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Opportunities and Constraints for Sustainable Development in Semi-Arid Africa

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1. INTRODUCTION

Too often environmental problems are treated simply within the limited, and narrow, scope of air and water pollution. In poor countries, however, depletion of natural resources is usually of greater importance than pollution in limiting sustainable development. Although society places a great deal of confidence in technological solutions to the problems of environmental unsustainability, socio-economic approaches may, in the end, be more effective in many situations.

In this paper, I will present a special application of systems analysis and modelling, combining both agro-ecologic and socio-economic approaches, that will allow a more rigorous analysis than the largely intuitive analyses common in the literature. This application provides a systematic approach to identify and classify obstacles to rural development, and to quantify the potential for sustainable use of natural resources. Using the Sahelian countries as an example, I will show that the necessary knowledge already exists to use natural resources effectively in Africa south of the Sahara Desert.

Nevertheless, existing knowledge is often poorly used, and that is why development of more intensive agricultural production systems for sustainable development is effectively promoted only in rare instances throughout the region. In semi-arid Africa, successful development of intensive agriculture requires optimal use of external inputs, due to unfavourable ecological conditions and to the existing social environment. Leguminous species and agroforestry techniques represent potential methods to optimize the use of fertilizers and other external inputs. Unfortunately, these agronomic techniques alone are insufficient for sustainable development of semi-arid Africa. Socio-economic policies of the countries concerned, as well as the environmental and trade policies of other countries with which they interact, must be modified to make such technological options accessible for local farmers.

2. APPROACH

Developing strategies to tackle problems related to environment and development, and identifying effective technological and socio-economic measures as building-blocks for such strategies, requires accurate definition and evaluation of the country's current environmental and developmental state. One useful method for countries or regions whose economy is based on agriculture focuses on analysing patterns and efficiency of natural resource use [*Breman, 1990a, b*].

The first step in this approach is to determine the maximum potential agricultural productivity at the carrying capacity of the existing resources for different forms of land use. That level of productivity is then compared with the actual productivity achieved by local production systems to establish whether resources are under-exploited, over-exploited or used optimally. In this analysis, systems analysis is used to determine the maximum level of sustainable production at the current level of inputs, and to identify the major constraints to optimal use of resources. Actual levels of production are derived from farming systems research, which should also identify the factors that lead to over- or under-exploitation of existing resources. Questions that farming systems research will address include: Is under-exploitation the result of ignorance or inequity? Is over-exploitation a consequence of irresponsible behaviour, of ignorance or of circumstances, such as overpopulation, that are beyond the control of the local population? What is the major constraint to increased carrying capacity of the natural environment: lack of skills, lack of interest in the future, lack of necessary means of production or lack of economic incentives to use them?

Answers to these questions are critical, since different intervention measures are required in all these cases to improve productivity. The role of technology may be particularly important in cases of existing or threatened over-exploitation caused by population pressure. But, even in those cases, 'environmentally sound technology' is not, by itself, a solution for sustainability, but only a '*conditio sine qua non*'.

3. KNOWLEDGE AVAILABILITY

Simply understanding the fragile ecosystems in the drier regions of tropical Africa provides sufficient basis for much more efficient land-use and development planning than many current approaches in widespread use. Two examples of indigenous production systems will be used to illustrate the profound understanding of the environment available even without citing scientific works.

Even before the word ‘agroforestry’ was introduced by Western science, farmers in West Africa planted *Faidherbia albida* to favour the growth of crops such as millet and sorghum [*CTFT, 1988*]. This leguminous tree is particularly valuable since it drops its leaves at the beginning of the cropping season, thus minimizing its competition for light with the crop.

The semi-nomadic pastoralists of West Africa have developed a livestock management scheme that achieves productivity levels up to 10 times greater than the levels achieved in arid regions of the United States and Australia [*Breman and De Wit, 1983*]. The pastoralists make intelligent use of the high-quality rangeland at the Sahara border to stimulate livestock growth as much as possible during the rainy season. Regrowth of perennials in flood plains and the savannah is exploited to maintain these weight gains as much as possible during the dry season.

