(a) First Position: Drought in the SSZ is an overwhelming, long-term phenomenon in which people play no part. Increasing aridity will inexorably destroy vegetative cover. Desertified areas will spread to engulf and obliterate what are already marginal environments of limited productivity. Resistance to desertification is futile.

(b) Second Position: Drought in the SSZ is a short-term, recurrent phenomenon, again independent of human influence. Resources suffer in the short run, but when a drought of five years' or less duration ends, local production systems sooner or later recover. Droughts of this sort can be endured, especially if food reserves exist in amounts adequate to tide people over periods of low output.

(c) Third Position: Desertification is a complex, still poorly understood process. It appears to be caused by interactions between drought and human abuse of the environment. Better management of the natural resource base could mitigate the impact of even serious droughts on the long-term viability of SSZ renewable resources, although prolonged droughts like the current one (one to three decades' duration) may well alter the natural resource base profoundly, especially when coupled with rising population pressure.

1.15 This paper takes the third position for two reasons. First, while the available evidence indicates that drought has long played a role in SSZ ecology (NAS, 1983a), past periods of short- to medium-term aridity have had relatively little permanent effect on the environment. On the other hand, severe drying trends lasting a century or more unquestionably did modify the natural vegetative cover. During the modern era (since 1900), however, when droughts of two decades or less have been the rule, much resource destruction has occurred at the hands of human users, whose numbers have increased far more rapidly than before (para 1.18). Second, whereas climate is a given, human behavior can be modified in response to changes in the environment. The desertification process is slow and insidious, and governments and rural communities have consequently been slow to react, despite the rapid growth in population. So long as there are unexploited techniques and more appropriate organizational arrangements and policies for encouraging better management of the environment, it would be short-sighted to ignore them by assuming, on uncertain evidence, that the principal cause of desertification is climate. The problem of desertification is nonetheless severe, since it is an example of conflict between the public interest in long-term resource use, and private short-term resource abuse. If there is no effective reconciliation between these two interests, the process of desertification will continue; while the process can be arrested, the end-result is irreversible.

A Complex and Multifaceted Problem

1.16 Drought, if not prolonged, does not in itself pose an enormous threat to the long-term viability of rural production systems in the SSZ, but
it accelerates the negative consequences of resource abuse. Overuse of one renewable resource, in turn, often reduces viability of others, and this negative dynamic intensifies when drought periodically strikes an area. This point can be easily illustrated. The spread of rainfed, extensive agriculture into forest, bush and pasture areas reduces total forage available to transhumant livestock, particularly when, as now, mixed farmers increasingly collect and stock crop residues to carry their own animals through the dry season period. When drought strikes, transhumant pastoralists do what they can to save herds. Lacking alternative forms of forage, they try to increase their animals' intake of browse. They vigorously lop trees already weakened by lack of soil moisture. Many trees die as a result of this abuse. Pressure then intensifies on the remaining woodstock during the next drought. Clearing fields for animal traction or machine cultivation may disrupt existing soil fertilization cycles based on nutrients that in-field trees return to the soil surface in the form of humus. If these organic nutrients are not replaced by organic and/or chemical fertilizers, crop yields decline. Stripping trees from fields also reduces the windbreak effect that even an open canopy can provide, and increases wind erosion. When fields are fallowed, in those systems where man/land ratios still permit it, natural regeneration occurs much more slowly. In the meantime, soils may suffer both wind and water erosion.

1.17 Urbanization likewise has a multi-faceted impact on the surrounding countryside, concentrating demand at specific points within marginal environments. Rural areas close to urban centers rapidly lose vegetative cover to meet the fuelwood demand of the adjacent urban area. If no action is taken to reduce fuelwood consumption in urban areas (para. 4.22), any environmental management effort in the adjacent rural areas will fail. Of equal importance, growing urban populations exert political pressure on regimes to maintain cheap urban food and fuelwood pricing policies. These reduce farmers' incentives to use inputs to produce foodstuffs more intensively, to plant trees and, in short, to invest in land and in the renewable resource maintenance necessary to sustain the rural base of production.

Population

1.18 Total population in the SSZ countries was estimated at 31 million in 1980. Overall densities remain low: 6 persons/km$^2$ for the entire area and, excluding the Saharan and Sahelo-Saharan zones, roughly 15 persons/km$^2$. Densities can reach 100 persons/km$^2$, however, in some areas, visibly overtaxing their carrying capacity. The average density in Senegal is now 20 persons/km$^2$. The lowest national density is found in Mauritania, with 1.5 persons/km$^2$, and the highest in Gambia, with 60 persons/km$^2$ (Table A-4). Population growth rates between 1980 and 2000 are expected to be about 3% annually. On this basis, the area will have 75% more people by the year 2000, or 54 million inhabitants. In 1961, by contrast, the population was 19 million!

1.19 Based on the ecological classification established by M. Keita (FAO, 1982:14-15) presented in modified form in Table A-5, the SSZ population in 1980 was remarkably unevenly distributed. While 80% of the people live in 25% of the total area south of the Sahelian zone, fully 40% of the people live in
only 6% of the total area. Furthermore, in the sub-zone comprising the Senegalese Groundnut Basin, Gambia, and the Burkinabe Mossi Plateau, fully 24% of the total population lived in only 2% of the total area; population density there was 60 persons/km², with the rural population at 45 persons/km². Such concentrations of demand for arable land and fuelwood lie at the root of resource abuse. It is in these areas that patches of desertification are most clearly visible; they will spread rapidly if resource management measures cannot be implemented.

1.20 Urban population growth rates reveal an even more volatile situation. Urban populations averaged 22% of national populations in 1981 (lowest: Burkina, 11%; highest: Senegal, 34%), but urban populations now grow at an average rate of 5% annually. Mauritania — arguably the country that has suffered most from the impact of drought over the past two decades — has experienced an 8.6% urban population growth rate in recent years. Senegal, with one-third of its population already urbanized, has the lowest urban growth rate at 3.3%. Rural–rural migration is also a growing phenomenon, although figures are scarce. It is clear, however, that people are increasingly moving away from the most densely-populated areas, notably the Burkinabe Mossi Plateau and the Senegalese Groundnut Basin, to more promising areas in the Sudano–Guinean zone.

1.21 Two important observations flow from these figures. First, when population grows at 3% annually, population doubles every 25 years. The ballooning demand for resources that this growth represents almost inevitably generates extensive resource abuse in the short run. Adjustments are not made quickly enough to these changing conditions: consumption accelerates, but at the cost of over-exploitation or "mining" of the resource base rather than investment in its improvement or even sustenance. The desertification process takes hold. Second, the destruction of the rural environment will almost certainly result in further uncontrolled urbanization, compounding the problems of already strained municipal administrations.
II. TRADITIONAL PRODUCTION SYSTEMS AND PRESSURES UPON THEM

The Three Basic Traditional Production Systems

2.01 TPSs have been tailored very precisely over time to contend with particular circumstances. The following three basic TPSs, which can even coexist in the same area, illustrate the range of approaches, rather than the richness of any one system. TPSs merit attention because they permit fairly large populations to exploit marginal regions in a sustainable manner.

The Agrosylvicultural System

2.02 Variations on this system are practiced by Nigerien Hausa and Burkinabe Mossi, among others. Production is based on rainfed agriculture in association with trees and shrubs. The system involves cultivation of several main plant species (millet, sorghum) as food crops and cotton for cloth. Secondary products are produced by systematically exploiting natural vegetation (trees for fruits and leaves as well as firewood and building poles, bark for cord and medicine, thorn branches for fencing, grasses for thatching, fodder, green manure, etc.). Small ruminants, particularly goats, often play a major role in this system. Production in the agrosylvicultural system is concentrated during the two- to four-month rainy season. Individuals, particularly adult men, often travel during the long dry season in search of temporary work.

2.03 Land, initially allocated on a usufructory basis, tends to become subject to life tenure, then inheritable property and, finally, the object of economic transactions (mortgage, sale, rent, etc.). As population pressure increases, control over land is allocated to smaller and smaller units until individuals exercise authority over highly fragmented parcels.

2.04 Trees in this system meet not only consumption demands, but also, in bushfallow and open field sites, non-consumption needs. If grown in sufficient numbers on fields, they protect exposed soils against wind and water erosion and also regenerate soil fertility by recycling subsoil nutrients as green manure in the form of leaves. Micro-organisms associated with root systems, such as nitrogen-fixing rhizobia and mycorrhizae which improve plant feeding, can also increase growth of certain species.

2.05 Agrosylviculture in the SSZ usually relies on intercropping, in order to make the best use of available sunlight through a complex pattern of leaf types and also to keep production options open and minimize negative impacts of seasonal climatic fluctuations. Agrosylviculturalists placed a premium on risk minimization, rather than output maximization, to guarantee subsistence production; this behavior is reflected, for example, in the selection of seed for basic foodstuffs, whereby several varieties adapted to different forms of risk are preferred to the "best" variety.

The Agrosylvopastoral System

2.06 Variations on this system are practiced by, for instance, the Senegalese Serer, Nigerien Bugage, and Malian Sarakollé societies. This
system relies on the same sort of field crop/tree/shrub associations characteristic of the agrosylvicultural system, but integrates livestock production to reinforce soil fertility, as well as for market sale. This system puts a premium on trees that produce browse or seed pods suitable for fodder. Trees may also be exploited commercially, for gum arabic (Acacia senegal), shea nut butter (Butyrospermum paradoxum), and other marketable food products, as well as for firewood and building materials.

Livestock in such systems must be accommodated during the wet and the dry seasons by carefully defined access to fields, as well as to surrounding bush and pasture areas. When people are cultivating field crops during the rainy season, animals must be stabled or herded elsewhere. During the dry season, after the harvest has been stored, herded or free-ranging animals can roam fields to forage on crop residues. In those systems based on systematic manuring, stock owners tether their animals (or the herder stables them) on fields at night: the concentration of droppings increases soil fertility. In the past, however, these systems rarely undertook systematic composting of manure mixed with straw or stalks.

Evolution of land tenure relations parallels that of agrosylvicultural systems. The same pattern of land use is observed: heavily fertilized gardens adjacent to dwellings, annually manured fields, often under a tree canopy and farmed on a nearly permanent basis, and bush fields fallowed after a relatively short period of cultivation. The most valuable areas are those which can be farmed continuously, either because proximity to dwellings permits easy fertilization, or because livestock are stabled on them. Since these lands do not have to be cleared before cultivation, labor costs are markedly lower than in the more remote areas of fallow and shifting cultivation.

The Sylvopastoral System

SSZ sylvopastoralists - Fulbe, Tuareg, Maures and Tubu - keep cattle, camels, sheep and goats. Ethnic groups and individuals within them tend herds of different species, sex and age composition. Most specialize to some extent in one species or another, and occupy environmental niches that meet the needs of their particular herd. Most within this group are transhumant pastoralists rather than nomads, i.e., some or all of the herding family moves with some or all of the herd during part of the year. Herders operating under normal conditions move within clearly defined ranges; usually, a group has both wet and dry season "home" pastures. Transhumant moves may be very restricted - a matter of a seasonal shift of a hundred kilometers or less - but they can also be nearly continuous circuits of four or five hundred kilometers north and south. Fulbe especially will go long distances into strange territory when necessary to preserve their herds. Tuareg and Maures tend to rely more on isolated wells to serve as magnets for freely grazing stock animals on surrounding pastures, and move less with their cattle than do Fulbe. Tubu, finally, may be the least mobile of all these groups.

The driving force behind these annual displacements is the need to find forage for the herd in all seasons. Most forage - pasture grasses, shrub and tree browse, and crop residues - appears irregularly in time and space. Herders typically congregate during the wet season in the Sahelian and Saharo-Sahelian zones, when rains usually produce grasses and accumulations of surface water on the desert edge. The abundance of food and easily available
water lasts only a few months, typically from July through September/October. Thereafter, until the next rains eight or nine months later, pastoralists depend on well water for themselves and their stock. Some seasonal water courses and a few perennial rivers provide water for longer periods for some groups.

2.11 In this sylvopastoral system, trees are a critical fodder source during the dry season. When the rains cease, grasses dry out and lose most of their nutrients. They still provide the bulk needed for ruminant diets, but vitamins, digestible proteins and minerals (NAS, 1983v:16) must come from other sources. Traditionally, tree and shrub browse have provided these elements.

2.12 Land tenure relations in earlier times reflected the relative political and military power of different herding groups. Those who could take and hold water points and rangeland did so; others moved on to underexploited or virgin areas. Within the group occupying a particular piece of rangeland, however, pasture was treated as regulated common property to which all group herds enjoyed access, provided regulations were respected.

