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BIOMASS PRODUCTION AND NUTRIENT STATUS OF THREE RANGE GRASS SPECIES IN AWASH NATIONAL PARK

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ABSTRACT

Three range grass species namely, *Chrysopogon plumulosus* