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Introduction

Ever since colonial administrators and western trained scientists became involved in sub-Saharan Africa in the early 20th century and were faced with the task of governing countries where livestock production was a major economic enterprise, the proper utilisation of rangelands became a major concern. While during most of the colonial era devastating epidemics (like rinderpest and pleuropneumonia) kept the growth of livestock populations in check, during the 1950s and 1960s regional campaigns of eradicating these major cattle diseases created a continuous increase in livestock numbers. It is estimated that between 1963 and 1970 annual growth of cattle populations averaged 2.8%, but slowed down to 1.25% per annum during 1970 to 1980 (Antenneh 1984).

While up to the 1950s constraints of feed shortages for livestock were outweighed by those of disease, concern over looming imbalances between supply and demand of grazing resources led to large investments in projects of water development, many of which were financed by foreign aid. This provision of water to hitherto underutilised grazing lands further stimulated herd growth, but at the same time encouraged more settled modes of production and reduced mobility. While watering rights of man-made traditional wells were tightly enforced and served as a control on over-exploitation, water sources that were publicly financed were open to all, breaking the age-old equilibrium between water and rangeland use (Sandford 1983, Swift 1984).

The need for establishing criteria and ways for determining the carrying capacity of African rangelands became more strongly felt when in the 1960s and 1970s several regions were hit by droughts (1960 to 1961, 1973 to 1976 in East Africa; 1969 to 1973, 1979 in West Africa) causing enormous stock losses.

This paper investigates common approaches to determine carrying capacity, elucidates the problems associated with applying the concept in sub-Saharan Africa, and suggests ways of broadening the concept to improve its applicability in this continent.

Definition and assumptions

Carrying or grazing capacity (CC) is defined as the maximum possible stocking of herbivores that rangeland can support on a sustainable basis (FAO 1988). Estimates of CC are commonly based on the assumption that livestock require a daily dry matter (DM) intake equivalent to 2.5% to 3.0% of their bodyweight. Thus, for a tropical livestock unit (TLU) of 250 kg of weight, 2.3 to 2.7 t of dry feed per annum is needed. To calculate an appropriate balance between forage supply and demand three multipliers are additionally required to adjust for:

1 - grazing efficiency (the proportion of total herbage livestock can harvest

2 - forage loss (due to trampling, fouling, decomposition, etc)

3 - proper use, which is the maximum proportion of forage that can be grazed without causing rangeland deterioration (FAO 1988)

Although each of these three factors need consideration, most estimates have used a single multiplier that combines adjustments for all. For example, Le Houérou and Hoste (1977) assumed that, in the Sahel, total dry matter (TDM) contained 40% edible forage, while in S Ethiopia, Cossins and Upton (1987) stated that one TLU required 8 t DM pa which converts to a utilisation rate of about 30%. Van Wijngaarden (1985) proposed a proper use factor of 45% of TDM during the dry season based on his finding that when use was higher, perennial grass cover declined in the subsequent growing season.

In the arid zone of Niger, where wind erosion and loss of soil organic matter are prime concerns, protective cover equivalent to 0.2 t DM Ha^{-1} should be left at the end of the dry season, while a natural decomposition rate of 4% per dry month was allowed, which over 9 dry months converts to a 30% decline of the end of the wet season biomass (Wylie *et al.* 1988). Hiernaux (1982) in Mali described a similar method of adjustment for rangelands with mainly annual species. Variable monthly rates of disappearance were assigned resulting in a 50% decline in standing biomass from October to March. Thereafter, during the hot and humid period of the late dry season rates increased so that at the end of June only 10% of the original biomass was left.

As a result of these adjustments and corrections, estimates of CC do vary. For instance, in the Sahel, along the 400 mm isohyet with an average TDM of 1.1 t ha^{-1} (Table 1), three authors (Le Houérou and Hoste 1977, Wylie *et al.* 1988, Hiernaux 1982) predicted a year-round CC of 5.2, 4.4 and 7.0 ha TLU^{-1}, (19, 23, 14 TLU km^{-2}) respectively, which compares reasonably well with 5.5 ha TLU^{-1} (18 TLU km^{-1}) for East Africa given by Pratt and Gwynne (1977) for the same annual rainfall.