Common Features

2.13 In most TPSs, deliberate tree planting never became a significant activity, since most areas enjoyed a surplus of natural forest cover. Selective cutting and management of the regeneration of natural forest cover, however, often produced stands of preferred tree/shrub species in the fields. Certain trees and shrubs were also preserved in bush stands, and served as the basis for restoring soil fertility on fallow lands. As part of these TPSs, humans protected trees, shrubs and bushes useful for many purposes in addition to browse, building materials, fuelwood and nutrient recycling. Fruits, gum, honey and medicines all justified protection of certain woody species. This deliberate plant selection has resulted in a large number of specific and valuable associations throughout the SSZ. Farming under a selected forest park canopy is perhaps the most visible example of this sort of activity.

2.14 While population pressure permitted — depending on local conditions, from 5 up to 25 people/km² (para. 2.21) — the two agriculturally-based systems included a phase of bush fallow, usually lasting a decade or more, to restore soil fertility. Many of the TPSs integrated anti-erosion and soil fertility maintenance measures into the production process. These included, depending on the group and the location, live fencing, shade trees, water harvesting through terracing, ridging, bunds, catchments, as well as intercropping, mulching and maintenance of field fertility by recycling nutrients through trees.

2.15 Before being subjected to disruption pressures as described below, these TPSs were not only technical systems but also, and perhaps more important, they were managed by local authorities. In this sense, the TPSs were participatory, although not necessarily democratic; at least, there were no top-down prescriptions emanating from a distant agro-bureaucracy. Decisions on issues such as land tenure, pasture management and use of woodstock were made by local, not distant, authorities. Such issues did not interest the ruling powers, so long as local people fulfilled their duties to pay taxes, and furnish tribute and soldiers. Powerful new disruptive factors, such as population growth and changes in political and
economic structures, have recently combined to erode the autonomy of formerly local decision-making bodies and the stability of formerly stable production systems. Their survival, or the scope for their revival, is now open to question in many areas.

**Carrying Capacities of Traditional Production Systems**

2.16 The carrying capacity (CC) of a natural system can be expressed as the amount of biological matter the system can yield (for consumption by animals, humans, etc.) over a given period of time without impairing its ability to continue producing, or the number of organisms it can support without being degraded (Webb and Jacobsen, 1982:8). Since carrying capacity will vary as a function of technology, the level of technology has to be specified. The following discussion examines the carrying capacities of traditional production systems such as those described above; this point cannot be emphasized too strongly and should be kept in mind throughout the following discussion. Furthermore, off-farm activities have not been taken into account even though SSZ people are often involved in elaborate exchange relationships that extend far beyond the zones where they reside.

2.17 Figures presented in this section on SSZ carrying capacities do not represent rigorous calculations based on hard data. Instead, they are estimates derived from the best available, but still partial, information. This holds for agricultural, pastoral and forestry production figures. They represent estimates of country or regional averages, which inevitably obscure significant local variations in soil conditions and other relevant physical factors. In addition, the uncertainty of rainfall throughout the area means that all averages are poor indicators of actual conditions in given settings in specific years.

2.18 In recognition of the difficulty of applying the concept of CC - because of the softness of the data - the Bank believes it important to pursue and refine calculations of the sort prepared, e.g., by Mory Keita (FAO:1982). Eventually, more reliable data will be generated, and more precise calculations of carrying capacities will be produced. Indeed, such data on the quality of resources and trends over time would also serve to help devise more effective land management practices and legal procedures. In the meantime, carrying capacity as estimated in this report is a useful analytical tool: it helps establish general relationships between population pressure and renewable resources in subzones of the region, and identify the most serious resource-related constraints.

2.19 **Carrying capacities using traditional practices** are derived in Annex 1 for crops (Table A-7), livestock (Table A-8) and the natural forest cover (Table A-9). These very approximate and therefore rounded estimates of "sustainable populations" are compared to actual populations in Table 3 below. These estimates do not take account of water resources which could be exploited for cropping under traditional production systems, e.g., uncontrolled flooding, flood recession cropping, bottomlands, and shallow groundwater, nor do they consider local resources favorable for livestock, such as the rich bourgou pastures in the vast Inner Delta of the Niger River or the flood recession pastures around Lake Chad. In addition, the constraint on livestock imposed by the prevalence of the tsetse fly in the Sudano-Guinean
zone and even in parts of the southern Sudanian zone has been ignored. The crop and livestock carrying capacities are calculated from soil suitabilities based on soil classification maps. These carrying capacities are to be added; the fuelwood carrying capacity, by contrast, is not additive, and also has to be assessed with respect to total, rather than rural, population.

2.20 Based on traditional agricultural and livestock systems, the sustainable rural population is 36 million, or considerably more than the 1980 rural population of 27 million. By contrast, the sustainable total population based on fuelwood from the natural forest cover is only 21 million, whereas the 1980 total population was 31 million. For all the imperfections in the data, these two broad findings are defensible.

2.21 Comparison of actual and sustainable populations by zone is complicated by the different bases of the data. Sustainable populations have been assessed by rainfall zones, demarcated by isohyets with 0.9 probability, whereas the only available breakdown of actual (1980) population is by forestry zones, defined mainly, but not exclusively, by rainfall. A crude attempt to adjust actual population data to the probabilistic rainfall zones is made in Table A-6. On that basis, the orders of magnitude of sustainable and actual population densities are as follows:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Sustainable Population</th>
<th>Actual Rural Population (No./km²)</th>
<th>Sustainable Fuelwood Population</th>
<th>Actual Total Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crops</td>
<td>Livestock</td>
<td>Sum</td>
<td>Population</td>
</tr>
<tr>
<td>Saharan</td>
<td>-</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>-</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
</tr>
<tr>
<td>Sahelian</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Sudanian</td>
<td>15</td>
<td>7</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>25</td>
<td>10</td>
<td>35</td>
<td>9</td>
</tr>
</tbody>
</table>

However imperfect the data base and the presentation by zones that necessarily conceals differences within zones, three general observations are suggested by these figures:

(a) in all zones, the carrying capacity of the natural forest cover is lower than that of crops and livestock with traditional production techniques. The natural forest cover is therefore the most vulnerable part of the ecosystem; indeed, in five out of the six zones, the actual population already exceeds the sustainable population. The natural forest cover is not just vulnerable, it is already being severely over-exploited.
(b) actual density greatly exceeds sustainable density in three cases (underlined): fuelwood, and crops and livestock in the Sahelo-Sudanian zone, and fuelwood in the Sahelian zone. These are clearly the zones most vulnerable to the desertification process; within them, certain subzones are even more vulnerable (para 1.19 and Table A-5). In the Sudanian zone, too, actual population density is already at the sustainable level for fuelwood, and will shortly be at the sustainable level for crops and livestock. In the Sudan-Guinean zone, by contrast, actual population is substantially lower than the sustainable population.

(c) the anti-desertification effort should focus on the most threatened area, the narrow Sahelo-Sudanian central belt or "heartland", and not, as sometimes suggested, on the desert fringe. But in the heartland, the scope for intensive production is much more limited than in the southern Sudan-Guinean zone. The few Bank rainfed agricultural projects in the Sahelo-Sudanian heartland have a disappointing record in respect of promotion of more intensive production: Senegal Sine Saloum (Credit 549 and Loan 1113) was reappraised but later halted; Mali OACV (Credit 491) led to a "pilot" follow-up project; and Niger Dosso (Credit 967) was closed on schedule with most of the funds unspent and no follow-up project envisaged. In the relatively underpopulated Sudan-Guinean zone, by contrast, where it could be argued that the need for intensification is not pressing, there is proven scope for profitable intensive production, and the project record is good: Mali Sud (Credits 669 and 1415), Burkina West Volta (Credit 706) and Volta Noire (Credit 1284) and Hauts Bassins (Credit 1285). The anti-desertification effort should therefore be two-fold: first, in the heartland itself, specific anti-desertification measures as well as any intensive production techniques that may be profitable should be undertaken; and second, in the Sudan-Guinean zone, existing, spontaneous settlement by people from the heartland should be further encouraged, but by taking into account the difficulties encountered in this zone.

Pressures upon Traditional Production Systems

2.22 With the consolidation by 1920 of the colonial regime throughout the SSZ, the political foundations were laid for several slow but fundamental changes that subsequently were to modify local environments. In comparison to conditions during the preceding three centuries, the colonial era and quarter century of independence after 1960 have seen relatively little warfare and disruption of trade. The last 70 years have been marked instead by increasing security and travel throughout the region, and above all by improved medical and veterinary facilities whereby human and animal populations have increased dramatically. Other changes, too, have put increasing pressure on TPSs.

2.23 Increasing monetarization produced marked changes in social institutions. The extended family in particular -- traditionally the major
unit of production — came under internal pressure. Younger men realized that they could meet their subsistence needs, pay taxes, and still have funds left over for their own purposes (dowries, etc.) if they could acquire land for food and cash crop production. Failing that, labor migration to coastal treecrop plantations, groundnut-producing regions and cities often offered comparatively lucrative employment. The result was a breakdown in the authority exercised by the heads of extended families. Younger men demanded their inheritance of land. If they could not secure it, some colonized new lands, while others migrated. This alleviated the pressure on the land and, moreover, led to what has become an important flow of remittances to those who stayed behind. Nevertheless, mechanisms that had earlier regulated the use of land and resources fractured in the process. Unregulated exploitation has gradually supplanted traditional practices of soil, pasture, tree and water conservation. The abnormally wet period, 1950-65, observed throughout much of the SSZ, initially masked the effects of these changes; given good rains, freshly cleared and fertile lands produced good harvests even in areas that would normally have been considered marginal. The drought of 1968-73 highlighted the effects of these changes, both in the marginal areas and in the SSZ heartland; extended family structures and their careful resource management practices had largely broken down, and the authority of local communities, which might have taken political measures to control resource abuse had family structures no longer sufficed, was increasingly constrained. These effects were further accentuated by the continuing dry period since 1973.

Increasingly centralized political authority has also challenged the capability of local decision-making bodies to manage their environment. Since independence, moreover, the objective of maintaining peace within national boundaries has been pursued by exercising strict control over all local organizations, sometimes by promoting new organizations such as cooperatives to challenge traditional authorities. The result has been confusion and then a passive attitude towards the local collective activities so often required for sound resource management. Obstacles to genuinely local organizational initiatives have become formidable. A local political entrepreneur interested in promoting village-level pasture management must usually first seek permission from a ministry in order to establish a voluntary organization. Once established, such a local institution usually cannot make rules about pasture use nor raise revenue for their implementation without special enabling legislation. The would-be organizer will conclude that efforts to marshal local initiative to manage pastures are pointless. Similarly, the French West African 1935 forestry code specifies protected species even on non-domanial lands and prohibits the cutting of such species without authorization from a forester; would-be planters of such species would have to obtain explicit exceptions to the code in order to assure themselves of their rights to harvest. The disincentives related to the costs of getting organized dissuade local populations from even considering how they might participate in the management of local renewable resources. The situation is not much better for individual initiatives, because their success so often depends on some sort of collective backing.

Increasingly urban-biased economic policies have promoted cheap food and fuel for urban consumers. Quite apart from their overall negative effects, these economic policies have also contributed to the desertification process. To the extent that low producer prices discouraged more intensive production, and the unpredictable behavior of public marketing agencies
increased farmers' risks, land-clearing for further extensive production and/or the shortening of fallow periods was promoted. It is in the area of fuelwood pricing, however, where economic policies have had the most direct effect. Fees charged for wood harvesting and transport permits have remained virtually unchanged since before independence, over a period when the market prices for fuelwood and building poles have increased dramatically. These prices have increased in real terms at a rate of 5% per year over the last decade. The failure to update stumpage fees - to bring them more into line with the cost of planting trees - has simply promoted destruction of the natural forest cover and no investment in replanting. In addition, an opportunity to fund ill-equipped national forestry services has been missed.

2.26 With rural population increasing at about 2% per year, and given the limited scope and incentives for crop intensification, the cropped area has expanded and the core of the agricultural TPS - adequate fallow periods - has come under attack. Indeed, increased production over the last two decades has come primarily from area expansion; such progress as has been realized in yields has been obtained mainly in the Sudano-Guinean zone. In the Sahelo-Sudanian zones, the result is that land is overworked and yields are tending to fall, notably in the Groundnut Basin in Senegal, the central Mossi Plateau in Burkina, and much of Niger (CILSS, 1983). In these areas, the traditional production systems are no longer operating, in the sense of working on a sustained-yield basis, yet have not been amended by widespread adoption of new techniques that could ensure sustainable yields.
III. REVIEW OF PAST DEVELOPMENT ACTIVITIES

Agricultural Sector Activities

3.01 During the colonial period, most efforts in the area of agronomy focused on annual cash crops, mainly groundnuts and cotton, since the SSZ was by and large self-sufficient in cereals and there were no promising export markets. The French established research centers (e.g., IRAT and IRCT), as well as a network of public agencies for the distribution and marketing of inputs ("Sociétés de Prévoyance", "Coopératives", etc.) in support of nationwide cash crop programs. Efforts were also made to implement large-scale intensive production and resettlement programs, such as the ambitious groundnut scheme in Kaffrine (Senegal) and the development of large irrigated areas along the Niger and Senegal rivers ("Office du Niger", "Aménagement de la Vallée du Sénégal"), originally for cotton production (para 3.04).

