Land-evaluation for semi-arid rangeland a critical review of concepts

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Introduction

The main objectives of rangeland evaluation are:
- determination of potential for animal production;
- establishment of margins for improvements;
- definition of measures necessary to achieve these improvements;
- determination of their consequences for long-term developments of the natural resource.

Despite all the efforts invested in rangeland evaluation over the past decades, there is little sign of improvement in the practice of extensive grazing (Jasiorowski, 1973), while the degradation of rangeland is alarming (United Nations, 1977). One could argue that that is due to the fact that results of rangeland evaluation programs have not been translated into effective actions to improve rangeland utilization. However, it is also questionable whether the recommendations that were developed were indeed appropriate. Part of the failures of livestock development projects may well be explained from a misinterpretation and underestimation of the productivity of present nomadic and transhumant livestock production systems and an overestimation of the opportunities to increase the productivity of semi-arid rangelands (Breman and De Wit, 1983). A critical review of some concepts used in land evaluation for extensive grazing seems therefore appropriate. For this purpose the Sahelian region will serve as an example. Most of the information will be derived from a research project on primary production in the Sahel, executed in Mali from 1976 to 1980 (Penning de Vries and Djitéye, 1982).

Present day approach of land evaluation for extensive grazing

The usual methods of rangeland evaluation contain at least the following elements:
- identification of land units based on characteristics of geomorphology, soil and vegetation.
- mapping of land units, using aerial photographs and satellite images;
- determination of species composition of the vegetations and peak bio- mass of the herb layer.

Other elements which are less often included because of greater demand for time and money are:
- measurement of physical and chemical properties of the soils;
- measurement of the quality of vegetation components as animal forage;

- distinction between palatable and unpalatable species;
- description and evaluation of the influence of rainfall, grazing and fire.

Even if the latter characteristics are determined in the survey, they are not necessarily used in the final estimation of carrying capacity and animal production because their influence is difficult to quantify. Calculation of the carrying capacity is on the primary production side mainly based on the observed peak biomass, sometimes after correcting for the difference in rainfall between the observation year and the long-term average. On the secondary production side, animal requirements are defined by a normalized intake of a standard animal. Management is loosely taken into account by a 'proper use factor'. Animal production itself, if indicated at all, is not estimated from available forage resources, but derived from data collected elsewhere, under often completely different conditions.

Those acquainted with these methods realize that such estimates of carrying capacity have a high degree of inaccuracy. So there is certainly a need for improved methods to assess carrying capacity and production potential of rangelands. Some argue that improvements can only be achieved by long-term monotoring of rangelands and extended stocking-rate trials. Others, like our team, stress the need to study basic processes determining primary and secondary production, combined with systems analysis for integration and extrapolation.

We will justify this approach by critically reviewing traditional methods of rangeland evaluation and indicating the scope for improvements.

The inaccuracy of the present-day approach: its magnitude and causes

As carrying capacity is derived from peak biomass, any variablitity in the latter will result in large discrepancies in individual estimates. Consequently, where the same region has been evaluated in different years, as is the case in some parts of the Sahel, large differences in estimated carrying capacity have resulted (Breman and Cisse, 1977). Differences in rainfall from year-to-year are certainly an important cause of variability, (Bille, 1977; Le Houerou and Hoste, 1977; Sicot and Grouzis, 1981), but are only one source of variation in primary production (Penning de Vries and Djitéye, 1982).

Improvements of rangeland evaluation can therefore only be achieved, if 'all' factors underlying the observed variability are taken into account. In addition to the dynamics of the composition and production of the vegetation, more attention has to be paid to the quality of the biomass produced, the various ecological constraints in different ecosystems and the relation between rangeland forage characteristics and animal performance. The first aspects are treated in this paper, the last one in a separate contribution (Ketelaars, 1984). Ketelaars limits himself in his paper only to growing, non-lactating, non-pregnant cattle. His approach should be used for other cattle and other species, to decrease the inaccuracy caused by the neglect of differences between animal species.

For each of the aspects treated here we will emphasize their importance, show how land evaluation can take advantage of todays insights, and indicate where gaps in the knowledge exist. In combination, both papers present a state-of-the-art report on a proposed method of rangeland evaluation (Stroosnijder and Breman, 1982; Breman, 1982).

Vegetation dynamics

Variations in vegetation composition of arid rangelands have been observed all over the world and our understanding of this phenomenon is increasing (Noy-Meir and Negbi, 1980). Variability is most extreme on rangelands dominated by annuals, such as in the Sahel and other regions with a single short and distinct rainy season (Boudet, 1975; Valenza, 1975; Granier, 1975; Diarra, 1976; Bille, 1977; Boudet, 1979; Breman et al., 1980; Grouzis, 1982; Hiernaux et al., 1983). These variations in vegetation composition cannot be neglected because they may be accompanied by differences of up to 2 $t \cdot ha^{-1}$ dry matter with the same amount of infiltrated rainwater. In the Sahel the highest biomass is produced by perennial grasses, or by fast germinating annual grasses having a C4-photosynthetic pathway. The lowest biomass is produced by slow-germinating dicotyledonous herbs having a C3-photosynthetic pathway. This difference in photosynthetic pathway is accentuated by the more favourable nitrogen-utilization efficiency of C4-species. In addition other differences between both groups justify attention for vegetation dynamics: The loss of biomass during the dry season due to physical deterioration and leaf fall in the absence of grazing is higher for the last group, but the risk of loss by fire is much higher for the first, because of the higher, less deteriorating biomass. If, however, perennial grasses dominate the vegetation, fire is not only a risk, but also a valuable management tool. These arguments show that vegetation dynamics may be a source of inaccuracy, especially if peak biomass measurements of a single year are used for rangeland evaluation.

Yet, in practice the situation may be less dramatic. On the one hand the importance of individual species for animal production potential is easily overestimated (see next paragraph, about forage quality). On the other hand, changes in vegetation composition and their effect on yield are to a considerable extent understood, and measurements on a certain pasture in a particular year can be used to extrapolate to years with different conditions. The vegetation composition is therefore an important indicator for the prevailing land type and rainfall regime, and it may be used to establish the range condition and its suitability for different animal species.

Predicting vegetation dynamics requires an understanding of the interactions between environmental factors and plant characteristics. Our understanding of the processes that play a role in these relations has increased substantially as a result of both field and laboratory research. The basic characteristics determining the vegetation composition under particular conditions are summarized (Table 1). It refers particularly to semi-arid rangelands, but the concepts themselves have general applicability.

Basically, there are two fundamental steps in explaining vegetation dynamics. First, the physical environment, characterized by a certain climate, substrate and exploitation intensity should be classified on the basis of its effect on conditions for germination, establishment, growth and reproduction of plant species. Secondly, plant species should be classified according to their strategy for germination, growth and reproduction. This means that we should de-emphasize the classification according to botanical name (taxon) as this says little about adaptive strategies. In Table 1 species are not classified by botanical names, but according to strategy for growth and survival into perennials and annuals, according to strategy for germination into fast and slow germinating species, according to type of carbohydrate assimilation, in C3 and C4 species, and according to growth habit in grasses and forbs.

Ecosystems are distinguished on the basis of amount and pattern of water availability and temperature regime. Moisture availability is such an overriding factor for the vegetation of (semi-) arid lands, that the main influence of the substrate is through its effect on the water balance, as governed by texture, slope and infiltration capacity. In coarse sands, and on loamy and clay soils in extended plains precipitation infiltrates almost quantitatively and homogeneously. Under such conditions, the resulting vegetation is homogeneous and rather poor in species number. The amount of rainfall and its distribution pattern determine which plant type dominates and what the ensuing length of its growing cycle will be.
In other landscapes where relief, crust formation or shallow soil depth lead to heterogeneous distribution of infiltration caused by local run-off and run-on, the vegetation is more heterogeneous and richer in species.
Temperature affects water availability indirectly through its effect on evaporative demand, but it also affects the vegetation directly through its influence on germination rate and CO_2 assimilation, with different optima for C4 and C3 species. Lower temperatures associated with rainfall events and shaded habitats seem to create niches for C3 species in the generally warm sub-humid and semi-arid tropics and could explain why these species are favoured by the presence of shrubs and trees. They also favour slow-germinating species as stem-cured hay and litter do. In all three cases the influence is indirect; exhaustion of the seed stocks of fast-germinating species is caused by germination flushes triggered by rainfall events much too small to provoke germination under the high evaporative demand of unprotected soil. Fire interferes by destruction of the plant biomass protecting the soil. Herbivory activity (including termites) does the same and can favour fast germinating species. The process is however counteracted by heavy grazing during the germination stage, which leads first to exhaustion of the seed stock of the fast germinating species. But much more important is the decrease by grazing in protective organic material on the soil surface lasting into the dry season. This leads, at the onset of the next rainy season, to crust formation and sealing under the influence of raindrop impact and hence to increased run-off. Thus slow-germinating species will be favoured.
The last plant characteristic treated in Table 1 is growth form. Erect grasses are favoured under high vegetation density, problably by competition for light. Fire and grazing also favour grasses. The latter effect is explained by their protective growing point. The first one by the removal of litter and its influence on conditions for germinating.

The consequences of the various interactions between environmental factors and vegetation characteristics for rangeland ecosystems in various ecological zones in the Sahara-Soudanian transect are summarized in Table 2. In the Sahara erratic and low rainfall allows only locally plant growth in wadis with run-on. The irregularity of rainfall causes slow, heterogeneous germination. In the extreme North winter rainfall and in the South summer rainfall leads to a dominance of C3 and C4 species respectively. Near the Atlantic coast

Table 1. Some qualitative relations between eenvironmental factors and plant characteristics in (semi-)arid rangelands.

Species characteristics	Perennials	Annuals					
Environmental factors		Germination		Photo synthesis		Growth habit	
		fast	slow	C4	C3	grass	forb
Climate:							
rainfall							
– irregular	+		+				
– fixed period:							
monomodal		+					
bimodal	+						
– limited (arid)		+	+				
– abundant (semi-arid)	+						
Temperature:							
– high		+		+			
– low			+		+		
Substrate:							
infiltration < rainfall			+				
infiltration = rainfall		+					
infiltration > rainfall	+	+					
Vegetation:							
mulch, shrubs & trees			+		+		
Density herb layer:							
– high						+	
– low						+	+
Management:							
fire		+				+	
grazing			+			+	

in Mauretania a transition occurs from the West-african monsoon climate with summer rainfall to the mediterranean climate with winter rainfall. Moreover, the temperature regime in that area is moderated by the influence of the sea. Consequently the chances for plant life are more favourable and because of the irregular rainfall pattern, which sometimes leads to deep wetting of the soil profile, perennials are also present. The northern Sahel is characterized by a short, but fairly fixed period of water availability, a low amount of available water, and high temperatures during the rainy

Table 2. Characteristics of vegetation types of the principal ecological zones of the Sahelian countries.

Species characteristics	Perennials	Annuals germination					
		fast		slow, heterogeneous			
Ecosystems		forb	C4 grass	C4 grass	C4 forb	forb	C3 grass
Sahara:							
continental:							
I > R, North	(+)					(+)	(+)
South	(+)			(+)	(+)		
maritime (West):							
I = R				+	+		
I > R	+			+	+		
Northern Sahel:							
I < R				+	+		
I = R		+ +	+ +	+	+		
I > R	+	+	+ +	+	+	+	
Southern Sahel:							
I < R		+	+	+ +	+	+ +	
I = R	+	+	+ + +	+ +	+	+	
I > R	+ +		+ +	+		+	
Soudan savanna:							
I < R	+		+ +	+ +		+ +	
I = R	+ +		+ +	+		+	
I > R	+ + +		+	+			