Table 1: Estimation of total DM production from annual to seasonal rainfall (t DM ha^{-1})

Rainfall (mm)	200	400	600	800	Ref
West Africa	0.6	1.1	1.7	2.2	(1)
Zimbabwe (WC:100mm)[a]	0.5	1.7	2.2	2.5	(2)
Zimbabwe (WC:200mm)	0.7	2.6	3.2	3.7	(2)
Kenya	1.1	2.3	3.6	-	(3)

(1) Le Houérou and Hoste 1977
(2) Dye and Spear 1982
(3) de Leeuw and Nyambaka 1989

[a] WC - water holding capacity

Average carrying capacity using TDM

To estimate CC, empirical relationships between annual or seasonal rainfall and total end-of-season herbaceous TDM ha^{-1} are commonly used (Table 1). Prediction for three areas in Africa indicate that over a rainfall range of 200 to 800 mm, TDM in t ha^{-1} in Kenya is higher than in West Africa due to higher fertility and greater water-holding capacity (WC) of the soils and lower evaporation rates because of altitude, conditions that give rise to a predominantly perennial grass cover. However, TDM production in West Africa differs less if it is further adjusted for soil water-holding capacity. Rains and Kassam (1979) suggested that TDM values for West Africa be adjusted 50% upwards for deep heavy upland soil and 50% downwards for shallow stony soils; thus for 400 mm of rain, TDM would range from 1.7 to 0.5 t DM ha^{-1}. This is a wider range than that given for Zimbabwe by Dye and Spear (1982), where TDM yields on heavy soils was about 50% greater than on sandy soils (Table 1). Similarly, van Wijngaarden (1985) in Eastern Kenya predicted for a seasonal rainfall of 200 mm, a yield of 1.1 t DM on deep sandy clay soils and 0.6 t on shallow gravelly soils.

Further corrections are required for the effects of run-off and for woody cover. Run-off is usually accounted for by substituting total by effective rainfall. For instance, in the 300 to 400 mm zone in Burkina Faso, Grouzis and Sicot (1983) showed that run-off was 10% to 23% of total rainfall and the results of their regression equation of effective rainfall on TMD is similar to that of Le Houérou and Hoste (1977). For a detailed account of the effects of run-off and run-on on primary productivity in the Sahel, reference is made to Penning de Vries and

Djiteye (1982) and to Hiernaux (1982).

Reduction of herbaceous TDM due to woody cover has been discussed by several authors. In Kenya, van Wijngaarden (1985) found that for each 10% increase in woody cover perennial herbaceous cover declined by 7% reaching zero cover when the woody canopy reached 90%. Rains and Dassam (1979) developed a non-linear relationship where at 20% woody cover TDM was reduced to 73%, and to a mere 17% when the ligneous stratum reached 60%. Timberlake and Reddy (1986) used this relationship to adjust their estimates of CC for grazing lands of Mozambique. An even large effect of the tree strata on herbaceous TDM was reported in the subhumid zone in Mali with a mean rainfall of 1,100 mm. Without tree cover, recorded yields were 5 t DM ha^{-1} which dropped linearly to 1 t when tree cover increased to 40% (Penning de Vries and Djiteye 1982). Rutherford (1978) confirmed the inverse relations between herbaceous production and wood cover in Southern Africa, and for his carrying capacity map in Botswana, Field (1978) assumed reduction of 5% in CC per every 100 units of trees/shrubs ha^{-1}. However, decline of herbaceous biomass due to woody cover is offset somewhat by increased browse production, the magnitude of which depends on species composition and degree of woody cover.

The livestock-oriented approach

Using total herbaceous forage productivity as the single criterion to predict the livestock support capacity has been criticised because biomass quality and feeding value for livestock are largely ignored. Thus, if the concept of CC would be expanded to include that the maximum allowable stocking rate should be set at a level so that the specific production objectives of livestock are to be met, CC should be linked to nutritive value, in particular to the crude protein (CP), energy and mineral content of the TDM (FAO 1988).

Predictions of forage quality in the Sahelian environment were based on the finding that below 300 mm of rainfall per season, soil moisture was the most important factor controlling plant growth, while above this isohyet soil nitrogen and to a lesser extent phosphorus became major contributing factors (Penning de Vries and Djiteye 1982). Plant N uptake was associated with herbage N-content at the end of the growing season, while the soil N-balance could be calculated from expected gains and losses. N-uptake by herbaceous plants is mainly governed by rainfall and over a rainfall from 400 to 1,000 mm, N-uptake increases from around 10 to 20 kg N ha^{-1}. As a consequence, for any given seasonal rainfall N-content of herbage at the end of the growing season becomes a function of total yield. Due to this N-dilution, Penning de Vries and Djiteye (1982) showed that across this rainfall gradient in West Africa TDM increased from 1.1 to 4 t ha^{-1}, while the end of season N-content declined from 1.0 % to 0.5 % (6.2% to 3.1% CP).