3.02 In implementing such nationwide and local programs, a number of technical and socio-economic problems were encountered, e.g., inadequate knowledge of the milieu, misperceptions of farmers' interests and aspirations, and high production costs. Thus, at about the time of independence, the single annual cash crop approach evolved into agricultural development projects based on the provision of extension services, inputs, credit and marketing facilities, often within the framework of elaborate support structures ("offices régionaux de développement rural, centres d'expansion ruraux", etc.). These projects aimed to address all the farmers' needs for the production of all crops in their cropping patterns. They were mainly based on more intensive agricultural techniques including use of fertilizers, improved equipment and animal traction. This agricultural development orientation evolved later in the 1960s into an approach that embraced other rural needs, such as forestry, livestock, feeder roads, water supply, functional literacy, and health care. These "integrated rural development projects" had the broader ambition of improving living standards in the rural areas.

3.03 The performance of these rural development projects, whether integrated or not, has varied considerably. Although they often included livestock and forestry "components", they were nonetheless dominated by one concern: crop production. Yet the existing, but increasingly constrained traditional production systems were indeed systems, incorporating crops, animals and trees. In practice, the livestock and forestry components of projects were usually designed as sectoral adjuncts to the crop components and implemented by separate agencies, with little or no field liaison with the "lead" agricultural agency. In the Sahelo-Sudanian zone in particular, this sectoral approach to a systems problem has resulted neither in improvements to the system, nor even in much progress in the sectors.

3.04 Investments in controlled irrigation have had a mixed record. The enormous irrigation potential in the SSZ, perhaps three million ha, was recognized early on: the Office du Niger scheme in Mali was started in the 1930s. Until the late 1960s, irrigation investments were concentrated in "large-scale" perimeters of a few thousand hectares. At that time, public investment started in small-scale perimeters, i.e., units of about 20 ha,
powered by a single small pump, or medium-scale perimeters of a few hundred ha. The record of the large-scale perimeters is poor; that they have not been managed in a sustainable manner is evidenced by the increasing need for rehabilitation. Small-scale perimeters have fared much better, in large measure because they were designed for, and farmers were capable of, incorporating small irrigated plots into their existing rainfed crop and livestock activities. The scope for investment in small-scale perimeters is, however, fairly limited since the site requirements are stringent. By contrast, the physical potential in large-scale irrigation is enormous, but it cannot be realized until performance on the existing large perimeters improves substantially.

Livestock Sector Activities

3.05 Traditional social structures in the pastoral areas have undergone profound changes since the beginning of the colonial period. With the passing of the privileged relationship that they previously enjoyed with subservient farmers, pastoral societies have lost much of their influence, and with it, their control over access to land. The period of relatively abundant rainfall, 1950-65, encouraged farmers to move into marginal arable lands in the Sahelian zone and little could be done to stop them, even where, as in Niger, an exclusive Pastoral Zone had been legally established. Herders have thus been forced back and for a longer period of the year into the more marginal northern Sahelian pasture lands.

3.06 Beginning in the 1920s, veterinarians (the first technicians to operate in West Africa) have provided vaccination services, thus tending to increase herd size and the threat of grazing pressure on the pasture lands. Most livestock projects implemented during the last three decades have emphasized animal health and pastoral water supplies, mainly large-bore open wells, but also mechanically-powered deep tubewells. These new wells were invariably supplied as public goods, and were therefore accessible to all comers; traditional control over access to pasture, governed by ownership of wells, was thereby eroded. Even today, public wells are still being constructed with no prior consultation with the local population, and often located in areas where it is mistakenly believed that pasture is relatively abundant. The overall result has been an increase in herd numbers, a decrease in pasture through more widespread cropping, and an erosion of traditional range management practices.

Forestry Sector Activities

3.07 Forestry Departments were first set up in the 1930s and, until recently, their main activity was the demarcation and policing of forest and fauna reserves. These reserves were set up primarily in the Sudano-Guinean zone, i.e., where land was relatively abundant, and particularly where diseases such as riverblindness and sleeping sickness hampered settlement.

3.08 In the last decade, several pilot reforestation plantations have been initiated, mainly in the Sahelo-Sudanian zone, where the natural forest cover is being most rapidly depleted. Although no inventory has yet been
made, it is already clear that the results are disappointing, not least because these operations were based on production techniques developed in the Sudano-Guinean zone. In fact, very little research has been done in the drier areas and there are today no technical packages really adapted to the harsh conditions of the Sahelo-Sudanian zone or further north.

3.09 In the last few years, work has begun on management of the natural forest cover and promotion of in-field natural regeneration, and community and family-based plantings. Although it is too early to draw conclusions, the initial results are not as cost-effective as anticipated.

3.10 Although long-established, Forestry Departments remain weak institutions in SSZ countries; forestry appears to be a postponable undertaking and therefore gets short-changed in the competition for budgetary resources. Perceptions may be changing, however, as suggested by the recent conferences in Niger and Senegal. Other perceptions must change too, for there is a strong preference among foresters for exotic tree species for wood rather than indigenous multipurpose tree species. Increasing evidence suggests, moreover, that farmers rarely perceive the utility of tree planting for wood as distinct from the need for many other forest products.

Common Weaknesses of Development Activities

3.11 Although development efforts have been organized along sectoral lines - agriculture, livestock or forestry - they nonetheless share certain weaknesses. In particular, planners have often misunderstood the logic of traditional production systems, and have thereby overestimated the ease with which improvements could be introduced and underestimated the negative consequences of intended improvements. Planners seem to have neglected the fundamental significance of rainfall variability and risk-avoidance in all SSZ production systems. It is now widely recognized that TPSs are based on probable outcomes and are designed to contend with the occurrence of bad rainfall years (although no system can cope with successive bad years). Most project designs, on the other hand, have tended to be based on average outcomes. The result has been that projects often incorporated overly optimistic assumptions that clashed with local concerns about ensuring survival in a difficult environment. This clash was not so severe in the Sudano-Guinean zone, because rainfall there is less risky, and it is precisely in that zone that the more notable successes are to be found.

3.12 One of the reasons for the failure to understand TPSs was that the practitioners of such systems were seldom consulted in a participatory fashion. Indeed, lack of participation by the ostensible beneficiaries has been another common weakness of development activities. Supposed beneficiaries usually have little input in the planning process, and project design suffers in consequence; nor are their views regularly solicited, and acted upon, during implementation. The old political adage that "those who can't say no, have no say" applies.

3.13 A third common weakness has been underestimation of (a) managerial weaknesses of existing institutions and/or the difficulty of setting up new institutions, and (b) the remaining strengths of local institutions. In fact, few attempts were made to investigate the organizational bases, capabilities
and limits of local institutions, particularly where cooperatives existed, since they were often assumed to be synonymous. More recently, however, dissatisfaction with the agro-bureaucracies has spurred interest in local groups as retailers of inputs, managers of credit, and organizers of primary marketing. Supported by adult literacy campaigns, many promising initiatives are now underway.
IV. ELEMENTS OF A STRATEGY FOR BETTER RESOURCE MANAGEMENT

General Observations

4.01 The diagnosis of the desertification threat by carrying capacity has highlighted significant differences between zones (para 2.21). Attention has also been drawn to significant differences within zones. Three general observations nonetheless apply: (a) the approach to development should be holistic; (b) it should be based on probable, not average, outcomes; and (c) it should be based on popular participation. Although these observations may appear elementary, it is in practice their neglect, not their application, that is striking.

4.02 A holistic design approach is necessary both because of the sheer complexity of the problem of managing the fragile resources of the SSZ and because field research has clearly shown that the people of the SSZ do indeed take a comprehensive approach to the natural resources on which they depend. Agrosylviculturalists perceive that trees do help reconstitute bush fallow, protect and enrich fields, and supply minor forest products as well as fuelwood and building poles. The emphasis on multiple use of land will often entail compromises whereby short-term productivity may be forsaken for more sustainable production. Development efforts will be more successful if based on a holistic approach that will also draw attention to the heterogeneity of areas often thought to be homogeneous.

4.03 A probable-outcome approach to the design of technical innovation is necessary, since contending with dry years is a major preoccupation of SSZ people. Benefit-cost ratios of 2.5:1 in "average" years may simply not be sufficiently attractive in the light of the probability of bad years. Fertilizer that can be applied as a top dressing, after a crop has been established, will be more readily adopted than fertilizer that is to be applied as a base dressing, before planting. Even in irrigation, which is far from riskless wherever mechanical pumping is required, farmers' adoption of more costly techniques will be conditioned by their assessment of the risk of pump failure and the impact on their crop of delayed repairs. Again, development efforts will be more successful if conceived in the light of probable, not average, outcomes.

4.04 A participatory approach to design and implementation is necessary, first, because the top-down approach has failed, and second, because local circumstances vary greatly over time and space. The informed, key decision-makers are the farmers and pastoralists themselves. Those who plan or execute development efforts should do so in a spirit of adaptation to changing local conditions. This requires knowledge that can only be provided by the participants themselves, so means must be found, or revived, to enable the ostensible beneficiaries to express themselves. In the early stages of design, university or even secondary school staff and students could be used to good effect to elicit farmers' and pastoralists' views. As design begins to take shape and during implementation too, local organizations are required that are able to take resource management decisions on the basis of some kind of majority rule, not necessarily unanimity; most resource management activities will require some degree of collective action, along with rules governing individual behavior. Legal barriers, however, often prevent such
organizations from acquiring powers of taxation and enforcement. Development efforts will, again, be more successful if conceived and executed by means of a two-way dialogue with the prospective participants, by helping them to organize, and by working through such local organizations that are capable of collective action.

4.05 A holistic, probable-outcome, participatory design approach would necessarily focus, more than in the past, on the search for possible improvements within existing production systems. Elementary anti-erosion protection measures (Annex 2) have long been used by the Dogon people in Mali, the Kurumba in parts of northern Burkina, the Serer in Senegal, and others (Gallais and Sidikou:15-17; Marchal, 1982:II, 433-45; Raulin:25-38; Dongmo, J.-L.; Péllissier et Diarra:44-46; Péllissier, 1979:1-8). Such local practices, if more widely known, might offer clues to improvements within existing systems elsewhere. But while the approach to implementation should indeed be participatory, implementation cannot also be holistic, or integrated, except in those rare cases when inter-agency coordination works well. Provided participation is assured and the design is sound, implementation through existing separate, sectoral agencies will usually be preferable, for purely practical reasons, to attempts to mount integrated endeavors or to create new agencies.

Actions Defined with Respect to Pressure on Carrying Capacity

4.06 However fragile the data base, the ratio of actual population to carrying capacity under traditional production systems is a useful tool for assessing possible actions. That ratio (para 2.21) showed that for fuelwood, the actual exceeded the sustainable population in all except the Sudano-Guinean zone. For crops and livestock, the ratio was more varied according to zone. Specific action programs will have to be site-specific, since people's interests, aspirations and readiness for collective action are not identical and the physical conditions, even in apparently homogeneous areas, are not uniform. The following discussion illustrates possible actions by reference to the three types of ratio between RP and CC; throughout, it is important to bear in mind that: (a) both production potential and rainfall reliability decrease towards the north, and (b) although CC is not a static concept, it is only in the Sudano-Guinean zone that there is, today, any proven scope for increasing CC.

Areas Where RP Does Not Exceed CC

4.07 In such areas in the south, everything is to be gained by increasing population. Not only is there excess CC under traditional production systems, but also there is great scope for increasing CC by more intensive methods. In the north, however, the most effective approach to maintaining renewable resources will be to rely on traditional production systems and to strengthen local organizations. This approach requires careful attention to the possible destabilizing effects of contemplated investments, notably in pastoral water supplies. It also requires that the authority of existing local organizations not be undermined, and this may entail giving formal legal recognition to groups whose authority is now informal. In the present state of knowledge, the scope for actually increasing CC is negligible, but two ideas are worth pursuing:
(a) **improvement of bushfallow.** The main goal of fallowing is to promote natural regeneration as rapidly as possible, both to protect bare soils against erosion and to re-establish fertility. The greatest returns to fallowing, measured by regeneration of fertility, occur in the first five years (Gorse, BDPA, 1973). If this period could be shortened by providing ground cover (with multipurpose trees/shrubs/bushes, preferably nitrogen-fixing, and grasses), carrying capacity could be increased.

(b) **forest parks,** i.e., trees interspersed as a protective canopy with crops, are a common feature of traditional production systems. These could be rendered more productive by (re-) introduction of non-invasive, multi-purpose trees such as *Acacia albida.*

In the heartland, too, there are still areas where RP does not exceed CC and, to the extent that that gap exists, increased population can be contemplated. The increase could come from the natural growth of the resident population or even from settlement, but the CC limit would likely soon be met and, in such areas, there is no proven scope for increasing CC. Moreover, there are likely to be good reasons (and deserving investigation if not obvious) why RP is less than CC in particular localities in an otherwise densely populated area, especially when spontaneous settlers are moving far away into the Sudano-Guinean zone instead of into nearby underpopulated parts of the heartland. While there may well be cases where public investment in, for instance, water supplies from deep aquifers, may remove a constraint to increased population in parts of the heartland, such cases are not likely to be common.

4.08 **Forestry plantations** for wood production are conceivable wherever RP does not exceed CC, but the practical possibilities are extremely limited since several conditions must be met. In the north, moreover, there is as yet no viable technical package. In the south, the three conditions to be met are: (a) transport costs from plantation sites to consumption centers must be acceptable; (b) soils must be of at least fair quality (and poor soils may be the explanation for low population in specific sites); and (c) such plantations must be developed with the consent of neighboring people lest there be costly reactions such as "accidental" fires in the plantations. It may be possible to buy the acquiescence of the local people by creating jobs related to the plantations or to force compliance through strict policing, but both these solutions will involve considerable costs.

**Areas Where RP Slightly Exceeds CC**

4.09 In these areas, where land has supplanted labor as the major constraint, more intensive production will be more profitable. But the rainfall zones in which these areas are located do not have high potential, and the evidence suggests that cash inputs are just not sufficiently profitable in comparison to the reduction of fallow. This may yet happen, as resources become further squeezed (but see para 4.10). In the meantime, exhortations to intensify production are futile and the accompanying agro-bureaucracy is a waste. If the CC cannot be increased, at least its decline might be arrested and this can be attempted in a number of ways, with the main focus on increasing soil moisture storage capacity:
(a) bunding and rock-terracing, and other elementary anti-erosion measures (Annex 2);

(b) green manuring and use of animal manure, provided it is possible to get the organic content up to some significant level (1-2%) and keep it there;

(c) improvement of bushfallows, insofar as they still exist, as at para 4.07 (a);

(d) improving wells and well networks to facilitate grazing on under-exploited dry season pastures, provided such under-exploitation is verified and such improvements are coupled with locally-run grazing systems;

(e) forest parks, as at para 4.07 (b), but also live fencing, promoted by mass rural forestry actions;

(f) revision of the forestry code to remove disincentives to the planting of currently protected species; and

(g) participatory management of the natural forest cover to promote complementary rather than competitive exploitation of the woodstock; this would include organized harvesting by cutting, pollarding or coppicing trees and lopping branches during the period just before the rains when the sap has begun to rise in most species, in order to promote rather than hamper natural regeneration.

While little research has been done to explore the potential of indigenous tree species for regenerating soils in cultivated areas, recent innovative techniques based on tissue culture and symbiotic root micro-organisms may produce faster-growing and more drought-resistant exotic and local varieties (Annex 3). If this promise is borne out, the prospects for rural forestry would be greatly improved, particularly in those areas where population is not too far in excess of carrying capacity.

Areas Where RP Greatly Exceeds CC

4.10 In these areas, where the land constraint is overwhelming, anything that can increase land productivity should be readily adopted. The facts are that overall land productivity is declining, which simply means that the available intensification techniques are just not sufficiently profitable on a wide scale. Faced with these facts, people are opting to move away, notably from the Burkinabe Mossi Plateau and the Senegalese Groundnut Basin. But even in these areas, the total rural population is still increasing, and resource capital is being consumed for short-term survival.

4.11 A formidable task in these areas is simply to arrest the decline in carrying capacity. In some localities, where local organizations are or can be made effective, small watershed management plans might be executed and maintained satisfactorily. In other areas, bunding and terracing at least could be promoted, also with some public support. More generally, however, individual actions are more likely to be easier to promote than group activities. Such actions, already being undertaken in some areas, include:
(a) manuring and mixed farming. Keeping livestock in densely-settled regions will increasingly require stabling and provision of fodder and feed supplements. Training in these techniques should pay off. The efficient use of manure, through additives and composting, could also benefit from special training efforts. Indeed, as governments can no longer afford subsidies on chemical fertilizers and as fertilizer prices increase, manure is becoming an increasingly valuable product.

(b) intensified cropping. Although the record is not encouraging on a wide scale, there are impressive pockets of intensive farming. Elimination of any negative distortions in input and output prices can only encourage more intensified farming, but the scope for such corrective policies in the SSZ countries is more limited than is commonly supposed (para 4.29). Vegetable and fruit farming is already well developed around cities as well as in certain surprisingly remote areas. Such intensive production will be limited by the domestic market until more vigorous efforts are made to develop markets in the coastal cities and, possibly, in Europe.

(c) forestry. In the densely-settled areas, forestry will have to be modeled on the "four around" planting approach, in which every space available to support a tree is used. In some areas, local people have already gone some distance in this direction. Faster-growing and more drought-resistant stock, engineered through innovative techniques (Annex 3), should meet with good demand in many areas.

Increased Carrying Capacity via Irrigation?

4.12 Irrigation clearly has the potential to change carrying capacity dramatically. Even at a large irrigated farm size of 3 ha per family, and eight people per family, the carrying capacity would be about 250 per km²! Moreover, most of the potentially irrigable areas are along the Senegal, Niger and Logone/Chari rivers in the Sahelo-Sudanian zone, where the actual rural population already greatly exceeds the carrying capacity using traditional rainfed practices. Within this zone, however, the areas of densest population are still several hundred kilometers away from the potentially irrigable areas.

4.13 More important still, the realization and management of this irrigation potential is confronted by complex problems, and it will remain a slow process even if all the prerequisites are met. Small-scale irrigation is not really relevant in this context, despite its relative success, since the scope is limited by site requirements and it serves as a complement to existing activities rather than a substitute. The real potential lies rather in large-scale irrigation, but that is precisely where performance has been poor, as far as yields, farm incomes, cost recovery, and maintenance are concerned. Major efforts are currently envisaged to improve performance in these related areas, but success is far from certain. Until performance is substantially improved, investments in new large-scale perimeters cannot be contemplated.
4.14 Assuming that performance does improve and that new investments become warranted, practical problems will pose a tight limit on the pace of development. Even if this were to attain 20,000 ha per year by the mid-1990s, and assuming a small farm size of 1 ha per family of eight, the 160,000 people who could be accommodated each year would represent only one-half of the current annual increment in the populations of the Sahelo-Sudanian and Sudanian zones. At such a pace of development, highly optimistic in the light of recent experience, it would take over 50 years to accommodate the same number of people who could readily be settled in rainfed farming in the Sudano-Guinean zone, at significantly less cost. These considerations, and the still unproven prospects for improving performance in large irrigation perimeters, suggest that irrigation as a means of increasing carrying capacity should be considered a long-term, partial solution; in the short term, priority should be given to improving the poor performance on existing irrigated perimeters, precisely in order to overcome the obstacles to realizing the long-term potential.

Upgrading Competence

Research

4.15 At various points in this paper, attention has been drawn to the paucity of past research efforts, the limits to current knowledge, and the need for a holistic, probable-outcome, participatory design approach to the problem of resource degradation. Possible research orientations are outlined in Annex 3. 1/ Many are not new, and could be accommodated by reorienting or concentrating work programs of existing institutions. In two areas, however, some institutional change seems warranted: agrosylvopastoral systems, and forestry.

4.16 Agrosylvopastoral systems include both the traditional production systems, described at paras 2.06 to 2.12, and the numerous modifications to them that are taking place as actual population begins to overtake the sustainable population. As a result of considerable efforts over the last 25 years, the traditional production systems are today fairly well understood. The dynamics of such systems, and in particular how they adapt to population pressure, are not nearly so well known. The recently-initiated production systems research first concentrated on systems of crop farming; efforts were made to involve farmers as informants in order to understand the economic decision-making processes of farm households, but primarily with respect to crops. More recently, but quite separately, work has been undertaken on decision-making processes in the livestock sector (ILCA, 1983). Some recent studies have begun to examine the role of trees in the pastoral economy (JEPSS/ILCA, 1983), and to explore the crop/mixed farmer's perception of trees and livestock in addition to soils and crops. But these studies remain too diffuse, too sectoral, and too little known. To remedy these deficiencies, an

1/ A Bank working group is presently examining research priorities and methods throughout West Africa. This paper therefore does not go into the question of relative priorities.
agrosylvopastoral systems research unit could usefully be established in an existing research institution located in the SSZ.

4.17 In forestry, too, a unit with a regional mandate could usefully be established in an existing institution located in the SSZ. This is a more narrowly technical need to identify promising wood and fodder species, and to develop the biotechnologies required for improving the behavior of selected species. In both these areas, there is scope for fruitful international division of labor. Disseminating the findings of this unit should be the responsibility of the agrosylvopastoral systems unit.

Training

4.18 Staff training is still largely a sectoral business and farmer training, too, is still largely a matter of informing people about specific techniques. Neither form of training is really conducive to a holistic, participatory approach to resource management. The good initiatives that have already been taken have been more by luck than design. Design would entail the training of both staff and farmers, and perhaps above all of local leaders, in anti-desertification concepts and techniques. The content of such training cannot easily be specified, however, since future activities will depend to a large extent on information yet to be gathered on the adaptive capabilities of traditional production systems, and there will necessarily be much learning-by-doing. In addition, some of the more promising techniques will require legal and/or procedural changes and such techniques will not even be worth exploring until these changes are made. Activities will incorporate some standard techniques, but the particular mix suitable for a given setting will have to be defined by staff and local people as a result of a two-way communications process. In order for this to happen, however, staff will first have to be trained in communications (in contrast to dissemination), in the strengths and weaknesses of traditional production systems, and in facilitating the creation of local organizations.

Reducing Demand

Population

4.19 Current population growth rates clearly cannot be sustained for very long without a deterioration in living standards unless there is dramatic improvement in rural productivity, or non-rural (or foreign) employment opportunities. The magnitude of the problem is best grasped by expressing the comparison between actual and sustainable populations in terms of numbers (rather than densities as at Table 3 above).
Table 4: Actual and Sustainable Numbers of People

<table>
<thead>
<tr>
<th>Zone</th>
<th>Crop/Livestock Sustainable Population</th>
<th>Actual Rural Population</th>
<th>(1 - 2)</th>
<th>Fuelwood Sustainable Population</th>
<th>Actual Total Population (3 - 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(million)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Saharan</td>
<td>)</td>
<td>0.8</td>
<td>)</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>)</td>
<td>1.0</td>
<td>-0.8</td>
<td>1.0</td>
<td>-1.7</td>
</tr>
<tr>
<td>Sahelian</td>
<td>3.9</td>
<td>3.9</td>
<td>-</td>
<td>0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>8.7</td>
<td>11.1</td>
<td>-2.4</td>
<td>6.0</td>
<td>13.1</td>
</tr>
<tr>
<td>Sudanian</td>
<td>8.9</td>
<td>6.6</td>
<td>2.3</td>
<td>7.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>13.8</td>
<td>3.6</td>
<td>10.2</td>
<td>7.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Total</td>
<td>36.3</td>
<td>27.0</td>
<td>9.3</td>
<td>20.9</td>
<td>31.0</td>
</tr>
</tbody>
</table>

Quite apart from the already overburdened fuelwood resources, the apparently comfortable margin of nine million people in farming is deceptive. Even if the rural population increases by only 2% per year, the rural population in the year 2000 will exceed 40 million, as against a total sustainable rural population of 36 million. The latter figure does not take account of proven productivity gains obtainable in the Sudano-Guinean zone, but nor does it take account of the declining productivity in the already over-populated zones or the tsetse fly constraint on livestock in the Sudano-Guinean zone. The overall effect of these three factors could well be positive, but even if the sustainable rural population were as much as 50 million, at 2% per year that level would be reached as soon as 2010.

4.20 However delicate, the population question can no longer be avoided. The most appropriate path will be to follow the one of least resistance, i.e., working first or even only in those areas where a demand for family planning already exists, and stressing above all the possibilities for child spacing as a way to reduce overall population growth. Historically, too, child spacing was practiced in many SSZ societies. The most appropriate methods will be male contraceptives and oral contraceptives for women, thereby avoiding the medical services required with barrier methods, abortion, or sterilization.

