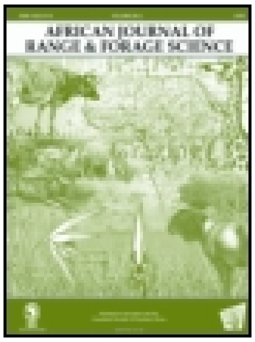

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Effect of *Balanites glabra* canopy cover on grass production, organic matter and soil moisture in a southern Kenyan rangeland

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A study was undertaken in Kenya's southern savanna rangelands to determine the seasonal effect of *Balanites glabra* canopy cover on aboveground grass biomass, grass species composition, soil organic matter and soil moisture content. The study was conducted during the period June to December 1999 in order to capture both the dry and wet season effects. The grass biomass in the sub-canopy zone (2–4m from tree trunk) was found to be significantly higher than in the mid-canopy (0–2m from tree trunk) and open grassland zones (4–6m from tree trunk) during the dry season. However, the difference between the sub-canopy and the open grassland was not significant during the wet season, implying that the role of a tree canopy in enhancing grass biomass is greater during the dry than the wet season. Variations in percent grass species composition from the mid-canopy to the adjacent open grassland were observed, indicating that while *B. glabra* canopy cover favours certain grass species, other species find the microclimatic conditions under the canopy unfavourable. Soil organic matter in the mid-canopy zone was significantly higher than in the sub-canopy and adjacent open zones during both dry and wet season. Although the sub-canopy zone exhibited significantly higher soil moisture content than the mid-canopy and open grassland zones during the dry season, the difference between the subcanopy and the adjacent open grassland during the wet season was not significant, suggesting that the tree canopy influence on soil moisture is more pronounced in the dry than the wet season.

Keywords: aboveground grass biomass, *Balanites glabra*, canopy cover, seasonal effects, soil organic matter and moisture

Introduction

In Kenya, rangelands cover over 80% of the total land area. Despite their relative aridity, these areas support over 25% of the human population, 60% of the cattle population, 70% of the small stock, 100% of the camels, much of the wildlife and a considerable amount of the overall biodiversity (Kariuki and Letitiya 1996, Keya 1998, Herlocker 1999, Noor *et al*. 1999). However, high human population, increased cultivation and cutting of trees for fuel and other uses currently threaten the integrity of the rangeland systems (National Research Council 1986, Burrows 1993). The pastoral production system in Kenya is no exception to this crisis that is common to other such systems in Africa.

The effects of trees on their understorey environments have recently received attention as range scientists have investigated the effects of maintaining or introducing trees into rangelands (silvo-pastoralism) (Belsky *et al*. 1993). These studies have been done in a wide variety of ecosystems, with various tree and herbaceous species and sometimes with different results. In a central Kenyan rangeland, Kinyua (1996) reported significantly higher herbaceous biomass in the sub-canopy zone of *Acacia etbaica* Schweinf. and *Acacia tortilis* (Forssk.) than in the open sites. Belsky *et al*. (1989), working in Tsavo National Park, Kenya, indicated that in areas of low tree density, moderate or high fertility and low rainfall, trees may increase forage production. In contrast, Engle *et al*. (1987) reported a substantial reduction in herbage production under and around *Juniperus virginiana* L. in north-central Oklahoma. Similarly, Jacoby *et al*. (1982) reported more herbage production away from *Prosopis glandulosa* (Torr.) than near the tree in a Texas rangeland. Kinyamario *et al*. (1995), Trilica and Kinyamario (1993) and Maranga *et al.* (1983), all working in Kenyan rangelands, observed that the understorey herbaceous species composition is generally different from that of the area immediately outside the tree crowns. In north-western Nigeria rangeland, Isichei and Muoghalu (1992) reported higher soil organic matter and soil moisture under trees than in the adjacent open sites. Joffre and Rambal (1988) found that trees improve the water storage capacity of the soil under their canopies in south-western Spain.