Scientific knowledge is able to explain both the value of *Faidherbia albida* cultivation [*Breman and Kessler, in press*] and the pastoral techniques of the semi-nomadic peoples of West Africa [*Penning de Vries and Djitèye, 1991*]. Penning de Vries and Djitèye [*1991*] presented detailed knowledge about the principals of primary production in the semi-arid zone of West Africa. Breman and De Ridder [*1991*] used this knowledge to develop a procedural manual for evaluating rangelands and animal production in the region. Pieri [*1989*] gives a synthesis on crop production, while Wilson et al. [*1983*] review animal husbandry production systems. More specialized works treat, for example, erodability of soil surfaces [*Casenave and Valentin, 1989*], wood production [*Clement, 1982*], desertification [*Mabbutt and Floret, 1980*], management of rangeland [*Audru et al., 1987*] and of village grounds in general [*Anon., 1981*] and soil and water conservation [*Critchley et al., 1992*].

Comparably important data sets exist for other arid regions in Africa. The Integrated Project in Arid Land (IPAL) of UNESCO, for example, analysed the dry north of Kenya [*Lusigi, 1984*]; the Savannah Ecosystem Project addressed a South African nature reserve in detail [*Huntley, 1978*]; drier parts of Botswana were studied by the Free University of Amsterdam [e.g., *Tolsma, 1989*], and by the ILCA [e.g., *de Ridder and Wagenaar, 1984*].

One characteristic of semi-arid land is commonly known, namely, the limited and irregular rainfall. Other common features, which are often equally important, are sparse perennial plant life, poor soils, low plant biomass and productivity and low levels of soil organic matter. These characteristics are heavily interwoven, and together with climate form the basis for the fragility of the ecosystems.

Availability of knowledge is not synonymous with *use* of knowledge, as will be illustrated by two examples. The first has been taken from southern Africa, the other from the Sahel.

In an analysis of soil erosion in Lesotho, Showers [*1989*] concluded that

The direct result of the colonial Basutoland anti-erosion campaign was the collection and concentration of large amounts of previously unchanneled water. Inadequate design and amateur implementation of the engineering works resulted in the uncontrolled movement of this channelled water across the landscape after major storm events. . . . It is probable that most of the gullies in Lesotho are caused by the construction of contour ridges.

An important reason for the lack of success in developing and implementing strategies for socio-economic development of semi-arid regions is probably the fixation on drought. Scientists in Israel, the United States, South Africa and the Sahel have shown, however, that soil poverty is at least as important an obstacle as limited water availability. Boon and Trouw [*1986*] studied the influence that scientific research had on the way two respected Dutch newspapers reported about the Sahel. During the 15 years after the beginning of the recent drought in the region, which made the Sahel well known among the general public in the Netherlands, the newspapers published extensively on the results of scientific research, which implicated soil poverty, overpopulation and the economy as main constraints to socio-economic development. Nevertheless, these publications had no effect on the way the Sahelian problem was generally presented over the years: drought was and remained the wrong-doer. If similar perceptions dominate elsewhere in the world, it explains why suppression of subsidies on fertilizer became a general element of structural adjustment programmes in West Africa. It explains also the enormous investments in dams and irrigation schemes instead of in the cheaper and more effective approaches of improving soil fertility.

4. ANALYSIS

The approach presented in Section 2 was used to assess patterns of resource use for a number of countries in the Sahel. Carrying capacity was compared to population density, and those areas in which population density exceeded carrying capacity were characterized as 'overexploited'. The available socio-economic data were not always sufficient to determine whether over-exploitation resulted primarily from lack of knowledge, unequal access to resources, irresponsible behaviour, lack of alternative choices or some other cause. However, lack of choices due to over-population appears often to be the main cause of resource depletion in the southern Sahel, northern Sudan and elsewhere in Africa. Evidence to support this conclusions includes the following illustrative examples.