4.21 Resettlement has a long tradition in the SSZ countries. Today, spontaneous migration into the Sudano-Guinean zone, although little known or understood, far exceeds the numbers of people being resettled under government-sponsored schemes. The latter have proven to be costly per family settled, and may not even have had any net impact on the total number of settlers. On the other hand, spontaneous migrants tend to destroy vegetative cover unnecessarily, thereby undermining the more cautious approach to resource husbandry of long-term residents. In addition, there are severe difficulties facing would-be settlers in the Sudano-Guinean zone, notably human and animal diseases as well as pests and predators unknown further...
north, lack of infrastructure in difficult terrain, and the relative fragility, after clearing, of soils under forest cover particularly in hilly areas. Given these problems, yet the unquestionable potential of the Sudano-Guinean zone to relieve population pressure further north, at least for the next two decades, it is surprising that settlement policies have not attracted more attention; nor are they even high on the policy agenda today. Here is a real challenge to governments and the donor community, to find answers to the following questions:

(a) what sorts of readily enforceable land-use regulations should be put in place to promote sustainable settlement in those parts of the Sudano-Guinean zone to which spontaneous migrants are moving?

(b) what further role, if any, can the public sector usefully play to encourage settlement into the Sudano-Guinean zone? What might be done via a land-use planning approach, whereby the location of investments in roads, wells, medical facilities and schools would be selected to favor those areas - and within them, those villages - suitable for reception of spontaneous settlers; in particular, what special health programs should be envisaged in these disease-prone areas?

Wood

4.22 The SSZ countries are already consuming far more than the total fuelwood output of the accessible natural forest cover; they are fast cutting into the capital stock of trees, and this is true in every zone except the Sudano-Guinean. The effects are most clearly in evidence in the vicinity of the cities. Reducing urban wood consumption is imperative and can in principle be achieved through more efficient techniques, greater reliance on other fuels, and more realistic pricing.

4.23 More efficient techniques are available but their acceptability is not yet proven. The cuisine of the SSZ consists mainly of simmered stews, sauces and grain porridges, whose preparation requires slow cooking and a great deal of wood with the traditional "three-stone" stove. More efficient stoves are now available and are being tested, but the results are not yet conclusive. The use of charcoal is not yet widespread, with the exception of Dakar and the larger towns of Mauritania. But as distances to fuelwood increase, transport costs will work in favor of charcoal rather than wood. Carbonization of wood consumes much energy, and known higher-yield conversion techniques, such as the improved Casamance kiln, should be promoted in order to improve charcoaling efficiency.

4.24 Building poles used in SSZ countries for traditional construction jobs are not fully termite-proof, especially poles cut from exotic, fast-growing tree varieties. Chemical treatment of building poles would increase their useful life, reduce consumption and thereby contribute to maintaining the natural forest cover. Creosote, one of the by-products of the carbonization process, can be easily collected from the Casamance-type earthen kilns, and could be used to treat building poles.

4.25 Other domestically-produced fuels offer disappointingly limited possibilities. Crop and animal residues, which are already used for fuel in
many areas, offer no great scope since they are also in demand for forage, mulching, fertilizing, etc. Introduction of solar energy and biogas is subject to severe technical limits. Petroleum exploration has not yet revealed much promise, although even a small field could suffice to warrant a small refinery, such as the one under consideration in Chad. Modern fuels such as kerosene, gas and electricity are, however, already used in urban areas, but they still remain beyond the reach of most urban households. This situation will not change unless local petroleum or hydropower can be produced at significant cost savings over current sources of supply. On the other hand, as urban fuelwood prices continue to rise as transport distances increase, the relative costs of kerosene and gas are likely to improve and further substitution for fuelwood can be expected.

4.26 Pricing of fuelwood and charcoal in all SSZ countries is determined primarily by the market. Apart from sporadic but ineffective urban retail price controls, the only public intervention is at the level of fees for cutting. Manipulation of these fees would have direct repercussions on retail prices. While nothing is yet known about demand elasticity or about cross elasticities, a sustained increase in cutting and transport fees would necessarily promote some economies in the use of fuelwood and, possibly, some substitution by other fuels. Pricing of the other fuels, except for the crop and animal residues, is regulated either directly or by taxation. Since this regulation is effective, there is scope for adjusting prices of substitutes, notably by holding down the kerosene or gas prices or even cross-subsidizing them.

The Policy Environment

Land Law

4.27 It is often suggested that communal tenure is the norm in West Africa and that individuals therefore have little incentive to make any long-term on-farm investments. This argument is questionable on three counts. First, the term "communal tenure" is used very loosely to cover different forms of ownership (by a chief, by a lineage...) and, more important, different forms of management (by entire groups, by representatives on behalf of group members, by individuals...). Second, given this diversity, it follows that not all forms of communal tenure entail disincentives for long-term investments. Third, the situation today is evolving: some tenure systems which were "communal" in the past have remained so, while others have evolved to accommodate increasing degrees of individual ownership and management control. In these latter areas, restrictions on sale of inheritable family lands may still apply, as in the northern Mossi Plateau in Burkina. But in other areas land has been sold for half a century or more, and can be mortgaged and loaned as well as inherited: all these types of transactions occur in the Hausa areas of southern Niger. The diversity and changes in "communal" tenure suggest, therefore, that lack of individual tenure is not a widespread impediment to long-term on farm investments, although it does apply in some areas. Furthermore, tenure need not be individual to be secure, since much depends on the kind of land use that is to be promoted (or revived). The clearest case is in the desert-fringe areas, where rainfall uncertainty entails that security can only be found in mobility, which implies some communal form of tenure. In such areas, what was
formerly a closely-controlled, regulated commons has been transformed, essentially by the provision of public wells, into an open access property from which no would-be user can be excluded; the prospects for sustainable resource management have thereby been diminished. It is therefore important that in framing land law, the distinctions between types of communal tenure be clearly recognized, and that those most conducive to sustainable resource management be promoted.

4.28 Although the general purpose of land law is to provide security, the present situation in SSZ countries is characterized by much uncertainty. The uncertainty arises not so much at the level of the content of land statutes but at that of the interface between the statutes and local rules: which will take precedence when conflicts arise, and how? Such uncertainty has particular implications for resource management, since many of the actions that can be taken to prevent degradation - anti-erosion works, forestry - will not have high short-term payoffs. Similarly, local organizations cannot be effective at managing their natural resources unless their powers have been clearly established. Land statutes in the SSZ countries have undergone little change since before independence, except for the broad provision that all land belongs to the state. Meanwhile, the population has nearly doubled and land is increasingly scarce. It seems opportune for governments to review their land statutes, and the case law developed in local courts, to see whether the statutes and/or the practice could be made more relevant to the promotion of sustainable resource management. In particular, the appropriateness of statutes vesting in the state residual control over all land should be re-examined; and while the principle of eminent domain must be upheld, the establishment of unambiguous procedures for expropriation and compensation is long overdue.

Incentives

4.29 The direction and to some extent the pace of the desertification process will be determined by the incentives provided to the rural population. To the extent that input and output prices for crops and livestock do not encourage more intensive production, desertification will proceed as a consequence of widespread extensive production methods. Although no trend analysis of effective protection coefficients is available for the SSZ countries, two generalizations are may be advanced for the last ten-year period:

(a) groundnuts and cotton have been less and less heavily taxed, and that incentive effect has more than outweighed reduced input subsidies; and

(b) millet and sorghum were never heavily taxed, and insofar as public marketing agencies endeavored to depress prices, they were not particularly effective; but input subsidies have been reduced and the net effect has probably been to reduce incentives for millet and sorghum production. On the other hand, rice prices which were effectively depressed have been allowed to rise considerably, and this must have had some impact on millet and sorghum prices, too. The effects of undue dumping of food aid are hard to assess, but here too, SSZ countries have begun to take action in the last few years to boost the selling price of food aid.
Overall, it is fair to say that the incentives for intensive production have clearly improved, although the cereals situation varies from one country to another. No longer can it be claimed that significant distortions in crop and livestock production incentives are impeding anti-desertification activities. The real problem now is that the intensive techniques or packages are just not sufficiently productive, below the 800 mm isohyet, to make their widespread adoption worthwhile. \footnote{That is, at current exchange rates. At a higher cost of foreign exchange, the return to intensive techniques will increase since all outputs are traded (or are substitutes for tradables) whereas not all inputs are traded. A perverse effect of a devaluation, however, would be that domestic fuelwood would become cheaper relative to imported fuels.}

4.30 By contrast, improvements in incentives can be envisaged in forestry and land matters. The natural forest cover is essentially a free good, and permit fees have often remained unchanged since before independence. Exploitation rather than investment is the rule. There is now a good case for a dramatic increase in permit fees for wood cutting and/or transport in order to: (a) encourage more efficient use of wood, as well as make wood substitutes relatively more attractive; (b) encourage investment in tree-planting; and (c) generate income for forestry services. A dramatic increase in permit fees would not imply a proportionate increase in retail prices: with a permit fee of CFAF 35 per stere in Niger, the urban retail price for fuelwood is currently CFAF 5500 per stere. A thirty-fold increase in the permit fee would yield not much more than a 20% increase in the retail price. Pasture and even cultivable lands are also often treated as free goods under current policies, whereby wells are often mistakenly sunk to permit access to ostensibly unexploited rangeland, and settlers in the less densely-populated areas are not subject to any land-use guidelines. In both these cases, legal incentives would help by offering land rights in exchange for management responsibilities.

4.31 Compensation. In respect of elementary anti-erosion measures in general, and of contour bunding in particular, it is often argued that the initial works should be subsidized since the benefits are long-term. A typical approach is to provide mechanical services as a capital grant and food-for-work as remuneration for beneficiaries' manual labor. Such compensation devices do, however, have unintended consequences which show up either in lack of maintenance or in disruption of local incentive systems. In many cases, anti-erosion works are not enough, and changes in existing land management practices are also required. Thus contour bunding should be accompanied by contour ploughing. But where land is held in plots running up and down the slope, it will be difficult to get everybody organized to work across the slope; unless this is achieved, the bunds will be subject to undue erosion, and maintenance requirements will multiply. Such maintenance may or may not be undertaken, but experience suggests that often it will not. While the causes of lack of maintenance have to be investigated for specific sites, there may well be a common cause: the initial subsidy may have induced the undertaking of works that are not worth maintaining (in the absence of a maintenance subsidy). Initial works subsidies may also disrupt local incentive systems by: (a) over-compensating labor, flooding inelastic local
markets and depressing prices, even to the extent that the net compensation effect is negative; or (b) rewarding investment - penalizing maintenance - and thereby creating precedents so that people will bargain for similar rewards for future investments. The key point here is that, while there is in principle a case for subsidies on initial works, the consequences should be fully thought out lest the unintended, negative consequences prevail.
V. IMPLICATIONS FOR ACTION

For CILSS

5.01 The above chapter has outlined the elements of a strategy rather than a strategy, in part because local situations are not homogeneous and in part, too, because there has been little debate within governments, or between governments and financiers, on what can be done about desertification. A beginning of such debate was made in 1984 – at Maradi in May, Dakar in July, and Nouakchott in October – but it must be further encouraged; this is clearly an important task for CILSS, to promote discussion at the regional and then national levels, with wide participation of all interested financiers.

For Governments

5.02 For governments, a considerable array of actions is suggested by the foregoing discussion of elements of a strategy. Some governments have already taken action on some of these elements and, because of differing resource endowments, not all elements are open to all governments; neither Mauritania nor Niger has any territory in the Sudano-Guinean zone. In general, however, little progress has been made toward better resource management and governments should systematically reflect on, and select for action from, all available approaches. These approaches go beyond the responsibilities of any one technical ministry, which suggests that the responsibility for reflection and action should be vested in a central authority, in the Prime Ministry or the Presidency. Indeed, desertification has not only demographic, social, technical, and economic dimensions, it also has a political dimension. Since solutions will have to be sought by a participatory approach to better resource management, this will require the political will to: (a) delegate authority from central government to local decision-making bodies, and (b) change laws, regulations, policies and prices to increase the incentives for better resource management.