These studies, however, have been conducted in different soils, climates and plant species. Different herbaceous plant species respond differently to tree canopy cover and different types of tree canopies have different impacts on their understorey (Burrows 1993, Jetsch *et al*. 1996). Burrows (1993) noted that the effects of trees on associated understorey herbaceous production vary with the species and environment. Jetsch *et al.* (1996) also argued that the functions of savanna trees may vary with their population structure, density and distribution. Therefore, in order to gain a better understanding of the tree/understorey layer interactions, as well as have a better basis for future decision-making on sustainable use and management of rangelands, more studies, with more trees and replicated over different eco-climatic zones, must be carried out.

The few studies on tree/understorey interactions so far conducted in Kenyan rangelands include a few specific tree species and objectives. Thus, there is a paucity of information on the interactions between trees and their understories in this region. Besides *Acacia* and *Commiphora* species, members of the family Balanitaceae (desert date) are common tree species in Kenya's semi-arid rangelands. In southern Kenyan rangelands, *Balanites glabra* (Mildbr. & Schlecht.) is the most common species of this family (Beentje 1994). The species is greatly valued for its edible fruits consumed by both humans and livestock. Its evergreen nature makes it the main source of forage and shade for grazing animals during the dry season (Dale and Greenway 1961, Noad and Birnie 1989, Makokha *et al.* 1999). Despite its dominance and silvo-pastoral and domestic values, its role in influencing herbage production and soil properties has not been documented. The objective of this study was, therefore, to determine the effects of *B. glabra* canopy cover on the understorey grass biomass production, grass species composition, soil organic matter and soil moisture in southern Kenyan rangelands.

Materials and methods

Study area

The study was conducted at Isinya Ranch, located in Kajiado District (between latitudes 1°2'–3°10'S and longitudes 36°5'–36°55'E), 50 kilometres south of Nairobi. The study area falls within eco-climatic zone IV, classified as semi-arid (Pratt and Gwynne 1977). The rainfall of the area is bimodal in distribution with the long and short rains occurring during March–May and September–November, respectively. The rains are erratic and unpredictable in nature, ranging between 450mm and 900mm annually. The mean minimum and maximum temperatures are 13°C and 25°C, respectively. The average annual potential evaporation ranges between 1 650mm and 2 300mm giving a rainfall to evaporation ratio of 25–40%.

The study site is situated at 1 500–1 850m above sea level on a gently undulating plain. The soils are an association of eutric planosols and pellic vertisols (Genga 1992). The vegetation consists mainly of *B. glabra* trees scattered in the open grassland and a few dwarf *Acacia drepanolobium* Harms. ex Sjostedt. in the lower canopy. *Themeda triandra* Forssk is the dominant grass species. Other grasses include *Pennisetum mezianum* Leeke., *P. stramineaum* Peter., *Setaria trinevia* Stapf., *Dichanthium insculpta* Hochst. ex A. Rich. and *Digitaria macroblephara* (Hack.) Stapf. The main shrub species is *Aspilia mossambiscensis* (Oliv.) Willd., which mainly occupies the mid-canopy areas immediately around the tree trunks. The vegetation type of the study site can be described as *Themeda triandra–Balanites glabra* open grassland.

The study was carried out in one of the reserve pastures of the ranch, usually grazed by immature or lactating cattle. The pasture was slightly grazed at the beginning of the previous year. However, at the time of the study, it had been ungrazed and unburnt for the whole of that year. The range condition and trend at the time of study was good with an upward trend, as evidenced by good ground cover of palatable species compared to other areas in the ranch, which exhibited heavy grazing and the presence of invader plant species.