(+) = local presence; + = not negligible; + + = dominant group, relatively low biomass, or co-dominant group; + + + = dominant, relatively high biomass; I = infiltration; R = rainfall.

season. Water availability in the soil is generally equal to rainfall amount as most soils are coarse sands where run-off is absent (I = R). This environment favours species which germinate rapidly with the first rains, which have a short growth cycle, and which benefit from high temperatures during the growth season. These are mainly C4- species, both grasses and forbs, as the open vegetations create opportunities for different growth habits. Locally, soils developed on weathered laterite or sandstone, occupying about 10% of the total area, exhibit run-off and run-on. Where run-off takes place (I < R) only the slow-germinating species survive as the seed stock of fast-germinating species is exhausted by successive germination

Table 3. Trends in vegetation composition of rangeland in the southern Sahel, on sandy soils with a high infiltration capacity.

Species characteristics	Perennials	Annuals germination				
		fast		slow		
		C4		C4		C3
Conditions		forb	grass	grass	forb	forb
Dry year after years of drought		+	+	++	++	+
Wet year after years of drought		+	+++	+		
Continuous heavy grazing			+	+	++	+++
Several years without fire, or bad start rainy season	+	+	+	++	+	++
'Normal'	+	+	+++	++	+	+
Good start rainy season	+		+++	+		
Wet year after several wet years	++		+++			

(Code see Table 2)

flushes. At the run-on places (I < R) higher moisture availability leads to a higher biomass and a more diverse species composition.
The southern Sahel is the domain of fast-germinating annual grasses dominating the eolian sands (50% of the area of the zone), the plains and depressions of the landscapes on weathered laterite or sandstone and part of the alluvial soils (10% of the zone). Slow-germinating annuals become important on places with run-off, especially in the plains and depressions. Perennials are stimulated on sites with relatively deep penetration of water due to run-on river-flooding. Their importance increases in the higher rainfall region of the Soudanian savanna. Here, as well as in the southern Sahel, grasses dominate over forbs due to competition for light.

The general picture presented in Table 2 refers to the long-term average situation. Large deviations from that general picture may occur under particular conditions or in individual years with special weather conditions (Table 3).
Interpreting conditions of a particular year or series of years in terms of conditions for germination, growth and repoduction of plant species, will help to explain the deviations in vegetation composition, from a 'normal' situation. A 'normal' year has to be regarded as the weighted mean of a long series of different years rather than as the situation with highest probability. The direction of fluctuations is around this average situation. A normal situation can thus be derived from the vegetation composition in any particular year if the conditions of that year are carefully interpreted using Table 1. If the necessary data for such an analysis like amount of rainfall,

rainfall pattern, grazing intensity and calendar, fire frequency and period (Stroosnijder and Breman, 1982) are lacking, field indicators may be applied:

- A relatively wet or dry precipitation regime in the recent past may be deduced using perennial plants and the mean lenght of the growing cycle of the dominant species present as indicators;
- recent grazing pressures may be deduced from the degree of vegetation gradients along transects radiating from a watering point of camp site;
- fire frequency may be deduced from the presence of standing dead residual dry matter, and a litter mulch.

The relations between environmental conditions and the associated vegetation dynamics are well enough established to take them into account in rangeland evaluation.
A more quantitative description of the 'normal' vegetation composition than that presented in Table 3 was derived on the basis of three years of observations on 70 permanent quadrats along a north-south transect in the Sahelian zone covering an average annual precipitation from 100-1300 mm. The relative importance of species types in the biomass at the end of the growing season for the three main landscapes of the southern Sahel is presented in Table 4. The data referring to sand dunes are the most closely related to the 'normal' conditions presented in Table 3. A difference is however the lack of perennials in the vegetation of sand dunes as presented in Table 4, an effect of the drought in the beginning of the seventies. This

Table 4. Relative importance (%) of species types in the biomass at the end of the growing season for the three main landscapes of the southern Sahel in Mali, during the period 1976 – 1987.

Species characterists	Perennials	Annuals germination			
		fast		slow	
	herbaceous	C4		C3	C4+C3
Landscape types		forb	grass	grass	forb
Sand dunes (limited relief; fine sands or loamy fine sands;	–	5	55	20	20
Loamy plains (fine sandy loams or loam; I = 50-70% R; local run-on);	5	5	35	20	35
Clay depressions (clay loam to heavy clays; I = 100-125% R; locally more run-on).	–	–	65	15	20

(I = Infiltration; R = Rainfall)

brings us to the last subject to treat under the heading 'vegetation dynamics', gaps in knowledge.

Application of an analysis along the lines presented here outside the Sahelian countries may be difficult, because the relevant species characteristics may not always be available, nor quantitative data like those presented in Table 4. Moreover, the Sahel is a rather extreme ecosystem because of its distinct, single, summer rainy season with high temperatures and its low, flat sandy soils. These conditions tend to favour one particular group of the species: the fast-germinating C4- type grasses. In other rangeland areas, the contribution of perennials and species with the C3-type photosynthesis is often much greater due to higher rainfall or less seasonality and to lower temperatures in the growing season. Such conditions are generally associated with greater distance from the equator, higher altitudes, or influence of the sea due to the prevailing wind direction.

There are several reasons to emphasize the relative importance of annuals and perennials:

- Most of the theory on range management has been developed for perennial vegetations; ,management aims and options are therefore often geared to the specific properties of perennial forage plants (e.g. Stoddart et al., 1975);
- Vegetation dynamics are less important as a source of inaccuracies in rangeland evaluation with increasing dominance of perennials;
- Perennials protect the environment better than annuals against degradation.

Because of the preoccupation of rangeland specialists with perennials, rural development programs in Sahelian countries often recommend rangeland management and improvement practices, based on the advantages of a high proportion of perennials in the vegetation. However, what is overlooked is the limited potential for re-establishment of perennial species in some of these ecosystems. We feel that the lack of detailed knowledge about perennials in the Sahel in comparison with the annuals (Table 2-4) is no extra handicap for rangeland evaluation during wet periods when they are more common. Since evaluation and management methods have been developed for perennial pastures, one has to know when and where perennials can be expected. Is the lack of perennials at a particular site an indication of severe drought or wrong grazing management for example? In Penning de Vries and Djitéye (1982) it is argued that annuals win the competition with perennials for water and nutrients, if both exploit the same resources, while long periods without any water occur too often. To verify this hypothesis, and to quantify 'long' and 'often', depth and duration of soil setting is studied for different rainfall regimes and substrates. The first results indicate that indeed in years with normal or below normal rainfall, annuals and perennials compete for the same water, at least where infiltration is equal or less than the annual rainfall. In general, annuals seem to be stronger competitors in this situation: the establishment of young perennial plants, as well as the survival of mature plants is hampered by lack of water during the long dry season.

Forage quality

A second source of inaccuracy in range evaluation is the method of evaluating quality of plant biomass. Errors are made when quality is regarded as a simple attribute of a plant species, or at most specified differentially for green and dry matter. In reality, however, quality is often neglected and the carrying capacity is simply derived from the peak standing biomass. An indication of the degree of inaccuracy resulting from both simplifications will be presented, followed by an alternative suggestion and an overview of the problems still to be solved.

The emphasis on species composition of vegetations in rangeland evaluation is justified in view of its indicator value for range conditions. There is a risk of overemphasis, however, if the forage quality is directly derived from such species compositions. Quality is much more an expression of a certain environment than a species characteristic. Of course, certain species are more palatable than others and some species will never be eaten by livestock because of spines or toxins. But the same species may vary widely in quality depending on the relative availability of water and nutrients. Breman et al. (1980) used the nitrogen concentration to demonstrate the variability in quality of three important annual grasses from central Mali. The N concentration in Cenchrus biflorus, Schoenefeldia gracilis and Diheteropogon hagerupii, at the end of the growing season for samples collected in the period 1976-1978 ranged from 0.7-1.7%, 0.7-1.5% and 0.4-0.9%, respectively.

Other examples from the same region and period indicate a variation from

Table 5. The relative importance, in percentages of the sampled permanent quadrats, of classes of nitrogen concentration for two C4 annual grasses (Schoenefeldia gracilis and Cenchrus biflorus), a C3 dicotyledon (Borreria radiata) and a C3 legume (Alysicarpus ovalifolius) at their stage of seed setting, in 1979, on a transect between the 200 and 1000 mm isohyets in central Mali.

Species	N	Nitrogen concentration (%)					
		0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
Schoenefeldia gracilis	21	62	38				
Cenchrus biflorus	21	16	71	10			
Borreria radiata	15	7	60	20	7	6	
Alysicarpus ovalifolius	16			25	63	6	6

(N = the number of permanent quadrats where the species were found and sampled).

0.4-0.8% for the perennial grass Andropogon gayanus; 0.9-2.6% for the C3 dicotyledon Borreria radiata; 1.6-3.1% for the legume Alysicarpus ovalifolius. Even within one single year a strong variability of nitrogen concentration exists in samples collected from sites with different soils and rainfall regimes (Table 5). All soils were very low in fertility. The high values of nitrogen concentration in Table 5 refer to situations with low rainfall, strong run-off or a short daylength determined vegetative growth period. They could , however, also be provoked by fertilization. Only knowing the species composition of the vegetation is of little direct help to estimate the quality of the forage.

Neglecting species composition and quality, and deriving the carrying capacity from the peak standing biomass is however also a cause of inaccuracy. This can be illustrated by estimating biomass and carrying capacity under different conditions for the pasture on sandy soils, shown in Table 3 (One situation is added: a plot protected for a very long time in a very favourable year). The peak biomass and its nitrogen concentration are estimated using data from Penning de Vries & Djitéye (1982). To calculate the carrying capacity in the usual way it is supposed that 35% of the biomass is consumed, and a Tropical Livestock Unit (TLU, a 'standard' animal of 250 kg liveweight) will eat 6.25 kg dry matter per day. The results are presented in Table 6. At the same place peak biomass varies with a factor of 10 between years, and so does carrying capacity, if quality aspects and pasture dynamics are neglected. In practice, the extremes will not often occur. But errors of a factor 2-3 can easily be made (Breman and Cissé, 1977). As it is clear from Table 6, the largest change in peak biomass will occur if perennials become dominant due to a series of years with favourable rainfall. If in addition grazing and fire are also excluded, a large stock of nitrogen can be built up with an associated high peak biomass. This may constitute a major reason for overestimating carrying capacity, if based on peak biomass measurements in pastures, which have not been grazed nor burnt for several years. If after a period of complete protection grazing (or fire) is reintroduced, pasture production will drop to a much lower level because nitrogen availability decreases as a result of reduced recycling of nitrogen in the soil-plant system. Table 6 also presents a carrying capacity value based on the alternative land evaluation method. That method, mainly based on the nitrogen balance of the soil-vegetation system, is presented in detail elsewhere (Penning de Vries and Djitéye, 1982.

The essential characteristics relating to the forage quality will however be mentioned briefly.

- It will be clear from Table 6 that biomass and species composition in an arbitrary year do not form the starting point for calculations of carrying capacity. The primary production of (semi-)arid rangelands, both in terms of quantity and qualily, can be reasonably estimated from the availability of water and nutrients.
- Species composition plays a role in describing the distribution of biomas quantity and quality, and their change throughout the year. A C4-type vegetation for example, will produce twice as much biomass as a a C3-type vegetation, with consequently half the nitrogen concentration in the dry

Table 6. The carrying capacity of rangeland in the southern Sahel on sandy soils with a high infiltration capacity, after Penning de Vries & Djiteye (P.P.S.) and based on traditional estimates in different years (biom.).

Moisture condition	$t \cdot ha^{-1}$	%N	Carrying capacity	
			biom.	P.P.S
Dry year after years of drought	1.2	0.9	5	
Continuous heavy grazing	2.0	1.0	3	
Badly started rainy season	1.0	1.0	6	
'Normal'	2.8	0.6	2	10
Well started rainy season	4.0	0.5	1	
Wet year after several wet years	5.5.	0.5	1	
Wet year after several wet years without grazing and fire	10.5	0.9	0.5	

(Carrying capacity in ha. TLU^{-1}).

matter. Other relevant distinctions are those treated in Table 1. Thus, not the vegetation composition in an arbitrary year is used, but that of a 'normal' year that is derived from it (Table 4).

- The calculation of the carrying capacity is based on the availability of the main limiting factor for plant growth and the related availability and quality of forage during the worst period of the year.
- The annual production of those animals is calculated on the basis of the amount and quality of ingested food. The distribution of biomass quantity and quality and their change over the year are taken into account, as well as the type of livestock system and its production options.

The last condition explains the difference in carrying capacity estimated by the method presented here and the more traditional one (10 against 0.5-5 $ha \cdot TLU^{-1}$). The figure of 10 ha per TLU refers to sedentary grazing of beef cattle at the condition of zero weight loss during the dry season. If a certain weight loss is acceptable the carrying capacity can be adjusted accordingly (Ketelaars, these proceedings). It is also possible to make adjustments for very dry years.

In the approach presented here fieldwork is no longer the basis for rangeland evaluation. It serves as the verification for theoretical estimates, and an effective way to assess deviations in for instance the supposed soil fertility and to establish the present condition of the rangeland.

So important elements for rangeland evaluation are the influence of rainfall amounts on nitrogen availability, and the modifying action of exploitation and fire on processes of the nitrogen balance of the soil-plant system.

With the method presented average amounts of nitrogen for a certain rainfall pattern and exploitation intensity may be estimated fairly accurately. However, considerable variations may occur and they are not yet completely understood. Sometimes a higher contribution of nitrogen from leguminous species than expected is the reason.

The presence of perennial species, causing a relatively low turn-over of nutrients in the soil-plant system due to their internal recirculation may also be a factor. A third and important factor is probably depth and duration of soil wetting, since that may influence the amount of nitrogen released by mineralization. Major efforts should be directed to increase our understanding of nutrient availability in rangeland ecosystems as influenced by climate, soil fertility and exploitation level.

Ecological constraints

A third source of errors is a lack of recognition of differences in constraints between ecological zones. This may result in incorrect appraisals of the primary and secondary production potential of rangeland. Three examples will be briefly treated all related to our central theme: rangeland evaluation has to lead to the recognition of the principal limiting factor for plant production, and its consequence for animal production.

The first mistake concerns the all too consequent pre-occupation with high biomass and green. An arbitrary example is the 'forage-index' an one-dimensional combination of quantity and quality scores of the vegetation. High biomass and green material get high scores, low biomass and dead dry matter low scores. (for example Dudzinski et al, 1982). Such an index will be correct in situations where perennials dominate or where differences in biomass reflect differences in plant production due to variation in soil fertility. But many rangelands have a more or less constant availability of nutrients with a wide variation in water availability. This condition is the basis of an inverse relation between the amount of biomass produced and its quality in rangelands all over the world (Breman and De Wit, 1983). Under these conditions low biomass has to score high, as is well recognized by pastoralists in the Sahel as witnessed by their migration pattern. And even when the primary production is strongly determined by shortage of nutrients, differences in vegetation composition such as illustrated in Table 1 may also cause an inverse relation between forage quality and quantity. The amount of nitrogen or phosphorus which comes available from the soil during the growth season, fixes the upper level of biomass production, as both elements can be diluted to only a certain minimum level. This minimum concentration ultimately depends on efficiency of nitrogen use. Short-lived species will often dilute less than long lived species, as do species of the C3-type in comparison with those of the C4-type. Legumes fixing their own nitrogen have still another special position. The assumption that green forage has a better quality than standing hay is not always true either.
To avoid definition of an oversimplified forage index it has to be established to which degree water or nutrients limit plant growth, and further which plant type uses the limited plant growth resources.
There are two main problems still to be solved, both related to quality aspects. The first one concerns the question to which degree perennial plant species have nitrogen and phosphorus concentrations different from those expected on the basis of the relative availability of these nutrients and of water in the top soil. Unlike annual species, perennials can remobilize nutrient reserves built up in the roots and stubbles, while their roots will have a greater chance to reach deep water and nutrient resources. At least

for woody species there is no significant decrease of the nitrogen and phosphorus concentration in the leaves with increasing mean annual rainfall from the North Sahel to the Soudanian savanna zone.
The other problem concerns digestibility. To a certain degree a parallel exists between digestibility and the nutrient concentration. But the question remains to which degree digestibility is species characteristic. Again woody species form a particular group, for example, tannins may interfer with digestion (Diagayété, 1981).

The second example of errors originating from neglecting differences in ecological constraints between zones is the 'proper use factor'. This factor is rightly introduced to indicate that only part of the estimated annual rangeland production can be exploited to avoid degradation of the resource. The just treated over-evaluation of high biomass in the forage index may be partly explained out of fear for rangeland destruction.
The proper use factor is always expressed as a fraction of the plant biomass (for example, 35% in the calculation of the carrying capacity in Table 6). This is logical if the main risk of grazing is the disturbance of the nutrient balance from the soil-plant system or from perennial plants as such (De Wit and Krul, 1982). If, however, soil erosion or increased run-off through crust formation is to be avoided, an absolute minimum amount of plant biomass is needed to protect the soil surface. As a consequence, variable fraction has to be used at a variable annual production, while years may occur that the total plant production has to be left ungrazed.
The amount of biomass needed to protect the soil surface against physical degradation will depend on soil texture, slope, and the amount of rainfall and its pattern. And again the presence of perennials has to be taken into account. Quantification of the relation between risk of soil degradation and the necessary protective cover is another worthwhile research subject to improve the accuracy of rangeland evaluation.

The last example of inaccuracy that results from extrapolation of data from one area to another, without proper attention for differences in the environmental conditions is related to optimum stocking rates. The fraction of the biomass that is available for exploitation is not only determined by environmental constraints, but also by the aims and the systems of animal production. The effectiveness of traditional pastoral systems is often underestimated because no distinction is made between production per animal and per hectare (Breman and De Wit, 1983). Evidence of low production per animal is used as a basis for the conclusion that over-exploitation takes place, in the sense that lower stocking rates could increase total production by an increase of the production per animal. That is not necessarily true, at short or medium-term, even if there are already signs of resource degradation. A maximum total production per hectare at a relatively low stocking rate and a high production per animal may probably be expected under the following conditions:

- soils susceptible to sealing, with the risk of increasing run-off;
- the regrowth of herbaceous perennials or green woody species forms often an unreplaceable forage resource;
- herd mobility is limited;
- milk is the main product.

Maximum total production per hectare at a relatively high stocking rate and a low production per animal on the contrary may probably be expected under conditions where:

- primary production is strongly determined by nutrient availability;
- annual species are dominant;
- mobile production systems exist;
- meat is a main product.

For each of these factors quantitative relations have still to be established for various ecological zones.

Conclusion

To improve the present-day rangeland evaluation method less emphasis should be placed on peak biomass measurements. Instead more attention should be paid to vegetation dynamics, forage quality and ecological constraints. Rangeland evaluation should be based on understanding of the nutrient availability and water availability for each particular rangeland, as these are the real determinants of the productive potential. Our understanding of the processes determining these factors is still incomplete, and research should concentrate therefore on the following topics:

- depth and duration of soil wetting;
- species specific contribution to forage quality;
- minimum biomass required for soil protection;
- optimum stocking rates for different rangelands, taking into account differences in animal species and production systems.

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