5.03 The priority areas for action by governments are those that, in combination, set the incentive framework for the day-to-day decisions of millions of decision-makers. Such areas for action are at (a) to (f) below:

(a) land law and practice, including the forestry code, should be examined to identify, and act upon, changes required to increase the incentives for sustainable resource management. This examination would be best done by a multidisciplinary task force reporting to the central authority;

(b) regulations and laws concerning social organization should be examined to identify, and act upon, changes required to reduce the barriers to the setting up or recognition of genuinely grass-roots organizations, empowered to make and enforce rules, and raise revenue, for collective resource management. This task would also best be done by a multidisciplinary task force reporting to the central authority;
(c) population control measures should be initiated. Such activities may appear to be unpalatable but need not be politically risky provided the focus is initially on satisfying existing demand;

(d) in a land-use planning framework, settlement policies should be re-examined, in the direction of support to and promotion of sustainable spontaneous settlement instead of organized colonization. This would be another task best done by a multidisciplinary task force reporting to the central authority;

(e) performance in existing irrigated perimeters has to be improved by, among others, de-controlling output marketing, input supply and on-farm management, and introducing full-cost pricing of operation and maintenance services. Quite apart from the need to reduce the fiscal burden, the enormous potential for increasing carrying capacities via irrigation cannot begin to be tapped through new perimeters until existing perimeters are made more sustainably productive;

(f) price incentives have to be moved even further in the direction of encouraging more intensive production techniques, and the market displacement effects of food aid have to be even further reduced. There is an overwhelming case for a dramatic increase in permit fees for cutting fuelwood, but there is no case for intervention in retail prices or in marketing. There is a good case for cross-subsidizing the most likely substitutes for fuelwood - kerosene and gas - from revenue raised on other petroleum products. While there is a case for subsidizing long-term measures such as elementary anti-erosion works, the consequences should be fully thought through lest the unintended, negative consequences prevail.

Within this incentive framework, successful development activities will be those which pay attention to:

(g) the ongoing participation of the key decision-makers - the beneficiaries - is crucial to both design and implementation. This requires a basic change in attitude of staff, from a deterministic top-down approach to one that is responsive to bottom-up opinion, and necessarily site-specific;

(h) the key to design is that the approach also be holistic, and based on probable outcomes. This approach should be applied to all development activities, starting in the most vulnerable area, the SSZ heartland. The key to implementation, provided participation is assured and the design is sound, is simplicity: implementation through existing, separate, sectoral agencies will usually be preferable to attempts to mount integrated endeavors or to create new agencies.
For Financiers in General

5.04 For financiers too, a considerable array of actions is envisageable, but much will depend on the actions selected as priorities by governments. For each of the priority action areas listed for governments at para 5.03, there are corresponding actions that financiers could take, ranging from technical assistance (a - land law and b - social organization), to pilot projects (c - population), to full-scale projects and/or sectoral adjustment (e - irrigation and f - price changes). In some areas, however, the actions that financiers might take are not entirely clear, notably (d - settlement). In this area, it is not clear how spontaneous settlement might be assisted beyond putting into place readily-enforceable land use regulations that offer land rights in exchange for management responsibilities. In other areas - the approaches to design and implementation (g and h) - one problem for financiers is that the outcomes are uncertain, or at least appear to be more uncertain than in conventional projects. Some financiers will be more easily able to accept such uncertainty than others, and/or to put in an unusually high supervision effort to offset it. The others by contrast might more easily be able to contribute to rural development funds, from which the particular activities identified by others' design teams could be financed. Whichever actions are selected by individual financiers, moreover, the impact will be greater the closer is collaboration among financiers. Clearly, too, it is important that those governments who choose to take serious action be seen to be supported by the financiers as a whole.

5.05 A further area for action by financiers is in research, and of four kinds:

(a) support to national or international agencies in pursuit of the research orientations outlined at Annex 3;

(b) support to the institutional changes, outlined in paras. 4.16 and 4.17, for an agrosylvopastoral systems research unit and a forestry research unit to the established within existing agencies located in the SSZ;

(c) studies on broad aspects of desertification: (i) a study by consultant climatologists and others to examine the proposition that there is now a trend towards increasing aridity (para 1.04); (ii) a continuing study, aiming further than the recent CILSS initiative for assessing output, to monitor the quality of resources over time, using satellite imagery and aerial photography as well as ground-truthing (which should involve the ultimate beneficiaries), with the dual objective of preparing more disaggregated estimates of carrying capacities, and devising more effective land use management practices and supporting measures;

(d) a specific study on the reasons for non-adoption of improved techniques in projects in the SSZ heartland. The Dosso project (para 2.21c) was based on the results of a successful pilot project; although rainfall in the project period since 1980 was notably lower than during the pilot project (1975-78), when the "good rains" appeared to signal a return to pre-drought
conditions, this explanation of the failure of the Dosso project is not entirely convincing. A more plausible explanation is that benefit:cost ratios of 2.5:1 or even better in average years are just not sufficient to induce widespread adoption, where the risk of lower-than-average years is high. If so, it is important to examine how the threshold benefit:cost ratio varies with rainfall variability; if a ratio of 4:1 is required at a rainfall coefficient of variation of 25%, then research should focus only on such breakthroughs and extension systems geared to crop intensification should be dismantled until such breakthroughs are discovered. Since the Bank's experience in the SSZ heartland is fairly limited, a study of this kind should include others' experience in the West African SSZ as well as experiences in similar conditions in East Africa.

For the Bank Group in Particular

5.06 For the Bank Group in particular, and bearing in mind strengths and weaknesses vis-à-vis other financiers, the priority areas for action are as follows:

(a) analyzing the needs and financing the costs of policy adjustments required to improve performance in existing irrigated perimeters. This is ranked as the first priority since, in addition to opening the door to investment in new irrigated perimeters and thereby increasing carrying capacities, better performance in existing perimeters would reduce the current, severe fiscal drain. Such work is presently in hand in the Senegal Valley and in the Niger Valley at Office du Niger, Mopti and in Niger;

(b) analyzing and financing the software required to promote spontaneous settlement, as well as the hardware required to implement a "land use planning approach" to guiding prospective settlers into the more promising areas. This could entail land use planning components of area development projects in the Sudano-Guinean zone, or free-standing settlement projects. Such work is not presently in hand;

(c) continuing to improve the operational rules and to finance rural development fund-type projects for funding particular activities identified by design teams. Such projects would be reliable disbursement mechanisms for many interested financiers who could not afford the overhead of organizing design teams;

(d) pilot projects, where grant funds were wanting, in population control, testing of manufacture and consumer acceptance of improved wood stoves, kerosene and gas burners, more efficient charcoaling techniques and building pole treatments, and fuelwood/charcoal marketing studies in order better to understand prevailing markets and to devise measures to reconcile private and public interests; and
(e) in the light of the disappointing results of the older Bank projects in the SSZ heartland, current projects include applied research components (e.g. Maradi in Niger) or are straightforward applied research projects (e.g., Koudougou in Burkina, and ODIPAC in Mali). These applied research initiatives were, however, designed in a rather piecemeal fashion, and a systematic review of what has been attempted, and obtained is required. This work is now in hand.

5.07 Let us all remember that the desertification process is slow and insidious, and that there are no quick-fix solutions.
ANNEX 1

STATISTICAL APPENDIX

TABLE A-1: Land Distribution by Climatic Zone

<table>
<thead>
<tr>
<th>Country</th>
<th>200m Saharan</th>
<th>200m-NLC b/ Sahelo-Saharian</th>
<th>NLC-350m Sahelian</th>
<th>350-600m Sahelo-Sudanian</th>
<th>600-800m Sudanian</th>
<th>800m Sudano-Aridian</th>
<th>Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senegal</td>
<td>-</td>
<td>1.4</td>
<td>11.5</td>
<td>37.5</td>
<td>20.0</td>
<td>30.2</td>
<td>19.6</td>
</tr>
<tr>
<td>Mali</td>
<td>55.3</td>
<td>11.4</td>
<td>5.8</td>
<td>9.9</td>
<td>5.1</td>
<td>12.5</td>
<td>124.0</td>
</tr>
<tr>
<td>Niger</td>
<td>65.0</td>
<td>12.2</td>
<td>12.1</td>
<td>9.8</td>
<td>1.0</td>
<td>-</td>
<td>126.7</td>
</tr>
<tr>
<td>Burkina</td>
<td>-</td>
<td>1.0</td>
<td>4.9</td>
<td>31.9</td>
<td>31.8</td>
<td>30.5</td>
<td>27.4</td>
</tr>
<tr>
<td>Mauritania</td>
<td>76.2</td>
<td>16.1</td>
<td>5.5</td>
<td>2.1</td>
<td>0.1</td>
<td>-</td>
<td>103.1</td>
</tr>
<tr>
<td>Chad</td>
<td>52.1</td>
<td>7.1</td>
<td>10.4</td>
<td>9.9</td>
<td>13.1</td>
<td>7.5</td>
<td>128.4</td>
</tr>
<tr>
<td>Gambia</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>62.8</td>
<td>37.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>55.9</td>
<td>10.5</td>
<td>8.5</td>
<td>10.5</td>
<td>7.1</td>
<td>7.5</td>
<td>530.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33.6</td>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>

\[a/\] Climatic zones defined by isohyets with 0.9 probability.

\[b/\] Northern limit of cultivation.

Source: FAO, 1976:I, 47-49, citing FAO, 1970 *An Agro-Climatology Survey of Semi-Arid Area in Africa South of the Sahara*, of which the main authors were J. Cochemé and P. Franquin.
TABLE A-2: Land Distribution by Soil Suitability

<table>
<thead>
<tr>
<th>Country</th>
<th>Surface Area (million ha)</th>
<th>Suitable for Farming</th>
<th>Soil Classification a/</th>
<th>Cultivated Area 1970</th>
<th>Suitable for Livestock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
<td>II &amp; III</td>
<td>IV</td>
<td>I</td>
</tr>
<tr>
<td>Mauritania</td>
<td>103.1</td>
<td>2.1</td>
<td>0.7</td>
<td>1.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Mali</td>
<td>124.0</td>
<td>14.2</td>
<td>4.0</td>
<td>7.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Niger</td>
<td>126.7</td>
<td>10.8</td>
<td>1.7</td>
<td>8.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Chad</td>
<td>128.4</td>
<td>19.8</td>
<td>5.6</td>
<td>13.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Senegal</td>
<td>19.6</td>
<td>6.3</td>
<td>0.8</td>
<td>4.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Gambia</td>
<td>1.1</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Burkina</td>
<td>27.4</td>
<td>8.9</td>
<td>0.7</td>
<td>7.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>530.3</td>
<td>62.7</td>
<td>13.9</td>
<td>43.1</td>
<td>5.7</td>
</tr>
<tr>
<td>%</td>
<td>100.0</td>
<td>11.8</td>
<td>2.6</td>
<td>8.1</td>
<td>1.1</td>
</tr>
<tr>
<td>%</td>
<td>100.0</td>
<td>22.2</td>
<td>68.7</td>
<td>9.1</td>
<td>19.6</td>
</tr>
</tbody>
</table>

a/ I = Suitable for irrigated cultivation.  
II & III = Fair to good for rainfed cultivation.  
IV = Marginal for rainfed cultivation.

Source: FAO, 1976:1, 47-49, 94.
TABLE A-3: Soil Suitability by Climatic Zone

<table>
<thead>
<tr>
<th>Zone</th>
<th>Sahelian</th>
<th>Sahelo-Sudanian and Sudanian</th>
<th>Sudano-Guinean</th>
<th>TOTAL</th>
<th>(thousand ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Rainfall</td>
<td>(NLC-350mm)</td>
<td>(350-800mm)</td>
<td>(above 800mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mauritania</td>
<td>479</td>
<td>737</td>
<td>130</td>
<td>606</td>
<td>-</td>
</tr>
<tr>
<td>Mali</td>
<td>1,923</td>
<td>468</td>
<td>249</td>
<td>1,908</td>
<td>2,868</td>
</tr>
<tr>
<td>Niger</td>
<td>890</td>
<td>4,226</td>
<td>-</td>
<td>860</td>
<td>4,694</td>
</tr>
<tr>
<td>Chad</td>
<td>710</td>
<td>2,302</td>
<td>184</td>
<td>3,243</td>
<td>7,031</td>
</tr>
<tr>
<td>Senegal</td>
<td>212</td>
<td>514</td>
<td>16</td>
<td>370</td>
<td>2,230</td>
</tr>
<tr>
<td>Gambia</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>266</td>
<td>50</td>
</tr>
<tr>
<td>Burkina</td>
<td>-</td>
<td>376</td>
<td>-</td>
<td>423</td>
<td>4,131</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4,214</td>
<td>8,623</td>
<td>579</td>
<td>7,245</td>
<td>21,610</td>
</tr>
<tr>
<td>%</td>
<td>7</td>
<td>13</td>
<td>1</td>
<td>12</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>13,416</td>
<td>32,056</td>
<td>17,241</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total %</td>
<td>21</td>
<td>51</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II = Suitable for irrigated cultivation.
III = Good and fair for rainfed cultivation.
IV = Marginal for rainfed cultivation.

### TABLE A-4: Current and Projected Population in the SSZ

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauritania</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
<td>24.0</td>
<td>8.6</td>
<td>3.1</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Mali</td>
<td>1.2</td>
<td>6.7</td>
<td>5.6</td>
<td>19.0</td>
<td>5.5</td>
<td>3.0</td>
<td>13.0</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>Niger</td>
<td>1.3</td>
<td>5.5</td>
<td>4.2</td>
<td>13.0</td>
<td>6.8</td>
<td>3.2</td>
<td>10.0</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Chad</td>
<td>1.3</td>
<td>4.5</td>
<td>3.5</td>
<td>19.0</td>
<td>6.5</td>
<td>2.3</td>
<td>7.0</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Senegal</td>
<td>0.2</td>
<td>5.7</td>
<td>28.5</td>
<td>34.0</td>
<td>3.3</td>
<td>2.9</td>
<td>10.0</td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td>Gambia</td>
<td>(10,000 km²)</td>
<td>0.6</td>
<td>60.0</td>
<td>19.0</td>
<td>5.0</td>
<td>2.8</td>
<td>1.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Burkina</td>
<td>0.3</td>
<td>6.2</td>
<td>22.1</td>
<td>11.0</td>
<td>3.8</td>
<td>2.6</td>
<td>10.0</td>
<td>33.3</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5.3</strong></td>
<td><strong>30.7</strong></td>
<td><strong>5.9</strong></td>
<td><strong>22.0</strong></td>
<td><strong>54.0</strong></td>
<td></td>
<td></td>
<td><strong>10.2</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Source:**
- IBRD background paper on the demographic situation in Sub-Saharan Africa, 1983.
- IDA in Retrospect, 1982.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Rainfall (\text{a/} ) (mm/yr)</th>
<th>Area (m²/ha)</th>
<th>Population (\text{b/} ) (million)</th>
<th>Density (Rural)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(%)</td>
<td>(±)</td>
<td>Rural</td>
</tr>
<tr>
<td>I Saharan (\text{c/} )</td>
<td>0-200</td>
<td>270</td>
<td>0.8</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51</td>
<td>0.80</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Very low population density,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>no forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II Sahelian (\text{c/} )</td>
<td>200-400</td>
<td>130</td>
<td>5.0</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24</td>
<td>4.85</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Low population density,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>low forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III Sahelo-Sudanian (\text{d/} )</td>
<td>400-600</td>
<td>20</td>
<td>5.7</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>5.15</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Medium population density,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>good forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV Sudanian A (\text{e/} )</td>
<td>600-1000</td>
<td>12</td>
<td>7.5</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.65</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>High population density,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>low forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V Sudanian B</td>
<td>600-1200</td>
<td>75</td>
<td>10.3</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
<td>8.95</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Medium, but growing population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>density, medium forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI Sudanian-Guinean</td>
<td>over 800</td>
<td>23</td>
<td>1.7</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>1.60</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Low population density,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>high forestry potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>530</td>
<td>31.0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.00</td>
<td>6</td>
</tr>
</tbody>
</table>

\(\text{a/} \) Rainfall bands are approximate since the basic data (population) were obtained by administrative unit. Area data by rainfall band differ from FAO 1976 data since the latter refer to isohyets with 90% probability.

\(\text{b/} \) Rural population defined as the difference between total and urban, with the latter defined as towns over 50,000.
c/ These two zones correspond to the Saharan, Sahelo-Saharan and Sahelian zones per FAO 1976.

d/ Area corresponds to only 35% of the FAO 1976 "Sahelo-Sudanian" zone.

e/ Cap Vert, Thiès, Diourbel and western Sine Saloum in Senegal, Gambia and Mossi Plateau in Upper Volta.

## TABLE A-6: Adjusted Distribution of 1980 Population

<table>
<thead>
<tr>
<th>Zone</th>
<th>Area</th>
<th>1980 Population</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m.ha)</td>
<td>Total (million)</td>
<td>Total (No./km²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rural</td>
<td>Rural</td>
</tr>
<tr>
<td>Saharan</td>
<td>296</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>56</td>
<td>1.0</td>
<td>2</td>
</tr>
<tr>
<td>Sahelian</td>
<td>45</td>
<td>4.0</td>
<td>7</td>
</tr>
<tr>
<td>Subtotal: Arid</td>
<td>397</td>
<td>5.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>55</td>
<td>13.1</td>
<td>23</td>
</tr>
<tr>
<td>Sudanian</td>
<td>38</td>
<td>8.1</td>
<td>21</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>40</td>
<td>4.0</td>
<td>10</td>
</tr>
<tr>
<td>Subtotal: Semi-Arid</td>
<td>133</td>
<td>25.2</td>
<td>19</td>
</tr>
<tr>
<td>TOTAL</td>
<td>530</td>
<td>31.0</td>
<td>6</td>
</tr>
</tbody>
</table>

### Notes:

- **a/** FAO, 1976 definitions, by isohyets with probability of 0.9.
- **b/** Table 1.
- **c/** Table A-5, adjusted as follows:
  1. Sahelian zone population allocated 20/80 to the Sahelo-Saharan and Sahelian zones here;
  2. Sudanian A zone population allocated 50/50 to the Sahelo-Sudanian and Sudanian zones here;
  3. Sudanian B zone population allocated pro rata with area, i.e., 17/75 added to the Sudano-Guinean zone to make up 40 million ha, 32/75 retained in the Sudanian zone to retain 38 million ha, balance of 26/75 added to the Sahelo-Sudanian zone which makes 52 million ha (not 55) because of the discrepancy in the arid zones area (400/397).
### TABLE A-7: Carrying Capacity with Traditional Rainfed Cropping Practices

<table>
<thead>
<tr>
<th>Zone</th>
<th>Cropped Land (m. ha)</th>
<th>Yield (t/ha)</th>
<th>Output (m. tons)</th>
<th>Sustainable Population (million)</th>
<th>Sustainable Population (No./km²)</th>
<th>Sustainable Population (rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahelian</td>
<td>2.2</td>
<td>0.3</td>
<td>0.7</td>
<td>2.8</td>
<td>6.2</td>
<td>5</td>
</tr>
<tr>
<td>Sahel-Sudanian</td>
<td>3.0</td>
<td>0.5</td>
<td>1.5</td>
<td>6.0</td>
<td>10.9</td>
<td>10</td>
</tr>
<tr>
<td>Sudanian</td>
<td>2.3</td>
<td>0.7</td>
<td>1.6</td>
<td>6.4</td>
<td>16.8</td>
<td>15</td>
</tr>
<tr>
<td>Sudano-Quinean</td>
<td>2.8</td>
<td>0.9</td>
<td>2.5</td>
<td>10.0</td>
<td>25.0</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10.3</strong></td>
<td><strong>6.3</strong></td>
<td></td>
<td><strong>25.2</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(a/\) One-sixth of area suitable for cultivation (Table A-1), based on an assumed 5:1 ratio between fallowed and cropped land (FAO, 1982:I, 100).

\(b/\) Based on assumed minimum per capita requirement of 250 kg of cereals per year (Le Houérou, 1977:26).

\(c/\) Inferred from total area per zone at Table 1.
### TABLE A-8: Carrying Capacity with Traditional Livestock Practices

<table>
<thead>
<tr>
<th>Zone</th>
<th>Pasture Land <strong>a/</strong> (m. ha)</th>
<th>Range <strong>b/</strong> (ha/SSU)</th>
<th>Sustainable Population <strong>c/</strong> (million)</th>
<th><strong>d/</strong> (No./km²) <strong>d/</strong> (rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saharan ❃️</td>
<td>50</td>
<td>20</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Sahelian</td>
<td>28</td>
<td>10</td>
<td>1.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>34</td>
<td>5</td>
<td>2.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Sudanian</td>
<td>19</td>
<td>3</td>
<td>2.5</td>
<td>6.6</td>
</tr>
<tr>
<td>Sudano-Guinean</td>
<td>19</td>
<td>2</td>
<td>3.8</td>
<td>9.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>150</strong></td>
<td></td>
<td><strong>11.1</strong></td>
<td></td>
</tr>
</tbody>
</table>

**a/** From Table 1.

**b/** Grazing area required to feed a Standard Stock Unit of 450 kg.

**c/** Based on assumed minimum herd requirement of 20 SSU to feed a family of eight people.

**d/** Inferred from total area per zone at Table A-1.

**e/** Including Sahelo-Saharan zone.

*Source:* Adapted from Strange (FAO, 1980:53) and Brown (1971).
TABLE A-9: Carrying Capacity of Natural Forest Cover

<table>
<thead>
<tr>
<th>Zone</th>
<th>Accessible NFC Growth a/</th>
<th>Demand b/</th>
<th>Sustainable Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m³/km²)</td>
<td>(m³)</td>
<td>(m³/head/yr.)</td>
</tr>
<tr>
<td>Saharan</td>
<td>0.01</td>
<td>0.03</td>
<td>0.5</td>
</tr>
<tr>
<td>Sahelo-Saharan</td>
<td>0.01</td>
<td>0.01</td>
<td>0.5</td>
</tr>
<tr>
<td>Sahelian</td>
<td>0.4</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Sahelo-Sudanian</td>
<td>6.5</td>
<td>3.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Sudanian</td>
<td>13.8</td>
<td>5.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Sudan-Guinean</td>
<td>14.1</td>
<td>5.6</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14.6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a/ Expressed per km² of total area of the zone (Table 1).

b/ The demand figures already reflect some energy substitution since crop and animal residues, kerosene and gas have to some extent replaced fuelwood.

Source: Adapted from Keita (FAO, 1982:8).
ANNEX 2

ELEMENTARY ANTI-EROSION TECHNIQUES

Increasing Organic Matter

1. Organic content of topsoils can be upgraded in several ways (Issa; Felker; Weber and Hoskins:1-17):

   (a) reintroduce or protect Acacia albida and many other indigenous tree species that fit in well with farming activities (such as mango, Moringa, Cordyla, karité, néré, tamarind, baobab, Borasus palm, Hyphaene thebaica, Parinari, and Balanites) around houses and compounds, along edges of vegetable gardens, and in farm fields;

   (b) rehabilitate, protect and develop natural gum arabic and Acacia spp. stands; and

   (c) promote sound farm management techniques including intercropping/mulching, crop rotation, tree crops, cover crops, use of manure and compost, rotational grazing, etc., for the restoration and protection of the soil.

Controlling Wind Erosion

2. Wind erosion control devices of the sort listed below can be created over time at relatively low cost and, if properly established, will greatly contribute to the stabilization of micro-environments (Weber and Hoskins:36-51; Pelissier, 1980):

   (a) windbreaks and shelter belts (Bognetteau-Verlinden);

   (b) live fencing;

   (c) palisades;

   (d) special seeding and planting (sand dune stabilization); and

   (e) roadside planting.

Controlling Water Erosion

3. If installations for water erosion control are properly set up and maintained, they can reverse erosion trends and maintain or increase soil fertility by trapping and retaining fine soil particles dislodged by moving surface water. They likewise facilitate water infiltration. If sufficiently numerous, they can maintain adequate soil moisture during "below average" rainy seasons, buffering the effects of drought. They may also contribute to the recharge of aquifers, now seriously threatened in the SSZ. Such installations include:

   (a) contour planting and farming;

   (b) vegetation strips;
(c) infiltration ditches;
(d) berms;
(e) terraces;
(f) bank and slope protection projects, including micro-watersheds;
(g) small check structures;
(h) small dams (Hooper);
(i) bunding; and
(j) rock terracing.

Harvesting Water

4. Surface water conservation should be seen as an extension and reinforcement of water erosion control installations. Whether they contribute to soil moisture and aquifer recharge, or prolong the growing season in selected areas by making dry season water available for gardening, they enhance the value of soils as a renewable resource. Most important among such devices are:

(a) mini-catchments;
(b) waterspreading; and
(c) small reservoirs.

Controlled Bush Fires and Early Burning

5. The vegetation of the West African savannah is considered by ecologists to be a "fire-climax". The influence of fire on the vegetation is particularly important in the Sudano-Guinean zones, and ground vegetation is dominated by perennial grasses. This area is often burned deliberately by:

(a) farmers clearing their fields of crop residues;
(b) farmers wanting to produce ash for fertilizer, a practice that brings about changes in soil chemistry associated with nitrogen-fixing bacteria;
(c) herdsmen and farmers seeking to destroy ticks and other disease-bearing organisms;
(d) herdsmen wanting to stimulate fresh and high-quality regrowth of perennial grasses at the end of the dry season; and
(e) hunters flushing out game.

A complete ban on deliberate burning, even if it were possible, would eventually result in an undesirable accumulation of combustible material and insect pests. All burning, however, destroys soil humus to some extent, and
capitalizing on the benefits of fire while minimizing its damage presents a challenge.

6. Controlled burning can take two forms:

(a) early burning, soon after the rains stop. The accumulation of combustible material is gradually reduced, and the relatively cool burn encourages new growth on trees and shrubs. The practice destroys grasses, however, that could be used for fodder or hatching; and

(b) late burning at the end of the dry season. The very hot fire that results destroys many dry trees and shrubs. This practice produces fresh and high-quality regrowth of perennial grasses, an advantage for cattle at the end of the dry season, when little feed is available.
ANNEX 3

RESEARCH ORIENTATIONS

Agricultural Research

1. Research on agricultural problems should give priority to the following five areas:

   (a) improved varieties of millet and sorghum, the staple crops of these areas;

   (b) techniques to maintain soil fertility and harvest water which will work in the marginal environments of the SSZ;

   (c) intercropping, including tree crops;

   (d) animal/plant associations in mixed-farming systems; and

   (e) low-cost pest control techniques.