The high quality in grass biomass in arid areas was confirmed in Kenya. In Turkana, average protein in cattle diets consisting almost entirely of grasses was 11.6% CP (1.8% N), and declined somewhat in the long dry season but remained above 8% CP or 1.3% N (Coppock *et al.* 1986). Similar levels of 7.0% to 8.8 % CP (1.1% to 1.4% N) in dry season grass were reported by van Wijngaarden (1985) working in arid Eastern Kenya. These trends in herbage quality along rainfall gradients explained the growth performance of cattle. In Northern Niger at 320 mm rainfall, steers gained up 80 kg during the short rainy season and lost little weight during the dry season provided sufficient forage was available (Klein 1981, Wylie *et al.* 1983), In contrast, cattle grazing rangelands receiving 400 to 500 mm further south, gained 60 to 90 kg during the rains, but net annual gains per head were much lower due to weight losses of 30 to 50 kg during the dry season (P Hiernaux, *unpublished data*).

Traditional livestock owners in the semi-arid and subhumid zones in West Africa have adopted several strategies to reduce this quality constraint in the dry season by herd mobility or by relying on feed sources other than dry standing grass. Transhumance patterns involve long-distance treks to better feed sources in flood plains such as the inner Niger delta in central Mali, the Benue river and the shores of Lake Chad. In Northern Nigeria sedentary stock owners achieved better dry season diets for their stock by herding them to cultivated land with crop residues after harvest in the early dry season and by switching to browse, valley grassland and regrowth after fire later in the dry season (Table 2). Similarly in central Mali, rice straw and grass regrowth in fields that were irrigated during the wet season were main sources of dry season feed for cattle, while small stock were taken to upland grazing grounds to enable them to browse (Table 3).

Table 2: Fodder composition of cattle diets in two agropastoral systems in three seasons in semi-arid Nigeria (in % of grazing time)

Annual rainfall	700 mm			1,000 mm		
Season	wet	early dry	late dry	wet	early dry	late dry
Months	Jun -Sep	Oct -Jan	Feb -May	Jun -Sep	Oct -Jan	Feb -May
Upland savanna	76	24	59	96	56	22
Regrowth after fire	6	1	11	-	-	-
Valley grassland	8	28	3	1	5	58
Browse	10	6	12	3	4	5
Sub total	100	59	85	100	65	85
Cereal residues	-	31	9	-	23	5
Legume residues	-	4	4	-	10	-
Cotton residues	-	6	2	-	2	10
Sub total	-	41	15	-	35	15

Adapted from: Van Raay and de Leeuw 1974

The presence of these extra feed resources accounted for the relatively high stocking rates of 10 ha TLU^{-1} (10 TLU km^{-2}) in the dry season and 6.4 ha TLU^{-1} (16 TLU km^{-2}) in the wet season in this area (Bourn and Wing 1985a).

Sources of variation

A shortcoming of the carrying capacity concept is that it is often regarded as a static assessment, while it should be seen as varying in space and over time. Spatial variability occurs at several levels and is caused by differences in soil type, grazing pressure and incidence of fire, resulting in variable species composition and degree of plant cover. In Sahelian rangeland, where annual species with either C_3 or C_4 photo-synthetic pathways and contrasting germination strategies occur together, small-scale spatial and temporal variation in yields is large (Breman *et al.* 1984). For instance, Hiernaux (1983) demonstrated that in a Sahelian dune landscape, total TDM measured over a 3 year period was 1.8 to 2.0 t on the crest, 0.5 to 2.0 t along the slope and 2 to 7 t ha^{-1} in inter-dune depressions that benefited from run-on moisture.

In rangelands with perennial grasses, the degree of plant cover is often an important source of variation. Van Wijngaarden (1985) found that apart from differences due to the depth, texture and fertility of soils, the response to rainfall was mainly governed by the amount of perennial plant cover. In pastoral areas, reduction of plant cover is often unavoidable and related to ‘sacrifice areas’ along livestock trek routes, around water points and homesteads.

Variability on a large scale can be sometimes deduced from detailed vegetation maps. In a limited area (260 km^2) in Burkina Faso, rangeland yields were recorded and mapped in 1977 and 1980 when seasonal rainfall was 440 and 310 mm respectively. The distribution of yield classes showed a range from 0.2 to 5 t ha^{-1} and differed markedly between years (Table 4).

In recent years the variability of TDM over large areas has been assessed through AVHRR/NOAA imagery[1] using regression equations of the Normalised Difference Vegetation Index (NDVI) of TDM which predicted herbage production in steps of 0.4 t ha^{-1} (Tucker *et al.* 1983, de Leeuw and Lamprey 1989). In Niger, in a rainfall zone of 150 to 400 mm,

[1] Advanced Very High Resolution Radiometer of the National Oceanic and Atmospheric Administration

Table 3: Annual diet composition (in %) of cattle, sheep and goats in a secondary production system in semi-arid Mali

Fodder source	Cattle	Sheep	Goats
Herbaceous grazing	53	59	11
Browse	4	34	87
Millet residues	6	7	2
Rice residues and grass regrowth	37	-	-

Adapted from: Dicko-Toure 1980

Table 4: Spatial distribution of herbaceous biomass in NW Burkina Faso in 1977 and 1980

Year	1977	1980
Mean rainfall (mm)	440	310
t DM ha^{-1}		(in % of area)
0.2 - 0.5	3	22
0.5 - 1.0	29	30
1.0 - 1.5	35	31
> 1.5	33	17
Weighted mean	1.1	0.8

Grouzis and Sicot 1983 (adapted from Figure 1) distribution patterns in 1985 and 1987 indicated that in about 40% of the pastoral area surveyed, TDM was 0.8 ha^{-1} or above (Table 5). However, in 1987 there was little plant growth north of 15.5° latitude, whereas in 1985 there was evidence of primary production as far north as 18° corresponding to similar trends in adjacent Sahelian countries (Tucker *et al.* 1986).

These inter-annual variations are caused by many factors, the major one being the effect of rainfall. In the Sahel, the Coefficients of Variation along the 200 to 600 mm gradient are usually 20% to 30% and for a mean of 400 mm of rainfall there is a 10% probability that the amount is less than 300 mm or more than 560 mm. Hence at $P > 0.8$, for the mean of 1.1 t as given in Table 1, TDM can vary between 0.9 and 1.5 t ha^{-1} (Hiernaux 1982, Penning de Vries and Djiteye 1982). Such inter-annual variations in yields were confirmed by Grouzis and Sicot (1983) in semi-arid Burkina Faso. For a mean rainfall of 400 mm, the median biomass was 1 t DM ha^{-1} ranging from 0.8 to 1.4 t at 90% and 10% probability respectively or corresponding to CCs of 7.4 and 4.1 ha/TLU (13.5 and 24.4 TLU km^{-2}) (Table 6). In 1977 the dry season stocking rate was estimated at 3.9 ha/TLU, which implies that the area was likely to be overstocked during most years.

In semi-arid areas with a bimodal rainfall distribution, variability is much greater. For instance, in Eastern Kenya an annual rainfall of 580 mm recorded over 73 years showed a CV of 52% due to the combined variability of two rainy seasons of 310 and 270 mm with CVs of 65% and 74% respectively. From a regression equation of seasonal rainfall on TDM, it was calculated that yields ranged from 0.3 to 7.5 t ha. In 25% of the years, annual yields were below 2 t and in 22% above 4 t, with a mean of 3.1 t ha^{-1} (Table 7). As a result, the mean CC would be about 2 ha TLU^{-1} which was close to actual stocking rates measured in Maasai group ranches with a similar rainfall (de Leeuw *et al.* 1984, Bell 1982). However, given this high inter-annual variability, it implies that in one year out of four, these ranches run the risk of being seriously overstocked, if the livestock population remains static and is not affected by drought or adjusted by sales.

Actual stocking rates

The question arises to what extent these theoretical estimates of CC conform to observed stocking rates. In Niger, the average CC over 1985 to 1987 was calculated to be 6.7 ha/TLU (15 TLU km^{-2}) in an area with a rainfall from 150 to 400 mm along a N-S gradient and producing an average TDM output of 0.7 to 0.8 t DM ha^{-1} (Wylie *et al.* 1988). No data

Table 5: Distribution of standing herbaceous biomass in Northern Niger in 1985 and 1987 derived from AVHRR/NOAA satellite data[1]

t DM ha^{-1}	1985[a]	1987[b]
	(% of area)	
0 - 0.2	3	34
0.2 - 0.8	57	30
0.8 - 1.4	38	24
> 1.4	2	12
Weighted mean	0.7	0.5

[a] Wagenaar and de Ridder 1986
[b] Wylie *et al.* 1986
[1] Location: 14.5^0 - 16.0^0; 5^0E

Table 6: Probability of rainfall, biomass and carrying capacity in Northern Burkina Faso

Probability %	90%	50%	10%
Rainfall mm	295	410	575
Biomass (t DM ha^{-1})	0.77	1.02	1.38
CC, ha TLU^{-1}	6.7	5.6	4.1

Grouzis and Sciot 1983

Table 7: Frequency distribution of annual herbaceous DM yield in semi-arid Eastern Kenya

Yield class t DM ha^{-1}	% of years	Yield mean	(SD)
<1.0	4	0.4	(0.3)
1.0 - 1.9	20	1.6	(0.3)
2.0 - 2.9	29	1.6	(0.3)
3.0 - 3.9	25	3.6	(0.3)
4.0 - 4.9	12	4.4	(0.2)
>4.9	10	6.4	(0.8)
Mean (n = 73)		3.1	(1.5)

Adapted from de Leeuw and Nyambaka 1988

on the livestock population were available for 1985 to 1987, but in 1981 to 1982 (prior to the serious drought in 1984) the actual stocking was estimated at about 13.5 ha/TLU (7.5 TLU km^{-2}) or close to half the theoretical capacity. These estimates came from systematic reconnaissance flights (SRF) during which livestock was counted in an area of 80,000 km^2. It was established that 60% of the total mass consisted of cattle, while camels, smallstock and donkeys accounted for 13%, 24% and 3% respectively (de Leeuw and de Haan 1983, Milligan 1982).