- The area of land used for arable farming exceeds the area of land considered either very suitable or suitable for cultivation, with 100% in North Africa and with 13% in (sub-)humid West Africa; both are equal in the Sudano-Sahelian zone [*Sombroek, 1993*]. Here and elsewhere in Africa, depletion of soil nutrients and erosion decrease the suitability of the land for agricultural development [*Stoorvogel and Smaling, 1990a, b*].
- The average population density of municipalities in the Sudanian savannah in south-east Mali is strongly correlated with the suitability of the land for agriculture. The lowest population density class (< 5 km^2) is found where rocks, shallow soils or soils with extreme textures dominate. The highest density (> 50 km^2) occurs on plains of loamy sands and floodplains [*Breman, 1990b*].
- The carrying capacity of rangeland in the Sahel as a whole has been estimated as 8 ha per tropical livestock unit for dry years. The stocking rate appeared much higher on the eve of the recent Sahelian drought, after decades of ample rainfall: less than 4 ha were available per livestock unit for the Sahel as a whole, which is the estimated carrying capacity for years with average rainfall. Starvation of more than one-third of the herds during the severe drought of 1972-1974 created a stocking rate near the theoretical carrying capacity for dry years. The overstocking that has been corrected by the drought can therefore be judged as inevitable. The average total land area available (300 ha per pastoralist family) is sufficient to provide a minimum subsistence income only if overstocked [*Breman and De Wit, 1983*].
- Figure 1 shows the natural production potential of West African soils in relation to rainfall. The growth rate of ruminants is highest on the high-quality rangelands near the desert border; arable farming is excluded in this zone. The optimum rainfall for annual cereal crops occurs in the Sudanian savannah zone, with its balance between water availability and nutrient losses due to run-off and leaching. Perennial crops, whose permanent root systems minimize the effects of low soil nutrient levels, can benefit from more rainfall, and achieve high levels of productivity in the humid tropics. The conditions for agricultural production and for human life are best in the

sub-humid Sudanian savannah, and it is precisely there that the highest population density is found.

- The estimated maximum carrying capacity, based on existing natural resources with no external inputs [*Breman, 1992*], is 1 person km^2 for nomadic pastoralism at the desert border, and 3 km^{-2} for sedentary animal husbandry in the savannah. A maximum sustainable population density of 7 km^{-2} can be achieved if the Sahel and savannah are shared by the semi-nomadic peoples combining these two subsistence strategies. Integrated land use, through arable farming and animal husbandry, can provide subsistence living for a maximum of 1, 11, 36 and 51 persons km^{-2} in the northern and southern Sahel, and in the Sudanian and Guinean savannahs, respectively. The actual average population density of the four regions is 1 (0-7), 13 (7-27), 33 (7-66) and 25 (with the range given in parentheses for different provinces of Niger, Burkina Faso and Mali, respectively). These data suggest that over-population already appears to be a reality in large parts of the southern Sahel and the Sudanian savannah. In these areas, only arable farming has the potential to nourish the population adequately. In those cases, animal husbandry is subordinated to crop production, with animal labour and manure production as its primary goals.

5. INTENSIFICATION OF AGRICULTURE: PRINCIPALS AND PROBLEMS

Intensification of agriculture becomes a must when over-population leads to over-exploitation of resources, particularly when migration is unfeasible, sources of income outside agriculture are scarce and the creation of alternative employment is economically less feasible. In such cases, external inputs are needed to offset the loss of soil nutrients and to increase the potential productivity of the existing natural resources. This implies that a change is needed in production systems, from self-sufficiency to market-oriented strategies.

A critical question is what inputs are needed, and when and where. The project Primary Production Sahel (PPS) addressed this question for semi-arid and sub-humid West Africa [*Penning de Vries and Djitèye, 1991*]. Over most of these regions, nutrients appeared to be more limiting than water for plant production. Only 10-15% of the rainfall is used by plants growing in natural rangelands, and the plants do not find adequate nutrients for growth, even when water is available. Soil improvement in these areas improves the efficiency of water use by a factor of 3 to 5. Nitrogen and phosphorus are the main limiting factors. Fertilizer can increase rangeland production in the southern Sahel from 1.5-3.0 t ha^{-1} dry matter to 4-12 t ha^{-1}. The quality of the fodder also increases: protein content may reach 12% when fertilized instead of 3-6% under natural conditions.

The predominance of soil poverty over lack of water in limiting rangeland productivity has important consequences for animal husbandry and arable farming. Fodder quality is inversely proportional to quantity. Where water is more limiting than nutrients, fodder quality is high. This is the case at the desert border, where crop production is impossible due to low and erratic rainfall. Going south, rangeland productivity increases with increasing rainfall, but fodder quality decreases.

Use of fertilizer increases production more than irrigation. Irrigation alone leads to a lower efficiency of water use than unsupplemented rainfall. In contrast, applying only 30 kg ha^{-1} of nitrogen, plus phosphorus and potassium, to rain-fed millet in the southern Sahel improved the efficiency of water use by a factor of two to three [*Bationo et al., 1991*]. Thus, by increasing effective water availability, fertilization can be considered an alternative to irrigation.

The relative availability of water and nutrients determines which external input is needed most to increase production, and to increase the carrying capacity of the natural resources. Water availability is a function of rainfall, redistribution of rainwater by run-off and run-on, and losses by evaporation and leaching. Nutrient availability depends on soil fertility, soil-enrichment processes (e.g., biological nitrogen fixation and weathering), nutrient inputs (e.g., by wind, water and animals) and nutrient losses through erosion, leaching and export by agriculture. In West Africa, the transition from nutrient- to water-limited production occurs at an annual rainfall of about 300 mm. In the Mediterranean region, evaporative losses are much lower, so the transition occurs at an annual rainfall of only about 150 mm. In areas where soils are shallow, with low water storage capacity, or where runoff is enhanced either naturally or due to human activities, the transition to nutrient-limited production occurs at higher levels of annual rainfall. In cases of enhanced run-on, the transition to water-limited production occurs at an annual rainfall of less than 300 mm, even in West Africa. But where soils are of greater than average fertility, or when fertilizer is used, the transition to water-limited production occurs at an annual rainfall of more than 300 mm.

The contribution of perennial herbs and of shrubs and trees to vegetation structure and productivity generally increases as the level of annual rainfall that induces the shift from nutrient- to water-limited production decreases (that is, as soil nutrient content increases). Soil organic matter content also increases as the threshold for water-limited production occurs at lower levels of annual rainfall. Both of these characteristics tend to increase the fragility of ecosystems with high rainfall thresholds for water-limited production. In this regard, semi-arid West Africa is one of the most extreme cases, with a high level of rainfall at transition, low contribution of perennials to annual production, low soil organic content and highly fragile ecosystems.

Areas with nutrient-limited production can be differentiated based on the degree of deficiency of different nutrients. Nitrogen is the most critical limiting factor in large parts of West Africa, but sometimes phosphorus is more limiting. Agricultural practices may cause potassium to become the limiting factor. The nature of the deficiency depends also on the nature of the crops and/or livestock tended. For example, leguminous crops are usually limited by phosphorus, since they can obtain nitrogen from the air. Cattle may be in trouble on rangeland limited by nitrogen, while goats may still thrive by browsing greenery from shrubs and trees.

Water is not the only factor that limits plant production at levels of rainfall below the threshold for nutrient-limited production. At very low levels of annual rainfall the vegetation itself may become limiting; the amount of antecedent biomass at the beginning of the rainy season may be too low to allow efficient use of the small amounts of available water. This may also occur at higher rainfall if over-exploitation of the vegetation causes its degradation.

The predominant environmental problems of arid lands are (1) depletion of soil nutrients and (2) degradation of the vegetation. The first pushes the transition between nutrient- and water-limited growth into areas of increasingly higher rainfall. The second increases the area of man-made desert. Both also lead to (1) a decrease in soil organic matter, which causes degradation in the physical structure of the soil and thus increased susceptibility to wind erosion and, ultimately, creation of active dunes on sandy soils; and (2) increased run-off and water erosion on soils with a finer texture. The end result is expansion of the desert, and transition from nutrient- to water-limited growth, in areas with increasingly higher annual rainfall.

Consequently, increased availability of nutrients, to avoid or to correct reduction in soil fertility, is the primary technological solution for lack of sustainability in semi-arid land. Irrigation and selective choice of plant species well adapted to arid conditions reinforce the use of fertilizer, and may improve the economic feasibility of its use. They may also be used to fine-tune fertilizer use, extending the limit of its utility for intensification of agriculture to more extreme conditions of soil and climate.

A crucial question is why intensification of agriculture, through the use of fertilizer and other innovations resulting from the 'green revolution', remains so limited in Africa? Fertilizer use in sub-Saharan Africa (SSA) is only 7 kg ha^{-1} yr^{-1}, compared with 32 in Latin America and 82 in Asia [*Bationo et al., 1991*]. Why does SSA remain such an extreme anomaly regarding productivity of both land and labour? Craig et al. [*1994*], analysing trends in both measures between 1961 and 1990 for major regions of the globe, found that South Africa, as well as Australia and New Zealand, have about the same level of land productivity as SSA as a whole, but a labour productivity 5 to 50 times greater. In 1990, China reached the same labour productivity as SSA, but had 5 times greater land productivity. All other parts of the world have higher rates of land and labour productivity than SSA. Over the past 30 years, land productivity doubled in the region, while labour productivity increased less than 30%; the area of agricultural land per worker decreased over this period from about 8 to 6 ha.

Van Keulen and Breman [*1990*] attribute the poor state of agricultural development to the poor quality of natural resources in the Sahelian countries, and to limited and unequal access to external inputs which arise from the local land tenure regime and from the world economic system. The three regions with levels of land productivity comparable to SSA, namely South Africa, Australia and New Zealand, have considerable employment outside agriculture in industries related to natural resources other than land (e.g., mining), while the availability of land per farmer is more than 20 times higher in the first case, and 130 times in the latter two cases.

Figure 2 shows clearly that low land productivity is associated with low rural population density. The converse, however, is not true: low population density does not necessarily signify automatically low land productivity. The relationships between land productivity and total population density are very similar.

Following the reasoning of van Keulen and Breman [*1990*], if no important sources of income exist outside agriculture, then problems may arise when limits of natural resources are reached and over-population becomes serious at low absolute population density. In that situation, there is no cheap labour available to stimulate industrialization. External inputs would be required to improve agricultural yield, but the absence of a significant national demand for agricultural products, and the local production conditions, lead to low efficiency in the use of external inputs. The latter effect is particularly prevalent in dry regions with poor soils. A local market for agricultural production is necessary to provide income to purchase external inputs, but it is extremely difficult for local producers to compete effectively under these conditions. The use of external inputs depends on infrastructure, distribution systems and so on. The per capita costs of the required infrastructure is variable, but may become very high when over-population occurs at low absolute population density and when land degradation starts before land has a value. This situation deteriorates even more if product prices are maintained at artificially low levels due, for example, to dumping practices or to failure to internalize environmental costs. For example, selling European meat and milk in the West African market is accompanied by depletion of natural resources in West Africa and environmental pollution in Europe.

6. OPTIMAL USE OF EXTERNAL INPUTS

Technological options for intensification of agriculture often produce a more than proportional increase of efficiency with increasing resource quality (soil, climate and vegetation). Therefore, the cost:benefit ratio of such options is lower in semi-arid regions [*Breman, 1990b*]. Nevertheless, two mechanisms can be employed in these regions to improve access to those options: (1) altering socio-economic conditions, such as increasing security in land tenure or subsidizing external inputs, to improve the cost:benefit ratio; and (2) increasing the efficiency of technological options, such as implementing measures to maximize the benefits of fertilizer use. The latter mechanism will be discussed below in more detail. Two examples will be treated: (a) the use of leguminous species and (b) techniques of agroforestry. In both of these cases, the most effective techniques from intensive and from ecological agriculture are combined in an effort to optimize the utilization of nutrients from both natural sources and from fertilizer.

6.1 Leguminous Crops

Planting *legumes* is often suggested as an inexpensive method for poor farmers to improve fertility of poor soils. Nitrogen is often the nutrient most limiting to plant growth. Symbiotic bacteria on the roots of leguminous species allow the plants to obtain useable nitrogen from the air, whereas all other species must absorb mineralized nitrogen from the soil. In Australia, for example, rangelands are seeded by plane with *Stylosanthes* and other leguminous species to improve productivity of the rangeland and of the grazing animals that depend on it [*Burt et al., 1983*]. Figure 3 shows that cultivation of leguminous crops, in areas of adequate rainfall, appears to provide far greater benefits when combined with application of phosphorus fertilizer. This example demonstrates the advantages of combining ecological and intensive agricultural methods.

Nevertheless, at least three problems limit the use of legumes in agriculture:

- Legumes require phosphorus for biological fixation of nitrogen from the air, and phosphorus is generally almost as limited as nitrogen [*e.g., Penning de Vries and Djitèye, 1991*]. The phosphorus content of leguminous shoots is 1-2 mg g^{-1} for Sahelian rangelands, while the minimum value required for effective nitrogen fixation is 1.5-2.0 mg g^{-1}.
- The high nutrient content of leguminous species, thanks largely to their nitrogen fixation, makes them very attractive to many herbivores, and sensitive to infestation by pests and diseases. They are therefore difficult to cultivate in poor environments. The large requirement for internal inputs, such as labour, and external inputs, such as pesticides, threatens to counterbalance the advantages of nitrogen fixation. In other words, the nitrogen obtained is not really free of charge [*Wooning, 1992*].

- The efficiency of fixation, and the output per unit input of external phosphorus fertilizer, decreases rapidly with decreasing water availability below a certain threshold. Several phenomena explain the steep decrease of nitrogen fixation with rainfall in the Sahel (600 mm yr^{-1} of rainfall). (a) Phosphorus availability requires moist soils, since phosphorus is a relatively immobile element. (b) Absorption of phosphorus by plants growing on poor soils is enhanced by the formation of *mycorrhiza*, an enlargement of the roots induced by symbiotic association with microbial fungi. The fungi become effective only after about 25 days following infection at the beginning of the growing season, which is of short duration in semi-arid regions. (c) As water availability decreases, nitrogen becomes less limiting, even on very poor soils. An internal feedback mechanism inhibits biological nitrogen fixation by legumes when nitrogen does not limit plant growth.

6.2 Agroforestry

Agroforestry has been promulgated over the past decade as an inexpensive alternative for fertilizer. Luxurious growth of crops such as millet in the vicinity of *Faidherbia albida* trees in West Africa is indeed appealing. Breman and Kessler (in press) quantified the increase in productivity associated with trees in relation to soil and rainfall in West Africa. Above-ground productivity of natural vegetation (woody plus herbaceous species) on, for example, the dominant loamy soils, exceeded productivity in the absence of shrubs and trees by 0.1, 0.5, 1.0 and 0.5 t ha^{-1} yr^{-1} in the northern and southern Sahel and the northern and southern Sudanian savannah, respectively. Productivity increases attributed to the herbaceous portion of the vegetation occurred only in the southern Sahel and the northern Sudan, with increases of 0.2 and 0.5 t ha^{-1}, respectively.

In the southern Sudan, herbaceous production of natural vegetation with shrubs and trees present is 0.75 t ha^{-1} lower than in their absence. The decrease is attributable to interception of light by the relatively dense stands of woody plants. The relatively low net increase in productivity by all vegetation in the presence of trees seems to be due also to the low efficiency of water use by woody plants in comparison with herbaceous species. Thinning the woody species and maintaining an even and regular distribution in the field leads to a net increase in productivity in the southern Sudanian savannah that is at least as high as that in the northern part. One mechanism through which woody species improve total productivity is an increase in the amount of soil organic matter, which is probably the poorest characteristic of dry land soils. Three-quarters of the increase can be attributed to this improvement in soil quality and to the perennial root system, which reduce losses of nutrients and water from the soil.

The data presented by Breman and Kessler (in press) show that, as in the case of legumes, the benefits of this agroforestry technique decrease with decreasing rainfall. In the Sahel proper, the region where improved production is most badly needed, the increases in productivity using this technique are negligible. Moreover, as in the case of legumes, the benefits of cultivating woody species-a technique from ecological agriculture-increase when combined with fertilizer use, a technique of intensive agriculture. An efficient agroforestry system in the Sudanian savannah prevents about 5 kg ha^{-1} yr^{-1} of soil losses. The use of nitrogen fertilizer increases this gain to about 15 kg. The indigenous agroforestry system can feed about 3 persons per hectare; the use of fertilizer increases this to 10.

7. 'THE EXPLOITER PAYS'

It will become clear why it is so difficult to stop resource depletion and degradation of dry land. It is wishful thinking to expect that in the future, with the open and 'honest' markets promised by the General Agreement on Tariffs and Trade (GATT), dry land agriculture can become competitive and be able to internalize environmental costs.

The philosophy that 'the polluter pays' is logical. But the poor farmer who causes resource depletion out of sheer necessity due to over-population of semi-arid regions cannot pay. He or she can, however, improve living conditions, and slow or stop depletion and desertification, if given access to external inputs like fertilizer [*Breman, 1987*].

Why should one not speak about subsidy if such access can be provided, in one way or another, by governmental or international support? Why should governments and international donor agencies not pay to protect desert borders against resource depletion and desertification, just as the Dutch pay for dikes to protect the nation against flood waters, and mountainous countries pay for afforestation of river drainage basins to control floods?

FIGURES

FIGURE 1: Relative Productivity of Animal Husbandry (Production Per Animal) and of Annual and Perennial Crops (Production Per Hectare) in Relation to Annual Rainfall in West Africa.

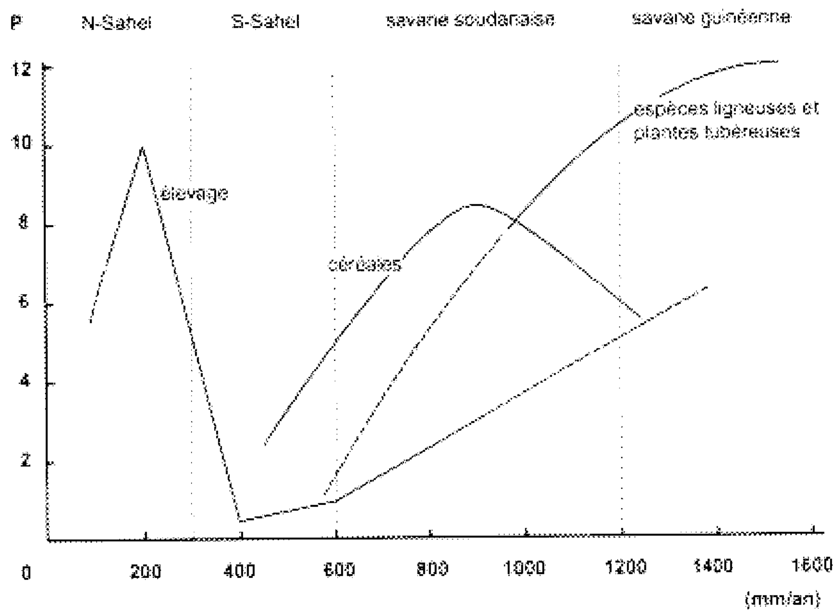


FIGURE 2; Rural Population Density per Country of Sub-Saharan Africa (Persons km^{-2}) in Relation to the Average Potential Productivity of the Land (t Ha^{-1} of Cereals using Fertilizer; based on Buringh and Van Heemst, 1977). Countries are grouped according to the Percentage of the Gross National Product Obtained from Industry.