2. Of these five, the first, improved varieties of rainfed staple crops, is the top priority, because these two crops account for two-thirds or more of the cultivated area in the SSZ. Some research in this area has been undertaken by ICRISAT, and by researchers working at Bambey in Senegal and Samaru in Northern Nigeria, but much remains to be done. In particular, research should focus on developing more drought-resistant varieties adapted to variable local rainfall conditions. Research should explore SSZ residents' strategies for intercropping varieties of different cycles, to take maximum advantage of the opportunities of any given season (rainfall patterns, associated pest and plant diseases, etc.).

3. Techniques for water harvesting and the maintenance of soil fertility must be improved through a combination of basic and applied research. Some relevant techniques have been known and utilized in the Sahelian and Sudanian zones for centuries, though most agricultural experts have only recently begun to accept their value (Richards, 1983). Minimum tillage, to avoid disturbing fragile soils, and such water-harvesting techniques as contour plowing, bunding, terracing and post-harvest cultivation to trap soil moisture and promote water infiltration at the beginning of the next rainy season, should receive particular attention. Such practices will work only if they can be fitted into existing patterns of labor demand within SSZ farming systems. Research, both basic and applied on these issues, must reflect a concern for labor constraints. Green manuring and chemical fertilization techniques must be adjusted to the fragile nature of the environment and to its low inherent potential. Actual placement of fertilizer, both chemical and organic, warrants attention. In addition, the scope for using natural revegetative mechanisms deserves examination.

4. Intercropping techniques, including tree/food crop associations, must be better understood. In most of the SSZ, a tradition of intercropping exists, and can form a basis for future development along these lines. Many farmers already understand the value of these practices, and also have an acute sense of the possibilities for improving yields while at the same time preserving soil fertility by appropriate associations.
Mixed farming systems, which have historically been practiced in most of the SSZ, should be strengthened and extended to new areas where possible. In the SSZ heartland, forage will be a serious constraint. Any attempt to increase the number of animals, particularly draft animals necessary to pursue many soil fertility strategies, will have to reckon with this likely shortage. Research should be undertaken into ways for producers to provide forage for their animals, either through better local pasture management or through production of multi-purpose crops on fields or fallow lands. Social implications of these changes will be important, particularly where transhumant herders have historically grazed their animals on crop residues, as is the case in much of the SSZ.

Pest management strategies that use low-cost, water-saving techniques should be thoroughly studied and adapted where possible to SSZ conditions. Again, traditional strategies in this area should be carefully studied for ways to overcome the constraints (cost, water availability, time) confronting SSZ farmers. Basic and applied research must, once again, be firmly guided by these constraints.

Forestry Research

Conventional approaches, such as the usual provenance testing or the use of cutting for vegetative propagation, are still useful, but the need cannot be stressed too strongly for innovative technologies that will lead to increased biomass production and improved tolerance of trees to environmental constraints. Two approaches already exist that can contribute to the improvement of the plant material and to the establishment of trees in the harsh Sahelian or Sudanian conditions by better use of available moisture and nutrients: the first is based on the use of plant tissue cultures, the second on the manipulation of symbiotic root microorganisms.

Special attention should be given at the outset to the choice of tree species able to withstand the major climatic and edaphic stresses (drought, fire, nutrient deficiencies).

The next step would be to undertake provenance testings or surveys aiming at identifying individual specimens (including trees) presenting the adaptability and the most desirable characteristics.

The third step would be to mass produce clones of the chosen individuals. When using vegetative propagation techniques, all regenerated plants (clones) are in theory exact duplicates of the original genotype. There are two main techniques: the one based on the use of rooted cuttings, the other based on the use of tissue cultures. A number of trees are propagated from rooted cuttings (e.g., Eucalyptus in Congo or Brazil; Casuarina funghuhniana in India and Thailand). This simple method should be applied wherever possible because of its low cost.

The term plant tissue culture is generally applied to all forms of plant cultures grown in vitro, ranging from undifferentiated single-unit protoplasts to complex multicellular and highly organized organ cultures.

Plant tissue culture methods can be used for mass propagation of a genotype selected for such highly desirable traits as rapid growth, shape,
palatability of leaves and twigs, resistance to drought or salinity, or high nitrogen-fixing ability. This technique, called micropropagation or clonal propagation, has the advantage of shortening the time necessary to reproduce a large stock of planting material from an individual specimen selected for its outstanding performance.

13. Plant tissue culture methods can be applied in a number of other promising areas such as disease control (meristem tip cultures to remove viruses from infected plants), long-term storage of germ-plasm and germ-plasm exchange, wide hybridization (e.g., in vitro pollinization and fertilization, fusion of somatic cells or protoplasts), production of haploid and homozygous breeding lines, variant selection (for resistance to drought, salinity,...).

14. It is now well established that symbiotic root microorganisms, (Rhizobium, Frankia and mycorrhizal fungi) can effectively contribute to tree productivity in marginal climatic and edaphic conditions. Since significant advances have been made recently in the manipulation of these microorganisms, it is now possible to contemplate their use in the field.

15. A number of trees have the potential for fixing atmospheric nitrogen through their symbiotic associations with Rhizobium (leguminous trees) or Frankia (nitrogen-fixing non-leguminous plants, now dubbed actinorrhizal plants). Promoting the nitrogen fixation capacity of these trees through inoculation with the proper symbiotic microorganisms or through selection of the plant host, is an elegant approach to making the forest ecosystem self-sufficient in nitrogen.

16. An effective symbiosis between trees and mycorrhizae (ecto- or endo-) is often beneficial and may markedly improve plant survival rates after transplanting by increasing the uptake of phosphorus and non-mobile microelements such as copper (Cu) or zinc (Zn) in deficient soils and by facilitating the water uptake under dry conditions.

17. Given the magnitude of the problem, it would be difficult to develop such an ambitious research program through the existing scattered and often under-equipped research centers. A real need therefore exists for a permanently staffed section in an international/regional center focusing on Sudanian and Sahelian zone tree and shrub species. Located in the SSZ region, this section would be the core of a network consisting on the one hand of African forestry centers and projects, and on the other of laboratories in industrialized countries wishing to participate in the improvement of the SSZ forest.

18. The main objectives of this forestry section would be:

(a) to identify the local and exotic tree species with the highest potential for wood and fodder production under SSZ conditions;

(b) to develop the biotechnologies required for improving the behavior and growth of selected species, these technologies being based on plant tissue culture or on the manipulation of the root symbiotic microorganisms; and
(c) to study the pathology (especially root pathogens such as nematodes) and some basic problems related to the physiology of selected trees (e.g., flower biology, resistance to drought and plant nutrition).

19. Associated laboratories from industrialized countries 1/ could contribute to this program by:

(a) providing periodic training for researchers focusing on the SSZ region; and

(b) developing methodologies for solving the practical problems raised by the selection and genetic improvement of trees and their associations with their root symbionts.

Pastoral Systems Research

20. Research must precede the preparation of development activities that focus on improving traditional production systems. This is as true of sylvopastoral systems as it is for agrosylvopastoral and agroforestry systems. Projects in these areas cannot succeed without detailed knowledge of the local context in which production occurs. Research into livestock production systems would contribute to overcoming obstacles that now plague livestock and other rural sector projects, i.e., inadequate planning because of imperfect knowledge of the constraints that influence producers' strategies, of the existing relationships among producers and of relationships between producers and government officials.

21. Pastoral systems research must explore three areas: (a) the inputs and outputs which determine continued production; (b) the economic, legal, social and political relationships that underlie production processes; and (c) the obstacles and opportunities facing different groups of pastoralists working in different settings. Those who share the same environment, but manage herds of differing species, age and sex composition, can be expected to adopt different pastoral strategies. Critical to adequate sylvopastoral project design is a clear understanding of these relationships and the incentives and constraints they present to individuals. This is the starting point for realistic negotiations with herders about ways in which development aid may improve their welfare.

22. As part of this research, open lines of communication can be established between project designers and implementers on the one hand, and pastoralists on the other. Pastoralists should be involved from the first stages of project design, furnishing ideas and evaluating proposals that will affect their lives if implemented. If they have already been involved in studies of production systems, as informants describing their own activities and the logic of their herding strategies, they will be much more likely to provide accurate information at the planning stage.

1/ Among the candidates are Texas University (US) and the University of Nice (France). NAS is currently planning the creation of an Institute that would be devoted to the study of Sahelian ecosystems.
23. The topics appropriate for applied production systems research will vary from place to place. They will certainly include, at different points in the SSZ, the following:

(a) current land tenure patterns in the pastoral zone, in terms of water and pasture property or usufructory rights;

(b) stock ownership patterns, and the extent to which it is possible to manipulate them by modifying government policies, including tax laws, and the extent to which it is desirable to do so;

(c) carrying capacity and maintenance requirements of different species, to examine the relative productivity of goats, sheep, camels and cattle;

(d) who currently sells stock in the pastoral zone, and in the agricultural zone, and why? Who doesn't and why?

(e) possibilities for enriching straw with chemical additives;

(f) the consequences of reallocating agricultural zone biomass available as forage from transhumant to farm animals, e.g., through stover stocking by mixed farmers seeking to ensure a reliable food source for their animals during the dry season;

(g) extent to which burning in the SSZ is: (i) an effective technique of pasture management; and (ii) a threat to environmental stability through destruction of soil humus, etc.; and

(h) extent to which pasture degradation is irreversible, justifying extreme measures to avoid it.


Contribution à l'étude de la désertification de l'Afrique tropicale sèche

(i) "Rapport de la mission forestière Anglo-Française-Nigeria-Niger (décembre 1936 - février 1937)."


(iv) Michon, P. 1973. "Le Sahara avance-t-il vers le sud?"


De Vries, Penning and Djiteye, editors. 1982. La productivité des pâturages sahéliens. Wageningen: Centre for Agricultural Publishing & Documentation.


Eicher, Carl K. 1982. "Facing up to Africa's Food Crisis". Foreign Affairs (Fall 1982).


Felker, Peter. 1978. *State of the Art: Acacia albida as a complementary permanent intercrop with annual crops.* Prepared for USAID; Riverside, California: Department of Soil and Environmental Sciences, University of California.


Monnier, Yves. 1981. La poussière et la cendre. Paris: ACCT.


1983. La participation, l'organisation locale, la politique d'utilisation des terres et du secteur forestier: orientations futures de la forêsterie sahélienne. Paris: CILSS.


- 62 -


No. 33. Guidelines for Calculating Financial and Economic Rates of Return for DFC Projects (also in French, 33F, and Spanish, 33S)
No. 34. Energy Efficiency in the Pulp and Paper Industry with Emphasis on Developing Countries
No. 35. Potential for Energy Efficiency in the Fertilizer Industry
No. 36. Aquaculture: A Component of Low Cost Sanitation Technology
No. 38. Bulk Shipping and Terminal Logistics
No. 39. Cocoa Production: Present Constraints and Priorities for Research
No. 40. Irrigation Design and Management: Experience in Thailand
No. 41. Fuel Peat in Developing Countries
No. 42. Administrative and Operational Procedures for Programs for Sites and Services and Area Upgrading
No. 43. Farming Systems Research: A Review
No. 44. Animal Health Services in Sub-Saharan Africa: Alternative Approaches
No. 45. The International Road Roughness Experiment: Establishing Correlation and a Calibration Standard for Measurements
No. 46. Guidelines for Conducting and Calibrating Road Roughness Measurements
No. 47. Guidelines for Evaluating the Management Information Systems of Industrial Enterprises
No. 48. Handpumps Testing and Development: Proceedings of a Workshop in China
No. 49. Anaerobic Digestion: Principals and Practices for Biogas Systems
No. 50. Investment and Finance in Agricultural Service Cooperatives
No. 51. Wastewater Irrigation: Health Effects and Technical Solutions
No. 52. Urban Transit Systems: Guidelines for Examining Options
No. 53. Monitoring and Evaluating Urban Development Programs: A Handbook for Program Managers and Researchers
No. 54. A Manager's Guide to "Monitoring and Evaluating Urban Development Programs"
No. 56. Action-Planning Workshops for Development Management: Guidelines
No. 57. The Co-composing of Domestic Solid and Human Wastes
No. 58. Credit Guarantee Schemes for Small and Medium Enterprises
No. 59. World Nitrogen Survey
No. 60. Community Piped Water Supply Systems in Developing Countries: A Planning Manual