Similar surveys were carried out in the Gourma region in Mali with 150 to 500 mm of rainfall (Bourn and Wint 1985b). Average wet and dry season stocking rates in 1983 to 1984 were estimated as 18 and 25 ha TLU^{-1} (5.6 and 4.0 TLU km^{-2}) respectively, and cattle and small stock accounted for 76% and 21% of the total livestock mass. Closer scrutiny of these SRF data showed that in the wet season the actual stocking increased steeply along the N to S gradient from 62 ha TLU^{-1} (1.6 TLU km^{-2}) in the 150 to 200 mm zone to 11 ha TLU^{-1} (9.1 TLU km^{-2}) in the 400 to 500 mm belt.

Much higher stocking rates were recorded in NE Senegal where development of artesian boreholes has been going on for more than two decades (Sutter 1987). In an area of 30,000 km^2 along a rainfall gradient of 200 to 500 mm, the average stocking rates was 7.4 ha TLU^{-1} (13.5 TLU km^{-2}) in 1983. However, aerial surveys indicated an uneven distribution across the area. In about 40% of the area stocking was less than 20 ha TLU^{-1} (5 TLU km^{-2}), whereas 25% of the area carried 15 to 50 TLU km^{-2} and another 5% carried over 50 TLU km^{-2} (Sharman 1983). During the favourable years of 1980 to 1982, average TDM was in the order of 1.0 to 1.3 t ha^{-1} and well distributed over the area. For instance in 1981, only 8% of the area yielded less than 0.4 t ha, while close to 40% produced 1.2 t ha^{-1} or more (Tucker *et al.* 1983). For this period, CC was calculated at about 5 h TLU^{-1} (20 TLU km^{-2}) or well above the actual stocking rate. However, in 1983 rainfall was extremely low (a mean of about 100 mm for 22 rainfall stations) with the result that in almost 80% of the area, TDM was below 0.2 t ha^{-1}, causing serious shortages of feed, a high rate of mortality and an exodus of stock to areas further south (Vanpraet *et al.* 1983). Simulation of TDM output in this area failed to predict such low yields. Cornet (1984), using a sophisticated water balance model, calculated that TDM yields of below 0.6 ha^{-1} would occur in 1 year out of 20, whereas in 4 years out of 5, yields exceeded 1.1 t ha^{-1}. Thus, in general, Sahelian rangelands were utilised below their capacity in most years, but were more heavily overstocked in exceptional drought years. However, there is no way of avoiding such opportunistic strategies of pastoral people, since the alternative of conservative stocking adapted to probabilistic incidence of almost complete rainfall failure would result in a reduction in the average human support capacity of those rangelands (Sandford 1983).

Higher stocking rates of herbivores with increasing annual rainfall was also shown by Bell (1982) using data for eastern and southern Africa derived from Coe *et al.* (1976). These trends were confirmed for all sub-Saharan countries by Bourn (1976) up to 1,200 mm, above which densities declined, supposedly due to increased tsetse challenge. However, when the sites used by Bell (1982) were separated into those with high and low soil fertility, the linkage between annual rainfall and level of stocking was less strong. In the rainfall range of 700 to 900 mm densities of herbivores (including wildlife) were equivalent to 25 to 33 TLU km^{-2} on soils with high nutrient status developed over volcanic, rift and alluvial parent materials as compared to 5 to 8 TLU/km^2 for low fertility sites over basement complex receiving 800 to 1,100 mm of rainfall. Bell (1982) concluded that TDM production alone is a poor indicator of edible feed for herbivores and that nutrient quality therefore is an important determinant of carrying capacity. This interaction between rainfall and soil nutrient status reinforces the relationships outlined by Penning de Vries and Djiteye (1982) as discussed above.

Although in line with Bourn (1976) the risk of trypanosomiasis has usually been linked to the low stocking rates in the subhumid zone in West Africa, the low quality of feed resources is another explanatory factor as most of this zone is characterised by poor soils derived from basement complex. However, with increasing population density the tsetse challenge is diminishing, particularly in Nigeria, and stocking rates in the subhumid zone have been rising rapidly over the last two decades. Nevertheless, during 1980 to 1984, cattle densities varied from 4 to 40 head km^{-2} with an overall mean of only 10 head km^{-2} for the entire zone (Blench *et al.* 1985). Since the average TDM is about 3 t ha^{-1}, a CC based on biomass alone would be in the order of 2 ha TLU^{-1} or about 65 cattle km^{-2}. However, extensive and repeated SRFs in Nigeria have indicated that cattle distributions are governed by many factors, chief among which are the density of dry season watering points, the rural population density and infra-structure (Blench *et al.* 1985).

Discussion and conclusions

Two major approaches, either plant- or animal-oriented, to determine CC have been described. In the first, feed resources are assessed and permissible use by livestock is pre-conditioned by proper use factors that are geared to prevent over-exploitation and to safeguard sustained range productivity. Feed output can be estimated from empirical or simulation models using rainfall or soil-moisture balance techniques, enabling longer term forecasting based on past climatic records. Livestock use is predicted from known daily feed intake requirements and proper use is mostly set at 30% to 50% of the available herbaceous biomass, the rate of use depending on the known or assumed fragility of the ecosystem.

The animal-oriented approach follows a similar pathway in that the permissible amount of feed taken off by livestock is determined as in the ‘plant-oriented’ approach. However, since permissible stocking rates are supposed to ensure the adequate nutrition of stock to attain desired production goals (in terms of survival, milk, growth, etc) herbage quality and nutrients output also need consideration. It is evident that in view of the seasonal variations in nutrient content of natural herbage, animal-oriented permissible stocking rates on the whole tend to be lower than those predicted by the plant-oriented approach. For instance, if sustained milk-yields during long dry seasons are a desired goal, large areas of land may be required to provide lactating cows with a diet of adequate nutritional value.

Both approaches pose problems which are associated with characteristics of the African environment and the production systems found in the various ecological zones. They relate to scale (the area of assessment), species mix, mobility, land tenure and production goals of actual producers.

The concept of CC assumes that livestock are kept within fixed areas of land with recognised boundaries. Such conditions rarely prevail in Africa. Mobility of stock together with communal land tenure and fluid rights of access to grazing and water do not facilitate the computation of meaningful carrying capacities. In both transhumant and agro-pastoral systems, stock rely on several niches within the ecosystem, while in areas with cropping, residues from crops are an important source of feed. The contributions of these different sources of feed to the annual diet are difficult to quantify nor is it easy to determine how much land is utilized by each herd.

The scale of the CC assessment has an important bearing on its validity and usefulness. If direct interrelationships between animal output and feed supplies are aimed at, resources within the grazing orbit of the individual producer need to be determined. This is more easily achieved for individual mixed farmers than for nomadic or transhumant pastoralists. For these latter groups, communal use of grazing resources implies that only aggregate values of carrying capacity are meaningful, the size of the area being dependent on the boundaries of common use.

While, for example, mixed farmers in semi-arid Kenya have legal title to their land enabling an assessment of feed resources of their stock, group ranches contain 30 to 50 families using an area of 10,000 ha or more with loosely defined grazing rights within their boundaries. In most of Southern Africa, stock-owning farmers have stable usufructury rights to the land they cultivate, while communal grazing lands are shared with many owners. This implies that the scale at which carrying capacity must be estimated is that of the entire village area. In West Africa, stock-owning farmers entrust their stock to pastoralists either on a permanent basis or during the crop-growing season when livestock may do damage to crops. Consequently, a calculation of CC has to include different land units sometimes many kilometres apart.

In developed countries, multi-species exploitation of rangelands is rather uncommon. Even if more than one species of livestock are kept, they are often allocated separate areas of grazing land. In Africa, multi-species enterprises are the rule. In the more arid zones, camels and smallstock predominate, while in better watered areas, cattle and smallstock are kept by smallholder farmers and by Maasai in group ranches alike. Consequently, several livestock enterprises are combined within the same management unit. As feed preferences between species differ, assessing the fraction of edible feed becomes more complicated, in particular where browse from woody species is an important component. In the developed world, the concept of CC has been applied mostly to cattle production enterprises and as a consequence, graminoid herbage chosen by cattle has become the norm for identifying desirable species. Herbs, dwarf shrubs and taller woody species are classed as undesirable and would decrease CC in proportion to their abundance. In multi-species enterprises, emphasis on graminoid herbage would underestimate CC if the grazing value of herbs and woody species is negatively assessed.

Nonetheless, the concept of carrying capacity is useful for planning purposes, calculations of the average productivity of land in terms of feed resources, and expected output of livestock. While long term averages may be required for general forward projections, the limitations of such data should be fully recognised in the light of sharp fluctuations over time and space. Upper and lower limits of CC need to be considered and linked with probability of expected levels of herbage production together with the interactive effects of over- and under-utilisation in the medium term.

Finally, the ultimate validity of the carrying capacity concept rests on the recognition that feed resources are governed by an interlinked set of environmental factors, which determine the upper and lower limits of primary as well as secondary productivity in the short term but even more so in the long term perspective. In view of the decline of per caput food output in Africa, there is a risk that policies to enhance the human support capacity of African grazing land in the short term will ignore the long term consequences. Therefore, although the concept of carrying capacity may be of limited utility for African conditions, the underlying principles on which it is based need full acceptance, without which no sustained resource management can be accomplished.

References

Antenneh, A (1984) ‘Trends in sub-Saharan Africa’s livestock industries’ *ILCA Bulletin* 18: 7-15

Bell, R V H (1982) ‘The effect of soil nutrient availability on community structure in African ecosystems’ in Huntley, B J and B H Walker (eds) ‘Ecology of Tropical Savannas’ *Ecological Studies* 42: 193-216 Sprinter-Verlag, Berlin

Blench, R M, D Bourn, and D Wint (1985) *Integrated air-ground surveys in the Nigerian sub-humid zone* Report to the ILCA sub-humid zone programme Kaduna, Nigeria

Bourn, D and F Wint (1985a) *Wet season distribution and abundance of livestock populations and human habitation in the Office du Niger Region of Mali* RIM Jersey, UK

Bourn, D and F Wint (1985b) *Wet season distribution and abundance of livestock population and human habitation in Gourma Region of Mali* RIM Jersey, UK

Breman, H, H van Keulen and J J M H Ketelaars (1984) ‘Land evaluation for semi-arid rangeland: a critical review of concepts’ in Siderius W (ed) *Proceedings of the workshop of land evaluation for extensive grazing*: 229 Publ 34 ILRI Wageningen, Netherlands

Coe M J, D H Cummings and J Phillipson (1976) ‘Biomass production of large African herbivores in relation to rainfall and primary production’ *Oecologia* 22: 341-354

Coppock D L, D M Swift and J E Elliss (1986) ‘Seasonal nutritional characteristics of livestock diets in a nomadic pastoral ecosystem’ *Journal of Applied Ecology* 23: 585-595

Cornet, A (1984) ‘Utilisation de models simples de bilan hydrique et de production de biomasse pour determiner les potentialites de production de parcours en zone Sahelienne Senegalais’ in Siderius W (ed) *Proceedings of the workshop on land evaluation for extensive grazing*: 207-228 Publ 34 ILRI Wageningen, Netherlands

Cossins, N J and M Upton (1987) ‘The Borana Pastoral System of Southern Ethiopia’ *Agricultural Systems* 25: 199-218

Dicko-Toure, M (1980) ‘The contribution of browse to cattle fodder in the sedentary system of the Office du Niger’ in Le Houérou, H N (ed) *Browse in Africa*: 313-319 ILCA Addis Ababa, Ethiopia

Dye, P J and P T Spear (1982) ‘The effects of bush clearing and rainfall variability on grass yield and composition in southwest Zimbabwe Zimbabwe’ *Journal of Agricultural Research* 20: 103-118

FAO (1988) ‘Guidelines: land evaluation for extensive grazing’ FAO *Soil Bulletin* No 58 Rome

Field, D I (1978) *Potential carrying capacity of rangeland of Botswana* Ministry of Agriculture Gabarone, Botswana

Grouzis, M and M Sicot (1983) ‘Production frequentielle du bassin versant de la mare d’Oursi: application à l’estimation des potentialites pastorales’ in Vanpraet, C (ed) *Méthodes d’inventaire et de surveillance continue des ecosystemes pastoraux saheliens*: 177-188 ISRA/FAO Dakar, Senegal

Hiernaux, P (1982) ‘Méthode d’evaluation du potential fourrager de parcour sahelien’ *Miscellaneous Paper* No 430 CABO Wageningen, Netherlands

Hiernaux, P (1983) ‘Distribution des pluies et production herbacée au Sahel: une méthode empirique pour caracteriser la distribution de précipitations journalières et ses effets sur la production herbacées’ *Doc Prog* 98 CIPEA Bamako, Mali

Klein, H D (1981) ‘Contribution à l’estimation de la production sur pâturage sahelien au Niger’ *Rev Elev Med vet Pays trop* 34: 211-220

Le Houérou, H N and C H Hoste (1977) ‘Rangeland production and annual rainfall relations in the Mediterranean Basin and in the African Sahelo-Sudanian zone’ *Journal of Rangeland Management* 30: 183-189

Leeuw, P N de and R H Lamprey (1989) ‘Prediction of vegetation cover, rainfall, growing season and crop yield using NDVI data: A review’ *ILCA Bulletin (in press)*

Leeuw, P N de, S Bekure and B E Grandin (1984) ‘Aspects of livestock productivity in Maasai group ranches in Kenya’ *ILCA Bulletin* 19: 17-20

Leeuw, P N de and C de Haan (1983) ‘A proposal for development in the pastoral zone in the republic of Niger’ in *Pastoral Systems Research in Sub-Saharan Africa*: 435-461 IDRC/ILCA Addis Ababa, Ethiopia

Leeuw, P N de and R Nyambaka (1988) ‘The prediction of rangeland primary production from rainfall data in arid and semi-arid Eastern Africa' in Dzowela, B H (ed) *Proceedings of the third PANESA workshop*: 260-268 ILCA Addis Ababa, Ethiopia

Milligant, K (1982) *Wet season aerial survey of the human and livestock populations and environmental condition in a central region of the pastoral zone of Niger* USAID/CIPEA Niamey

Penning de Vries, F W T and M A Djiteye (eds) (1982) *La Productivité des Pâturages Saheliens* Centre for Agricultural Publishing and Documentation Wageningen, Netherlands

Pratt D J and M D Gwynne (eds) (1977) *Rangeland Management and Ecological in East Africa* Hodder and Stoughton London

Raay, H G T van and P N de Leeuw (1974) *Fodder resources and grazing management in a savanna environment* Occasional Paper No 45 Institute of Social Studies The Hague, Netherlands

Rains, A B and A H Kassam (1979) *Land resources and animal production* Consultants' working paper No 8 FAO/UNFPA Project INT/75/P13 AGLS FAO, Rome 28p

Rutherford, M C (1978) 'Primary production ecology in Southern Africa' in Wager, M J A (ed) *Bio-geography and ecology of Southern Africa*: 623-652 Junk The Hague, Netherlands

Sandford, S (1983) 'Organisation and management of water supplies in tropical Africa' *ILCA Research Report* No 8 Addis Ababa, Ethopia

Sandford, S (1984) 'Pastoral strategies and desertification opportunism and conservation in drylands' in Spooner, B and H S Man (eds) *Desertification and Development: Dryland Ecology in Social Perspective*: 61-80 Academic Press London

Sharman, M J (1983) 'Approche systèmique du suivi continu d'une zone pastorale' in Vanpraet, C (ed) *Mèthodes d'inventaire et de surveillance continue des ecosystemes pastoreaux saheliens*: 149-160 ISRA/FAO Dakar, Senegal

Sutter, J W (1987) 'Cattle and inequality: herd size differences and pastoral production among the Fulani of North Eastern Senegal' *Africa* 57: 196-218

Swift, J, (ed) (1984) *Pastoral Development in Central Niger* Ministère du Développement Rural USAID Niamey, Niger

Timberlake, J R and S J Reddy (1986) *Potential pasture productivity and livestock carrying capacity over Mozambique* Inst Nac Invest Agronl Publ No 49 Maputo, Mozambique

Tucker, C J, C van Praet, E Boerwinkle and A Gaston (1983) 'Satellite remote sensing of total dry matter accumulation in the Senegalese Sahel' *Remote Sensing Environ* 13: 461-474

Tucker, C J, C O Justice and S D Prince (1986) 'Monitoring the grasslands of the Sahel 1984-1985' *Int J Remote Sensing* 7 (11): 1571-1582

Vanpraet, C L, M J Sharman and C J Tucker (1983) 'Utilisation des images NOAA pour l'estimation de la production primaire en pilieu sahelien' in Vanpraet, C L (ed) *Mèthodes d'inventaire et de surveillance continue des ecosystemes pastoreaux saheliens*: 299-319 ISRA/FAO Dakar, Senegal

Wagenaar, K T and N de Ridder (1985) *Estimates of biomass production and distribution in ILP zone in 1985 based on satellite NDVI values* Working Document ILCA Addis Ababa, Ethopia

Wijngaarden, W van (1985) *Elephants-Trees-Grass-Grazers: Relationships between climate, soils, vegetation and large herbivores in a semi-arid ecosystem (Tsavo, Kenya)* ITC Publ No 4 Enschede, Netherlands

Wylie, B, J Harrington, R Pieper, A Maman and I Denda (1988) *1987 Pasture Assessment Early Warning System* Integrated Livestock Production Project Government of Niger/Tufts University/
USAID/New Mexico State University

Wylie, B, R Senock, L Synder, B Roettgen and B Porter (1983) *Range research and results* USAID NRL preliminary report Niamey