Experimental set-up and procedure

The experimental set-up consisted of three treatment sites with respect to a *B. glabra* tree herein referred to as zones. Eight trees (replicates) from the dominant size-class (canopy height ≥2m and crown diameter ≈6m), growing under similar conditions (same soil type and terrain), were selected for this study. Exclosures were erected around each tree to keep out grazing animals. Around each tree, three zones were marked in concentric rings at equal intervals. Based on the distance from the tree trunk, the zones were designated as mid-canopy (0–2m), sub-canopy (2–4m) and open grass (4–6m). Species composition was determined using four 0.25m^2 quadrats in each zone. In each quadrat, grass species were counted and the numbers recorded. Herbaceous species from the same quadrats were clipped, grasses were then separated from other species and analysed for aboveground biomass. Grass samples were oven-dried to a constant weight at 80°C for 48 hours. Biomass was expressed as the weight of dry matter per unit area (t ha^{-1}). Sampling for both species composition and biomass was done monthly during the dry season (June–September) and bimonthly during the growing season (October–December). Samples for soil organic matter and moisture determination were taken at 0–30cm and 30–60cm depths, using an auger at four equidistant points within each zone. Sampling for organic matter was done monthly during the dry season and bimonthly during the wet season, while that for moisture content was done weekly throughout the study period. New sampling points were marked in each zone on every sampling date. Organic matter and soil moisture were determined using the Walkley-Black method (Nelson and Sommers 1982) and gravimetric method (Gardner 1986) respectively.

Data analysis

The standard analysis of variance technique was used to determine if there were differences among the three zones in terms of soil organic matter, soil moisture and grass biomass. Turkey's Least Significant Difference (LSD) test was used to separate means for each zone. A correlation analysis for grass biomass, soil organic matter and soil moisture content was done in order to determine the percentage variation in grass biomass that is explained by differences in these soil properties. Tests of significance were performed at 5% level criterion (Steel and Torrie 1980).

Results

Effect of B. glabra *canopy cover on aboveground grass biomass*

There was significantly higher ($P \leq 0.05$) grass biomass in the sub-canopy than in the mid-canopy and adjacent open grassland during the dry season (Table 1). However, the difference between the sub-canopy and open grass was not significantly different ($P \leq 0.05$) during the wet season. On the other hand, the open zone had significantly higher ($P \leq 0.05$) grass biomass than the mid-canopy zone during both seasons. The correlation between grass biomass and soil moisture content ($r^2 = 0.98$; $P = 0.001$) was higher than that between the former and organic matter content ($r^2 = 0.41$; $P = 0.420$).

Effect of B. glabra *canopy cover on grass species composition*

Themeda triandra was the most dominant grass species in the open and sub-canopy zones during both the dry and wet season. In the mid-canopy zone, *P. mezianum* was the most abundant. The same grass species were encountered during both seasons. The details on the grass species composition are presented in Table 2.

Effect of B. glabra *canopy cover on soil organic matter content*

Soil organic matter content in the mid-canopy zone was significantly higher ($P \leq 0.05$) than in the sub-canopy and adjacent open zone during both dry and wet seasons (Table 3). Organic matter generally decreased from mid-canopy to the open zone during both seasons. In all the three zones, organic matter was significantly higher ($P \leq 0.05$) during the dry season than the wet season. The difference was highest in the mid-canopy (25%) followed by the sub-canopy (20%) and open zone (19%).

Effect of B. glabra *canopy cover on soil moisture content*

The soil moisture content in the sub-canopy zone was significantly higher ($P \leq 0.05$) than in the mid-canopy zone during both the dry and wet seasons (Table 4). During the former season, the soil moisture content in the mid-canopy zone was not significantly different ($P \leq 0.05$) from that in the adjacent open zone. However, during the wet season, it was significantly lower ($P \leq 0.05$) in the mid-canopy than in the adjacent open areas. The moisture content was lowest in the open zone during the dry season, but it was lowest in the mid-canopy zone during the wet season.

Discussion

The relatively higher grass biomass in the sub-canopy zone of *Balanites glabra* may be attributed to the higher soil moisture (Table 4). Heitschmidt and Dowhower (1991), Frost and Edinger (1991), Kinyua (1996), Frost and McDougald (1990), Belsky *et al*. (1989), and Schott and Pieper (1985) reported higher grass biomass in the sub-canopy zone (drip-

Table 1: Mean grass biomass (t ha^{-1}) in three different canopy zones during dry and wet seasons

Season	Mid-canopy	Sub-canopy	Open grass
Dry	1.75^{1a} (0.27)	8.04^{2a} (3.78)	3.10^{3a} (0.70)
Wet	8.28^{1b} (2.28)	16.62^{2b} (7.35)	16.87^{2b} (5.43)

Treatment means with different number superscripts in the same row and those with different letter superscripts in the same column are significantly different ($P \leq 0.05$)

$LSD_{Canopy\ zone}$ = 0.53; LSD_{Season} = 0.43. Standard deviations are given in parentheses

Table 2: Grass species composition (%) in three different canopy zones during dry and wet seasons

Season/Species	Mid-canopy	Sub-canopy	Open grass
Dry season			
Themeda triandra	7 (4)	29 (6)	68 (13)
Pennisetum mezianum	33 (8)	29 (11)	5 (3)
Pennisetum stramineaum	20 (6)	17 (4)	5 (2)
Setaria trinevia	13 (7)	13 (5)	11 (4)
Digitaria macroblephara	13 (5)	4 (1)	5 (3)
Dichanthium insculpta	13 (2)	8 (4)	5 (2)
Wet season			
Themeda triandra	5 (2)	26 (8)	37 (12)
Pennisetum mezianum	46 (10)	22 (6)	7 (2)
Pennisetum stramineaum	18 (7)	22 (10)	15 (6)
Setaria trinevia	14 (4)	19 (5)	19 (8)
Digitaria macroblephara	9 (5)	7 (3)	11 (2)
Dichanthium insculpta	9 (3)	4 (2)	11 (3)

Standard deviations are given in parentheses

Table 3: Mean soil organic matter content (%) in three different canopy zones during the dry and wet seasons

Season	Mid-canopy	Sub-canopy	Open zone
Dry	4.76^{1a} (1.04)	4.13^{2a} (0.44)	1.57^{3a} (0.39)
Wet	3.79^{1b} (0.54)	3.11^{2b} (1.25)	1.27^{3b} (0.48)

Treatment means with different number superscripts in the same row and those with different letter superscripts in the same column are significantly different ($P \leq 0.05$)
$LSD_{Canopy\ zone}$ = 0.23; LSD_{Season} = 0.19. Standard deviations are given in parentheses

Table 4: Mean soil moisture content (%) in three canopy zones during dry and wet seasons

Season	Mid-canopy	Sub-canopy	Open zone
Dry	7.99^{1a} (3.33)	12.94^{2a} (4.72)	7.33^{1a} (2.06)
Wet	19.45^{1b} (2.40)	31.32^{2b} (9.68)	31.28^{2b} (6.83)

Treatment means with different number superscripts in the same row and those with different letter superscripts in the same column are significantly different ($P \leq 0.05$)
$LSD_{Canopy\ zone}$ = 0.92; LSD_{Season} = 0.75. Standard deviations are given in parentheses

line) than in the interspaces between trees or the mid-canopy zone. Schott and Pieper (1985) attributed this to higher canopy height, lower canopy density and lower litter accumulation in the sub-canopy than in the mid-canopy. This implies that the sub-canopy receives less shading and litter effect than the mid-canopy, resulting in higher light penetration into the sub-canopy zone.

The results of this study indicate a 50% lower grass biomass under the tree (mid-canopy) than in the adjacent open grass. This is comparable to the results of Frost and Edinger (1991) who reported 30% less herbaceous biomass under *Quercus wislizenii* DC. and *Pinus sabiniana* Dougl. canopies than in the adjacent open areas in Sierra Nevada, central California. Heitschmidt and Dowhower (1991), Ratliff *et al.* (1988) and Schott and Pieper (1985) attributed this phenomenon to differences in the amount of radiation received in the respective zones. In New South Wales, Australia, Harrington and John (1990) observed that herbaceous biomass was negatively correlated to the canopy density of *Eucalyptus* species. In contrast to these findings, Grouzis and Akpo (1997) reported 1.5–4.0 times higher herbaceous biomass under *Acacia tortilis* (Forssk.) and *Balanites aegyptiaca* (L.) than in the adjacent open areas in northern Senegal. Belsky *et al.* (1993), found that herbaceous-layer productivity was 95% higher under the canopies of *A. tortilis* and *Adansonia digitata* (L.) than in the adjacent open areas in Tsavo West National Park, Kenya.

The substantially lower grass biomass in the mid-canopy than the adjacent open grassland may be as a result of tree-induced effects such as rainfall interception by the canopy, reduced total solar radiation reaching the ground and competition between trees and herbaceous plant species for water and nutrients (Belsky *et al.* 1993). *Balanites glabra* canopy is generally denser at the centre than around the edges. This creates higher shade intensity, which reduces the photosynthetic rate of grasses, resulting in lower grass biomass in the mid-canopy than the sub-canopy and adjacent open grassland. However, Pieper (1990) argued that apart from reduced light intensity at higher canopy densities, competitive interactions for water and nutrients between the tree and herbaceous plant species and litter accumulation could partly account for the low grass biomass in the mid-canopy. In contrast, Heitschmidt and Dowhower (1991) emphasised that the major factors affecting herbaceous biomass production under any tree's canopy are mainly climatic, particularly precipitation.

The insignificant difference in grass biomass between the sub-canopy and the adjacent open grass zone indicates that the role of the tree canopy in enhancing herbaceous biomass through improved soil moisture is less pronounced during the wet than the dry season. The difference in soil moisture between the sub-canopy and the open grass zone during the wet season was less than 1%, compared to 43% during the dry season. These findings are supported by those of Heitschmidt and Dowhower (1991) who observed that when rainfall is well distributed and soil water is not limiting throughout the growth period, trees have little effect on the understorey pasture production. The positive relationship between the grass biomass and rainfall (moisture) implies that water is the principal factor in plant growth. The enhanced grass biomass during the dry season through improvement of soil moisture content suggests that it is the soil moisture that mainly limits grass biomass in arid and semi-arid rangelands.

The variation in percent species composition across the canopy zones may be attributed to differences in soil properties among the zones (Tables 3 and 4) as well as differences in shade and water stress tolerance among the grass species. The results of this study agree with those of Belsky *et al.* (1993), Kinyamario *et al.* (1995), Joffre and Rambal (1988), Trilica and Kinyamario (1993), Harrington and John (1990), and Maranga *et al.* (1983). The authors indicated that the understorey herbaceous species composition is generally different from that of the area immediately outside the tree crowns. They attributed the difference in species composition to differences in shade, water stress and grazing tolerance among the herbaceous species.

In Nairobi National Park, Kenya, Kinyamario *et al.* (1995)

demonstrated that *T. triandra* was less adapted to water stress in the mid-canopy, but more tolerant to grazing pressure in the open zone. This explains, in part, the apparent dominance of *T. triandra* in the open, where grazing pressure and water stress are higher than under the canopy. Trilica and Kinyamario (1993) and Kinyamario *et al*. (1995) reported dominance of *P. maximum* Jacq. under the tree canopies and *T. triandra* in the adjacent open grasslands in Nairobi National Park, Kenya. Maranga *et al*. (1983), working in south-eastern Kenyan rangeland, found that *T. triandra* was almost exclusively restricted to areas outside the tree canopies. Kinyamario *et al*. (1995) attributed the difference in herbaceous species composition between areas under the canopy and the adjacent open grassland to differences in carbon assimilation rates and water use efficiencies among the herbaceous species.

The absence of major variations in grass species composition between the dry and wet seasons, suggests that, besides soil moisture (rainfall), other factors such as soil organic matter and carbon-dioxide assimilation rate are modified by tree canopies. These factors, in turn, affect the grass species composition. In Tsavo West National Park, Kenya, Belsky *et al*. (1993) observed that the change in herbaceous species composition between the area under *Acacia tortilis* canopy and that of the adjacent open grassland, was more marked in a humid than in an arid environment.

The soil organic matter content in the mid-canopy and sub-canopy zones was 59–67% higher than in the open (Table 3). In comparison, Felker (1978) reported 50–100% more organic matter content under *Acacia albida* (Del.) canopy in a semi-arid zone in west Africa. Similar results have been reported by Isichei and Muoghalu (1992), Belsky *et al*. (1989), Frost and Edinger (1991), Kinyamario *et al*. (1995) and Schott and Pieper (1985), where locations adjacent to the tree trunk had greater accumulations of organic matter than either the canopy edge or open grassland areas. The higher organic matter content under the canopy than in the adjacent open grass could be attributed to the accumulated leaf litter from the trees, dead grass and their slow decomposition. The lower organic matter content in the open zone, on the other hand, may be attributed to the fact that the main source of organic matter is the herbaceous plants, which contribute much less total biomass. The decomposition process is slow under the canopy due to shading which results in low temperatures and thus low microbial activity. The results of this study are in agreement with those of Isichei and Muoghalu (1992) who observed higher soil organic matter content during the dry season than during the wet season in a savanna region in north-western Nigeria. This phenomenon was attributed to improved soil moisture and enhanced decomposition of the organic matter.

The higher soil moisture content in the sub-canopy than in the adjacent open zone during the dry season could be attributed to reduced temperatures and evapo-transpiration rates, resulting in less water depletion in the sub-canopy zone than in the open grassland zone. Kellman (1979) and Joffre and Rambal (1988) reported that trees improve the soil structure and hence the water storage capacity of the soil under their canopies. Young (1997), Joffre and Rambal (1988) and Wallace (1996) attributed the higher moisture content in areas under tree canopies than the adjacent open areas to low evapo-transpiration rates, due to shading, reduced surface runoff and lower soil bulk density. They indicated that these factors have been shown to improve water infiltration and storage capacity in the sub-canopy. The improved water condition under tree crowns described by Joffre and Rambal (1988) implies that the tree canopy may modify the amount of precipitation reaching the soil, the water storage capacity of the soil and the amount of water lost through evapo-transpiration.

The results of this study show that *Balanites glabra* enhances the soil moisture storage under its canopy, but not in the zone further away from its trunk. The relatively lower soil moisture in the mid-canopy than in the sub-canopy zone indicates that trees can also have negative effects on soil properties. Such factors may include tree trunk expansion, which consequently leads to soil compaction and thus higher bulk density, lower water infiltration rates and increased runoff in the mid-canopy zone. Tree canopies in conjunction with the litter that accumulates under them intercept precipitation, which is later lost through evaporation. This reduces the amount of water that is available for infiltration into the soil (Schott and Pieper 1985, Naeth *et al*. 1991).

Maranga *et al*. (1983), Kinyamario *et al.* (1995), and Belsky *et al.* (1989) have observed the importance of tree canopies in modifying evapo-transpiration rates. Maranga *et al*. (1983) argued that the area under a tree canopy generally receives less precipitation than that outside the canopy, but the canopy reduces evapo-transpiration rates, resulting in higher soil moisture content under trees than in the adjacent open sites. The insignificant difference in soil moisture content between the sub-canopy and open grass zone during the wet season suggests that when water (rainfall) is unlimited, the effect of tree canopies in improving the soil moisture status is not there.

Conclusions

The results of this study show that *Balanites glabra* canopy has positive influences on some soil properties that are beneficial to grass biomass production. This is evident in greater soil organic matter and moisture contents, which correspond to relatively higher grass biomass in the sub-canopy compared to the open zones. However, the results also reveal that there is a certain threshold of distance from the tree trunk beyond which growth and primary production of herbaceous plant biomass declines and that the microclimate under the tree canopy favours some species more than others. Although tree canopies may have beneficial effects on the understorey layer, the effects are not uniform throughout the sub-canopy layer and may vary with season. Further, the role of tree canopies in enhancing soil moisture and grass biomass is greater during the dry than the wet season.

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References

Beentje HJ 1994. Kenya Trees, Shrubs and Lianas. National Museums of Kenya, Nairobi, Kenya.

Belsky AJ, Amundson RG, Duxbury JM, Riha SJ, Ali AR and Mwonga SM 1989. The effects of trees on their physical, chemical and biological environments in a semi-arid savanna in Kenya. Journal of Applied Ecology 26: 1005–1024.

Belsky AJ, Mwonga SM, Amundson RG, Duxbury JM and Ali AR 1993. Comparative effects of isolated trees on their undercanopy environments in high and low rainfall savanna. Journal of Applied Ecology 30: 143–155.

Burrows WH 1993. Deforested in savannah context: problems and benefits for pastoralism. In: Proceedings of the XVII International Grassland Congress, Massey University, Palmerston North, New Zealand, 18–21 February 1993. pp 2223–2230.

Dale IR and Greenway PJ 1961. Kenya Trees and Shrubs. Buchanan's Kenya Estate Ltd, Nairobi, Kenya.

Engle DM, Stritzke JF and Claypool PL 1987. Herbage standing crop around eastern redcedar trees. Journal of Range Management 40: 237–239.

Felker P 1978. State of the art: *Acacia albida* as a complementary permanent intercrop with annual crops. Report to USAID. University of California, Riverside, USA.

Frost WE and Edinger SB 1991. Effects of tree canopies on soil characteristics of annual rangeland. Journal of Range Management 44: 286–288.

Frost WE and McDougald NK 1990. Tree canopy effects on herbaceous production of annual rangeland during drought. Journal of Range Management 42: 281–283.

Gardner WH 1986. Water content. In: Methods of Soil Analysis. Part I. Physical and Mineralogical Properties. American Society of Agronomy (2nd edn). Agronomy Series No. 9. American Society of Agronomy, Madison, Wisconsin, USA. pp 493–544.

Genga GO 1992. Ranch Plan for Maasai Rural Training Centre. Range Planning Unit, Ministry of Agriculture, Livestock Marketing and Development (GoK), Kajiado, Kenya.

Grouzis M and Akpo LE 1997. Influence of tree cover on herbaceous above- and below-ground phytomass in the Sahelian zone of Senegal. Journal of Arid Environments 35: 285–296.

Harrington GN and John GG 1990. Herbaceous biomass in a *Eucalyptus* savanna woodland after removing trees and/or shrubs. Journal of Applied Ecology 27: 775–787.

Heitschmidt RK and Dowhower SL 1991. Herbage response following control of honey mesquite within single tree lysimeters. Journal of Range Management 44: 144–149.

Herlocker DJ 1999. Rangeland Resources in Eastern Africa: Their Ecology and Development. GTZ, Nairobi, Kenya.

Isichei AO and Muoghalu JI 1992. The effects of tree canopy cover on soil fertility in Nigerian savanna. Journal of Tropical Ecology 8: 329–333.

Jacoby PW, Meadors CH, Foster MA, Hartmann FS 1982. Honey mesquite control and forage response in Crane County, Texas. Journal of Range Management 35: 424–426.

Jetsch F, Milton SJ, Dean WRJ, Rooyen NV 1996. Trees spacing and co-existence in semi-arid savannas. Journal of Ecology 84: 583–595.

Joffre R and Rambal S 1988. Soil water improvement by trees in the rangelands of southern Spain. Ecology of Plants 9: 405–422.

Kariuki DP and Latitiya W 1996. Livestock production and health challenges in pastoral areas: Samburu District, Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya.

Kellman M 1979. Soil enrichment by neotropical savanna trees. Journal of Ecology 67: 565–577.

Keya GA 1998. Impact of Land Use Patterns and Climate on Vegetation Ecology of Semi-arid Nomadic Pastoral Ecosystems of Northern Kenya. PhD Thesis, University of Trier, Germany.

Kinyamario JI, Trilica MJ and Njoka TJ, 1995. Influence of tree shade on plant water status, gas exchange, and water use efficiency of *Panicum maximum* Jacq. and *Themeda triandra* Forsk. in Kenya savannah. Journal of African Ecology 33: 114–123.

Kinyua DM 1996. Microenvironmental Influences of *Acacia etbaica* and *Acacia tortilis* on Herbaceous Layer Production in Mukogodo, Rangeland, Laikipia District. MSc Thesis, University of Nairobi, Nairobi, Kenya.

Makokha W, Lonyakou S, Nyang M, Kareko KK, Holdings C, Njoka TJ and Kitalyi A 1999. We work together: land rehabilitation and household dynamics in Chepareria Division, West Pokot District, Kenya. RELMA Technical Report Series No. 22, Nairobi, Kenya.

Maranga EK, Trlica MJ and Smeins F 1983. Water relations of *Panicum maximum* and *Digitaria macroblephara* on semi-arid rangeland in Kenya. East African Agricultural and Forestry Journal 48: 74–80.

Naeth MA, Bailey AW, Chanasyk DS and Pluth DJ 1991. Water holding capacity of litter and soil organic matter in mixed prairie and festuca grassland ecosystems of Alberta. Journal of Range Management 44: 13–17.

National Research Council 1986. The Improvement of Tropical and Subtropical Rangelands. National Academy Press, Washington DC, USA.

Nelson DW and Sommers LE 1982. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties (2nd edn). Agronomy Series No. 9. American Society of Agronomists, Madison, Wisconsin. pp 539–579.

Noad TC and Birnie A 1989. Trees of Kenya. TC Noad and A Birnie, Nairobi, Kenya.

Noor IM, Guliye AY and Farah KO 1999. Traditional camel production among the Somali and Borana pastoralists of Moyale District, Kenya. The African Pastoral Forum, Working Paper Series No. 21, May 1999. PINEP, University of Nairobi, Kenya.

Pieper RD 1990. Overstorey-understorey relations in pinyon-juniper woodlands in New Mexico. Journal of Range Management 43: 413–415.

Pratt DJ and Gwynne MD 1977. Rangeland Management and Ecology in East Africa. Robert E Krieger Publishing Co., Humington, New York, USA.

Ratliff RD, Duncan DA and Westfall SE 1988. Influence of overstorey type on herbage production on California annual grassland range. Abstract of 41st Annual Meeting of Society of Range Management, February 1988, Corpus Christi, Texas, USA.

Schott MR and Pieper RD 1985. Influence of canopy characteristics of one-seed Juniper on understorey grasses. Journal of Range Management 38: 328–331.

Steel GD and Torrie JH 1980. Principles and Procedures of Statistics. McGraw-Hill, London.

Trilica MJ and Kinyamario JI 1993. Photosynthesis and water relations of two savannah grasses as influenced by shade and water stress. In: Proceedings of the XVII International Grassland Congress, Massey University, Palmerston North, New Zealand, 18–21 February 1993. pp 114–115.

Wallace JS 1996. The water balance of mixed tree-crop systems. In: CK Ong and PA Huxley (eds) Tree-crop Interactions: A Physiological Approach. International Centre for Research in Agroforestry, Nairobi, Kenya.

Young A 1997. Agroforestry for Soil Management (2nd edn). CAB-ICRAF (International Centre for Research in Agroforestry), Nairobi, Kenya.