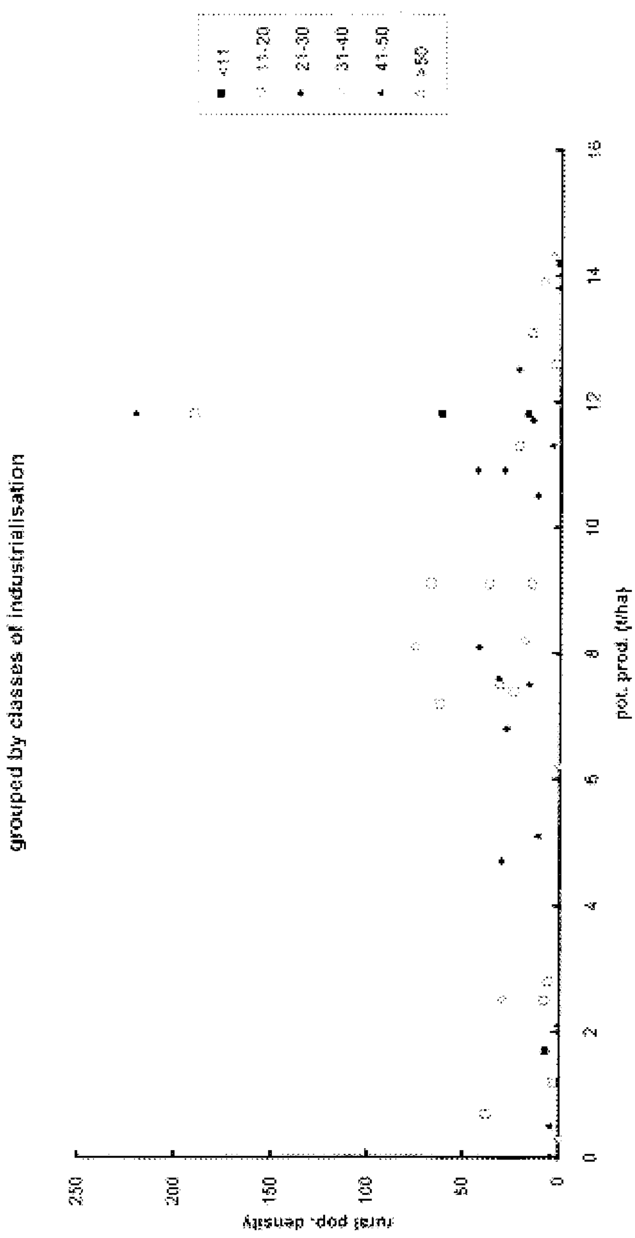
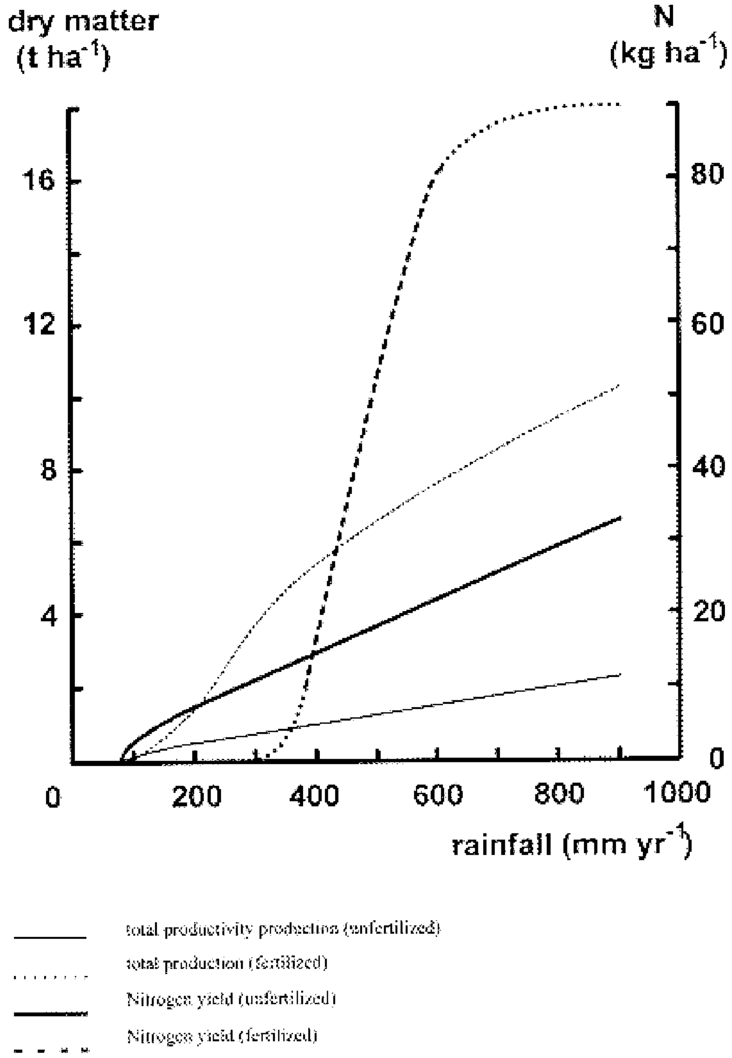


FIGURE 3: Productivity of Legumes (in T Ha^{-1}) and their Nitrogen (n) Yield in Relation to Rainfall in West Africa, With and Without Phosphate Fertilization. (data from Penning De Vries and Djitèye, 1991, and Wetselaar and Gangry, 1982.)



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