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RANGELAND PRODUCTIVITY AND EXPLOITATION IN THE SAHEL

by

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Programs to develop the traditional livestock farming of the Sahel have often been ineffective despite great human and financial contributions. Efforts directed at better pasture and herd management, pasture improvement, livestock fattening, and increased marketing, have failed to improve the overall productivity of the herds and to stop range deterioration. A major reason is that many of these efforts are based on an incorrect understanding of the Sahel, of its pastures, and of how they are used. For instance, it is generally thought that (i) the productivity of Sahelian pastures is limited by rainfall; (ii) livestock herds in the Sahel are too large because the nomadic and seminomadic herdsmen consider them a status symbol and a means of saving; (iii) the animals are kept until they are very old, whether or not they are productive; (iv) the large herds cause considerable overgrazing, even in years with reasonable rainfall; (v) with drought, the shortage of forage causes high mortality and increased erosion and degradation of rangelands; and (vi) overgrazing and the composition of the herd are the reasons for the poor condition of the animals and the low output of animal husbandry.

Summary. Results of a Malian-Dutch research project on the Sahelian pastures and their utilization suggest reasons why some efforts to develop traditional livestock farming in this area have been unsuccessful. Failure to appreciate the effects of low soil fertility as well as low rainfall on pasture production has resulted in underestimation of the productivity of the nomadic and seminomadic livestock farming system and overestimation of the possibilities for increasing production by better management and by modernization.

This picture is the basis for the philosophy that the problems have to be solved primarily by preventing overgrazing, since at present the climate cannot be influenced and irrigation can only be used locally. Smaller herds and the development of areas of nonuse (wells), in addition to improvement of the herd composition and animal health, will improve the output of livestock farming. Future good management of the rangelands, improvement of the rangelands by importation of plant species, improvement of livestock by crossbreeding and selection, integration of livestock farming and arable farming, and improved marketing structures are expected to make possible financial independence and the end of desertification for the Sahelian countries. Desertification is viewed as such an urgent problem that direct attempts have been and still are being made to prevent environmental degradation through reforestation projects and by the prevention of bushfires and the cutting of shrubs and trees.

We summarize in this article results of a Malian-Dutch research project entitled Primary Production Sahel that was designed to reappraise the problems of farming in the Sahel and propose possible solutions. The research team, a multidisciplinary group of workers from the Institut d'Economie Rurale (Bamako, Republic of Mali), the Agricultural University and the Centre for Agrobiological Research (both in Wageningen, The Netherlands), and many others analyzed the natural rangelands in the Sahel. Results and conclusions from this research project have been published (*1*) and will be used without further justification.

The Sahel Environment

The Sahel, the southern fringe of the Sahara, is a semiarid transition zone between the desert and the savannas of West and Central Africa (Fig. 1). The dominant climatic factor of this region is the single, short rainy season: the rains fall during 2 to 4 months, and the rest of the year is dry. The total amount of rain varies greatly from year to year, with the variability increasing with decreasing mean annual rainfall. At the southern border of the Sahel, the mean annual rainfall is 600 mm, with a 10 percent probability of dry years with 400 mm or less. At the northern border, the rainfall is 100 mm, with a 10 percent probability of dry years of 50 mm or less. The rains fall in summer when temperatures are high and potential evapotranspiration is 3 to 5 mm per day.

As a consequence of this regime, the rangelands are mainly thorn-shrub steppes, dominated by annual grasses. Their growing season is only 2 to 2.5 months in the south and not more than 1 month in the north but may be somewhat longer for the rare perennial grasses and for shrubs and trees, which are nearly all without leaves during a large part of the long dry season. The coverage of woody species is less than 5 percent on the dominant sandy eolian soils, which absorb the rainwater well and homogeneously. However, soils developed on sandstone or laterite and on ancient river sediments, with dominant loam or loamy-clay texture, often show strong runoff on most of their surface. This

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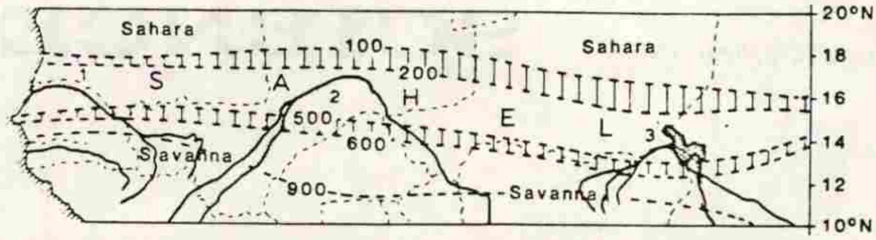


Fig. 1. The Sahelian part of West Africa with the transition zone (hatched) to the Sahara desert and the savanna areas with an indication of some annual rainfall lines and the major river systems (1. Senegal; 2. Niger; and 3. Chari and Lake Chad).

results in local accumulation of rainwater, temporary puddles, and deep percolation. It is only at these spots where the coverage of woody species can exceed 20 percent.

Such climate, vegetation, and soil characteristics result in a shortage of green vegetation and drinking water for large parts of the region during most of the year. For this reason, the borders and floodplains of Lake Chad and the rivers Senegal, Niger, and Chari (Fig. 1), with vegetations dominated by perennial grasses, are indispensable for the pastoral people and their herds. Perennial grasses are also important along smaller streams in the savannas and are more widespread in regions with more than 800 mm of annual rainfall.

The spatial and temporal variability of rainfall and of vegetation seriously limits the use of descriptive studies of productivity of Sahelian rangelands. Therefore the research team developed a system analysis approach in which information on plant ecology and physiology and physical and chemical properties of soil was integrated in dynamic simulation models that in turn were experimentally evaluated during several years under a wide range of conditions. Traditional, descriptive vegetation studies were also used to verify the results and to assess their usefulness outside the area of experimental study. For example, a transect of 1250 km from the 150- to the 1100-mm isohyet was studied during four successive years, at the end of both the dry and wet seasons. Such analyses and the models were designed to determine, with a minimum of experimental effort, the quantity and quality of the production of natural vegetation and the constraints on growth.

Main Results

The mean annual production in the rainfall zone of 500 mm appears to be 2000 kg/ha, whereas the production under conditions in which neither nutrients nor water is the limiting factor amounts to 55,000 kg/ha. If only nutrients are limiting and water is in optimum supply, the production is about 5000 kg/ha. However, with only a natural rainfall and optimum supply of nitrogen and phosphorus, the production is increased to 10,000 kg/ha. Frequently, under natural conditions, growth in the first part of the growing season is limited by phosphorus and in the second part by nitrogen. Whatever the mechanisms, if both elements are supplied sufficiently, production in the southern part of the Sahel can increase by as much as a factor of 5 (Fig. 2). We conclude therefore that low availability of nitrogen and phosphorus is a more serious problem than low rainfall. This conclusion is supported by our study of fertilizer application and water balance that was carried out under natural conditions. The average annual balance showed that the vegetation did not transpire more than 10 to 20 percent of the rainwater under natural conditions in the southern border of the Sahel. About 60 percent evaporates and 25 percent disappears as runoff. Evaporation is relatively high because a fairly large part of the rain falls before and after the growing period of the vegetation. This does not explain the limited use of rainwater by the vegetation, since at the end of the growing season 10 to 20 percent is still present in the soil, within the reach of plant roots. In other words, the herb layer, which forms the major part of plant biomass, stops growth before the water supply is depleted.

Often much less water remains in the soil when rangeland is fertilized, since transpiration increases to a maximum of about 50 percent of the rainfall. Improved soil fertility leads to the use of more water by the vegetation, improved water-use efficiency, and thus higher production. Once again, the limiting factor for growth is the deficiency of nitrogen and phosphorus rather than water.

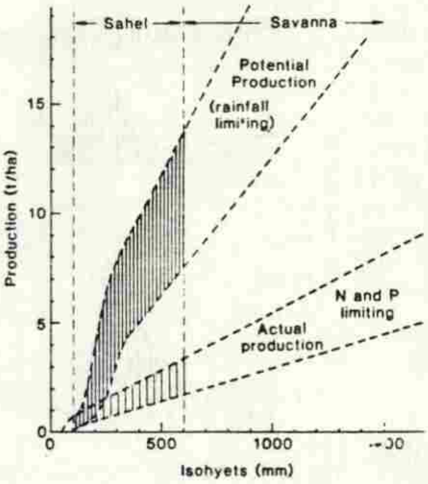
These observations do not apply to the same extent in all parts of the Sahel, the important factor being the relative availability of water, nitrogen, and phosphorus. Sandy soils with good water absorption capacity and clay depressions where water accumulates show relatively high water availability, and nitrogen and phosphorus will soon become factors limiting production. But where runoff is high, because the area slopes or has low water absorption capacity, and where surface soils have low water-retaining capacity, water availability is likely to take over this role.

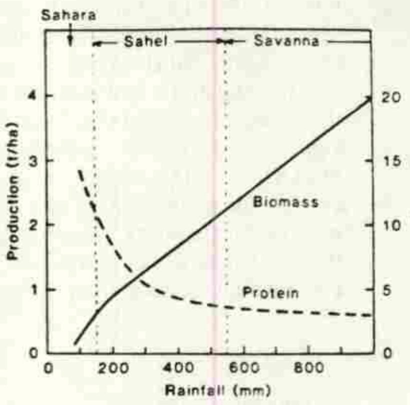
In Fig. 2 the mean annual rainfall from the north to the south is given along the horizontal axis and two ranges of production along the vertical axis—the lower range, actual production, reflects existing fertility conditions and the higher range, potential production, optimum supply of nutrients. The relative influence of fertilization decreases with decreasing rainfall, indicating that the availability of water decreases much more rapidly from south to north than does the fertility of the soil. This is confirmed by soil analyses.

In the Sahel, the transition from growth determined mainly by nutrients to that determined by water occurs at an annual rainfall of about 300 mm. Water is thus the limiting factor for plant growth only in the northern half of the region (Fig. 1), which is used almost exclusively in the short rainy season for animal husbandry. Because of local differences in soil fertility and in runoff, the 300-mm dividing line is by no means an absolute and definite line. Grazing, for example, affects this line, because grazing affects the availability of nutrients and water.

On loamy sand and sandy loam, the decrease in water availability due to grazing is a dominant factor. With decreasing soil cover and protection, and because of trampling, crust formation and deterioration of the soil structure occur. Under such conditions water will soon be the main determining factor for growth, and even at the same concentrations of nitrogen and phosphorus these elements are less limiting. Locally their availability may even increase. Specific legumes like *Zornia glochidiata*, which supply the soil with additional nitrogen, are more likely to establish themselves, because of their germination behavior. In addition, these soils, because of their crust-forming properties, are often characterized by the presence of drinking water for livestock. Frequent visits of livestock to temporary puddles produce an accumulation of droppings and urine and thus of nitrogen and phosphorus.

On sandy soil the reverse may occur. Nitrogen and phosphorus are transported by herds to camps and drinking places. However, a change in water absorption capacity does not occur, since the texture of the sand does not allow crust formation. Nitrogen and phosphorus deficiencies therefore increasingly determine growth.





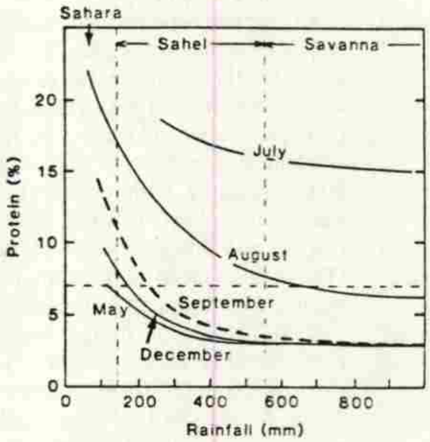


Fig. 2 (top left). Ranges of actual and potential plant production of pastures (metric tons of dry matter per hectare) in relation to the mean annual rainfall. Fig. 3 (top right). Mean rangeland production (metric tons of aboveground dry matter per hectare) and the protein content in the biomass (percentage at the end of September) in relation to mean annual rainfall. Fig. 4 (bottom right). The mean protein content of the rangelands as a function of the mean annual rainfall in different months of the year.

Forage Availability and Quality

The biomass annually produced by the rangelands depends mainly on the absolute availability of the growth-limiting factor. The availability of water relative to that of nitrogen and phosphorus determines the quality of the forage produced.

Since digestibility and phosphorus content vary roughly in the same way as the protein content (*1*), only the latter is treated here, and it is one of the most important criteria of forage quality. Protein content is closely related to the nitrogen content in the vegetation, which in turn is dependent on the availability of nitrogen in the soil and the extent to which it determines plant growth. When water is the growth-limiting factor throughout the growing season, the protein content in young green tillers is about 18 percent, and at the end of the growing period it is still 12 percent. When nitrogen is limiting, however, the protein content in the growing plant decreases rapidly to values of 3 to 6 percent.

In the Sahel countries, water limits growth at the border of the Sahara. This changes over rapidly to growth limited by nitrogen (and phosphorus) with increasing rainfall to the south. Biomass increases then, but the protein content decreases (Fig. 3). With water availability rising from 50 to 1000 mm annually the total mean production increases from nearly 0 to 4 metric tons per hectare. The protein content in the fully grown plants declines from 12 to 3 percent. Thus low water availability produces a small amount of biomass of good quality, and higher water availability results in more biomass of increasingly inferior quality. It is irrelevant whether low water availability is caused by low rainfall, by low absorption capacity, or by soil degradation from grazing.

In livestock farming, biomass production and quality are important not only at the end of the growing season but throughout the year. However, this very quality is lacking in vast areas of the Sahel during a major part of the year (Fig. 4). The protein content should be at least 7 percent to keep livestock in good condition (horizontal dashed line in Fig. 4). For growth and milk production it should be higher. This means that the total vegetative biomass might be used as forage throughout the Sahel only during July and August. In September, the protein content remains only high enough in the northern Sahel, but here, too, the mean quality drops below the minimum protein content of 7 percent in the course of the dry season. Nevertheless, the quality remains considerably higher in the north than in the south Sahel and in the savanna.

The inverse relation between the amount of biomass and its protein content is observed not only in biomass variations related to differences in water availability, but also in those related to differences among species in the duration of vegetative growth that are induced by day length, to the difference in biomass between perennials and annuals, and to the differences between the dominant fast-germinating C_4 species and the slow-germinating "weeds" (*2*).

Selective Grazing by Livestock

The quality of the vegetative biomass is not homogeneous. Even at the minimum mean protein content of 3 to 4 percent, there still is a fraction with acceptable quality. To survive in the dry season, and for good production in the rainy season, the animals have to graze selectively, and cattle have a highly selective tongue to do so. It should be noted that livestock cannot compensate for poor quality by consuming more. On the contrary, with decreasing quality, activity in the rumen also decreases so that intake capacity decreases.

Diallo (*3*) showed that almost throughout the year the protein content in the herbage consumed by zebu was 2 to 5 percent higher than the average content of the grazed rangelands. Selectivity implies a choice between both place and species. Areas of low biomass are favored, and the species preference tends to parallel protein content. Specific plant parts may also be selected. For instance, in the dry season the seeds and fruits have the highest protein content, followed by regrowth of perennials and then by leafy annuals. Stems of perennial grasses and of cereals such as millet and sorghum have very low protein content.

When growth is limited by water rather than by nitrogen and phosphorus, not only the mean quality of the plants but also that of each plant part is higher. Consequently, the fraction of plants of acceptable quality is greater toward the Sahara. In practice this means that even in an absolute sense, the quantity of forage of acceptable quality at the worst time of the year (the end of the dry season) is higher in the north Sahel than in the south Sahel and in the savanna. Figure 5 illustrates this with the trend in three quality classes throughout the year: "good" enables growth and milk production, "moderate" is just good enough for maintenance, and "bad" is useless. Furthermore, the good forage in the north has a higher average protein content than the good forage of the south (Fig. 4).

Livestock Farming

The three traditional systems of livestock farming—nomadism, seminomadism, and sedentary animal husbandry—represent three different ways of life and are specific human answers to the painful choice between high-quality forage or drinking water. Each system is more or less associated with one of the three main climatological zones in the area (Fig. 6) and different livestock densities (Table 1). New strategies for livestock raising (Fig. 6) are also discussed below.

With respect to forage quality, the north Sahel is the most suitable for livestock farming. However, the total quantity of forage can feed only a relatively small number of livestock throughout the year, since a lack of drinking water makes vast areas inaccessible in the dry season. Therefore, relatively few nomads live with their herds at the border of the Sahara.

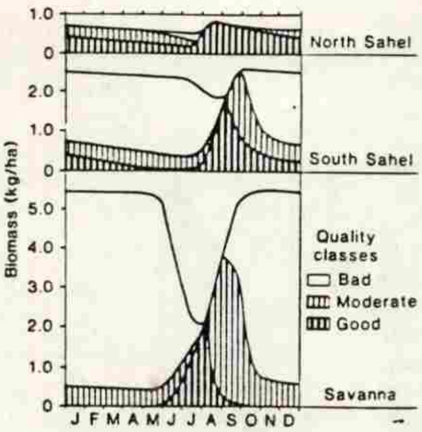


Fig. 5. The biomass throughout a year, with normal rainfall, without grazing and fire losses, and specified per quality class, in the north Sahel, the south Sahel, and the savanna.

Livestock performance in the south Sahel and in the savanna is poor; even in the rainy season, the quality of the forage is poor. However, in areas so far south that rainfall is high enough for perennial grasses to grow, a great number of livestock are able to survive by selecting the regrowth during the dry season. Sedentary livestock farming in this zone is mainly a secondary activity of arable farming.

The sedentary and pure nomadic systems are of little importance in comparison with the seminomadic system, which in this region is called transhumance. This system benefits from good production possibilities in the north Sahel in the rainy season and from the opportunities for survival in the south in the dry season (*1, 3–5*). To accomplish this, twice a year the herdsmen and their herds migrate over hundreds of kilometers. Women, children, and older men stay behind in the villages, which are mainly located in the river basins, the south Sahel, and the northern savanna (Fig. 1). This form of livestock farming is a very effective way to exploit the rangelands, as was shown by a case study for our project (*1*). Traoré (*4*) and Diallo (*3*) described the migration of a herd of zebu between the central delta of the Niger and the Mauritanian Sahel. They followed the herd for more than a year to study fodder availability and quality (*4*), the behavior of the herd (grazing selectivity), herding, and herd demographics (*3*). The availability of forage and the variation of its protein content during 14 months are illustrated in Fig. 7.

At the beginning of the rainy season the herds migrate to the north of the Sahel to graze there from July to October. The total standing biomass, almost exclusively annual grasses and herbs, is less than 1000 kg/ha. The protein content is, however, 10 to 20 percent and the digestibility 60 to 70 percent. With some selective grazing the cattle then appear to grow at a rate of 0.5 kg day per head. The migration south, to the central delta or the savannas, is prompted by lack of drinking water and not by lack of food. For the rest of the year in the south, the cattle are able at most to maintain their weight. The only production then is calf birth, calf growth, and some milk.

Life weight is maintained in spite of the low mean protein content of the herbage (3 to 5 percent) and the low mean digestibility (~ 40 percent), by selective grazing, which is favored by bushfires. As soon as there are signs of shortage of food, the herds migrate to a new area; this is reflected by the abrupt changes in the availability of biomass in Fig. 7. Fires, more than grazing, are the reason for the rapid decrease in the biomass from November to April.

Both the herds of the seminomads and those of the farmers are of essential importance as a source of manure for traditional arable farming. The use of fertilizers is unprofitable, at least in cereal growing. However, nitrogen and phosphorus deficiency is at least as important in arable farming as in rangeland production. In many places too much of the available acreage is already in use to allow effective fallow periods. Permanent or semipermanent use of land is

Table 1. Acreage (in hectares) required to feed one animal of 250 kg for 1 year in a normal and in a dry year (10 percent chance) and the average area available before (1970) and after (1975) the drought.

System	Area required		Zone	Area available	
	Normal	Dry		1970	1975
Nomadism	14	42	Sahara border	33	50
Transhumance	3.5	8	Sahel	3.7	6
Sedentary	10	20	Savanna	16	20

Table 2. Livestock production in the Sahel and two comparable regions (semiarid tropics with less than 500 mm of rainfall per year).

Region	Protein production (kg/year)		Fossil energy input (10^3 kcal per man-hour)
	Per hectare	Per man-hour	
United States (*6*)	0.3 to 0.5	0.9 to 1.4	25 to 35
Australia (*6*)	0.4	1.9	150
Sahel (*1*)			
Nomadism	0.4	0.01	0
Transhumance	0.6 to 3.2	0.01 to 0.07	0
Sedentary	0.3	0.04	0

possible because nutrients in the droppings and urine of livestock that graze in the surrounding wastelands are transported to the village and fields. The manure accumulates as the result of livestock passing to the village well and corral. But conscious use of droppings is also common. Manure, intermixed droppings, and urine from the corral is applied to fields, and nomads are asked to set up their camp on the fields in exchange for the use of the village well and as payment for cereals.

Animal Production

Daily milk production is about 0.5 to 0.75 liter per cow for human consumption. This may seem low but is nevertheless an important output for this subsistence livestock husbandry. During migrations far from the village it is the main food for the herdsmen. Some more productive cows with newborn calves are also kept in the village to produce milk for the women and children as well as for sale.

On the basis of birthrate, mortality, and growth, the mean annual increase in live weight appeared to be 20 percent (3) or 50 kg per tropical livestock unit, which is the equivalent of 250 kg of livestock biomass. This is relatively high for Sahelian cattle. The mean annual production from sales plus herd growth is 15 percent, compared with 32 and 40 percent for sheep and goats, respectively (5).

This low production per head is not an indication of a bad breed, as judged by growth and milk production during the top seasons and experiments with high-quality feed. Thus management, environment, or both have to be blamed. Before judging, however, one has to realize that the low production per animal does not mean a low output per acreage. This is shown by a comparison with livestock production in regions of comparable rainfall in Australia and the United States (Table 2). Livestock farming in areas of these countries with less than 500 mm of annual rainfall produces 0.3 to 0.5 kg of animal protein per hectare per year (6). Our estimates yielded the same values for nomadic and sedentary livestock farming in the Sahel, whereas for its main system, the seminomadic, we found 0.6 to 3.2 kg per hectare. The low value is for herds that use the northern savanna during the dry season, and the high value for the herd studied from the Niger inner delta. Production per man-hour, however, was

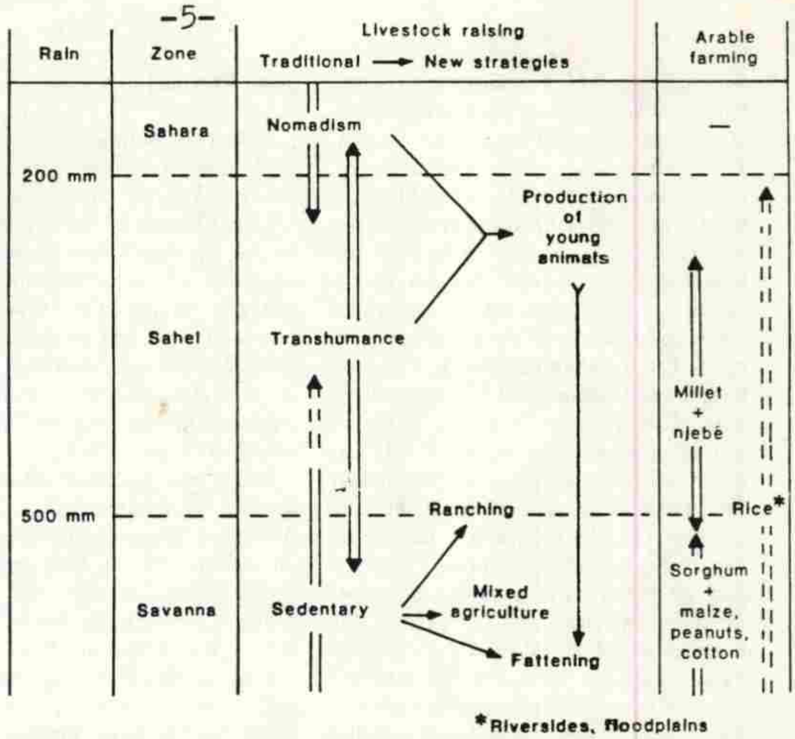


Fig. 6. Traditional livestock farming systems and suggested new strategies in relation to climate and arable farming.

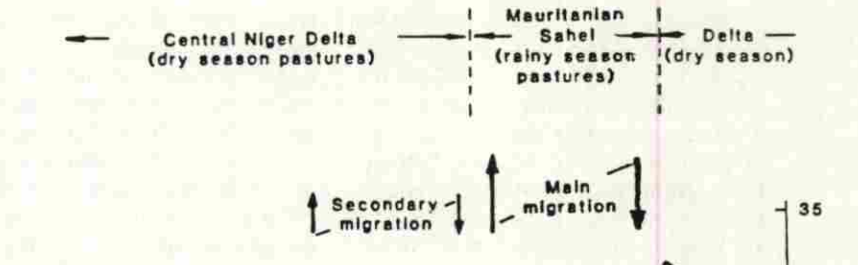


Fig. 7. The availability of forage and the fluctuation of its protein content (as a percentage of dry matter) during 14 months of seminomadism for a Diafarabé herd (Republic of Mali).

only 0.01 to 0.07 kg of protein in the Sahel and 0.9 to 1.9 kg in the arid regions of Australia and the United States. These latter values can only be achieved by mechanization and the use of fences, trucks, and so forth, which is expressed in fossil energy input in Table 2. In the Sahel such input is negligible. An American or Australian rancher exploits thousands to hundreds of thousands of hectares. The Sahelian herdsman, with only hundreds of hectares at his disposal, is obliged to exhaust these while hardly producing enough for his family. He has no choice, and he cannot keep a smaller herd to improve persistence of the ecosystem. The mean herd size for an acceptable subsistence minimum must be four to five tropical livestock units per member of the family. Before the drought in the early 1970's the overall value available in the Sahel was 4.5 tropical livestock units per person and just after, 2.8 units. Total herd size has returned to the 1970 level, but livestock density is still only 3.5 tropical livestock units per person because of the population increase of 2.5 percent per year.

The suggestion that a smaller herd will produce more in an absolute sense is not true for rangelands such as the Sahel that are dominated by annual plant species, whose production is mainly determined by the availability of nitrogen. Nitrogen losses from the vegetation are already high without grazing. When more cattle are kept, less nitrogen is lost by volatilization and fire, so that animal production is almost proportional to herd size (*1*). This phenomenon and the low subsistence level mean that livestock farmers sell about 12.5 percent of the mean yearly herd production and use the remaining 2.5 percent for herd growth (*7*). They have to accept the risk of losses in very dry years for a maximum profit in normal and good years. This strategy raises the stocking rate of the herds above the physical limits of the ecosystem.

The catastrophic mortality of livestock during the drought in the early 1970's also showed that the stocking rate of the rangelands had grown too high. Theoretical calculations of the carrying capacity, based on the results of our research, indicate considerable overgrazing, in the physical sense. This is shown by comparing both the carrying capacity in dry and normal years and the stocking rates before and after the drought (Table 1). Between 1970 and 1975 almost 40 percent of the livestock died, but since then grazing pressure has been rising again to predrought levels.

Some Comparisons

In broad outline, the situation described above is not specific for the Sahelian region. Uneven seasonal rainfall distribution in many regions causes an uneven distribution in the availability of fodder, and in general the fresh grass at the beginning of the season provides forage of good quality that then deteriorates. The inverse relation between quality and yield also occurs under rainfall gradients in many regions, although it is not always recognized.

It has been documented in the United States, for example, that the biomass decreases gradually from tall-grass regions with 600 to 1000 mm of annual precipitation through the short-grass prairies east of the Rocky Mountains with 250 to 650 mm of precipitation to the desert grasslands in the Southwest with 250 to 500 mm of precipitation. The quality of the grass increases along the same gradient: "Almost all tall-grass species leach badly and lose much of their nutritive value upon maturity," while "most of the desert grasses are highly preferred and nutritious, furnishing feed through most of the year despite a short growing season" (*8*, pp. 26 and 30–31). In northern Australia, "the arid zone accounts for a surprising 40 percent of the value of total annual animal product," while in the humid zone (more than 750 mm of annual rainfall), for the tropical tall grassland, "soil fertility is a major limiting factor, with low nitrogen and phosphorus levels most evident" and "the restriction on carrying capacity is the very low quality of the native pastures during the long dry season" (*9*). The distinction between sweet grass and sour grass in southern Africa can certainly also be traced back to low production and high quality and vice versa, and Smith (*10*) states for the Hyparrhenia savanna of Zambia that "the inverse relationship between quality and yield govern to a large extent the profitability of any management practice."

Of course, important differences between rangelands and their potentials may also occur because of absolute or relative differences in water and nutrient availability, differences in the nature of the relation between water availability and rainfall, and differences in the ultimate effect of different growth-limiting nutrients. These factors change the onset and slopes of the actual production curve in Fig. 2, as well as the point where the potential production curve departs from the actual one. Such changes will influence the curves in Figs. 3, 4, and 5. For example, the same rainfall at lower potential evapotranspiration will cause a steeper actual production curve. A higher availability of nitrogen, by a higher availability of phosphorus or a slower turnover of organic matter by less extreme temperatures (or both), will maintain production at the potential level for a longer period. Growth limited by a nutrient other than nitrogen will cause less decrease in the protein content during plant development.

There are also important differences between the Sahel and the regions where most of the current knowledge on range management has been gathered, which are associated with the type of climax vegetation. In the Sahel annual grasses dominate even where there is no grazing (*2*), whereas in the other regions management may be geared toward the maintenance of a climax vegetation of perennial grassland plants. Grazing systems like deferred grazing, rotational grazing, and rest-rotation are therefore geared to the morphology and physiology of perennial grasses (*8*) and unsuitable for the Sahelian situation.

The experience with perennial pastures or soils with reasonable fertility may also have led to the idea that the better pastures are those with greater biomass. Applied to the Sahel, where nutrients limit the production of annual grasses, this is a mistaken idea that leads to overestimation of the value of wells, boreholes, fire control, fodder conservation, rangeland regeneration, and other important management ideas.

Development Options

One common thread running through all the proposed interventions to improve the situation for the Sahelian animal farmer is that the improvement of range and herd management alone, without external inputs, such as fertilizers and improved plant varieties, can increase animal production. This assumes underexploitation of resources under conditions where plant nutrients are limiting production or overexploitation under conditions where water or the vegetation itself is the limiting factor. But, as has been discussed, the animal production is jeopardizing the precarious nitrogen balance in the southern Sahel, whereas the risk of overgrazing in the north, where water limits production, is small (*11*).

More efficient exploitation of the land in the short run, through better management, will lead to an increased exhaustion and overexploitation in the long run. We see essentially two possibilities for improving the situation in the Sahelian region. The first one is the creation of other possibilities for gainful employment for the pastoral people. This would result both in a decrease in grazing pressure and an increase in the price of livestock products. To maintain the stocking rate at the present level it would be necessary to find employment elsewhere for at least the equivalent of the yearly population growth of 2.5 percent. This possibility seems remote, however, because livestock farming is still one of the best investments in the region, in spite of overexploitation of the resources.

The other possibility is to arrest further depletion of the Sahelian region and to improve its production potential by introducing some main nutrients from outside. Technically, the possibilities are the direct use of urea as a source of nitrogen, the use of protein-rich by-products from fertilized arable land, the growth of fertilized forage crops, and the fertilization of rangeland.

On rangeland, phosphate could be used to stimulate the growth of the naturally occurring leguminous herbs but, although the effect is notable, the returns would be too small to make this profitable. This is also true in Australia, where phosphate is not used on rangeland with annual rainfall below 700 mm. Use of phosphate to stimulate the growth of leguminous crops on arable land has much better prospects, especially when species are grown which have seeds that can be used for human consumption and leaves and stalks as a protein-rich forage for fattening. A promising development is the use of cowpea and peanuts for this purpose. Even at current prices this practice appears to be profitable in the mixed farming systems of the savanna. And in the Sahel proper, where this practice is not profitable in the strict economic sense, it may be the most feasible improvement available for the seminomads.

It would be a first step to arrest further exhaustion of the land and to meet the increasing pressure on the environment. Since only phosphorus has to be imported, its use could be more cost-effective than expensive antidesertification projects such as dune fixation, the establishment of greenbelts, and so on, and in the long run more sensible than direct food aid.

A frequently made suggestion is to integrate the Sahelian livestock farming with the arable farming in the savanna as suggested by the "new strategies" in Fig. 6. The seminomads would supply young animals that would be fattened in the south. Often overlooked, however, is the fact that the low fertility of the soil leads not only to low yields but also to by-products of very low quality. As soon as herds have to graze on millet or sorghum fields after harvest, they rapidly lose weight. Thus, before livestock and arable farming can be integrated, agriculture in the south should first be intensified by fertilization with phosphorus and the production of leguminous crops. Even then it is doubtful whether the farmer on the savanna will be able to produce enough quality forage to keep his own sedentary livestock in good condition. And as long as he cannot, he is not likely to pay any worthwhile price for the young animals from the north.

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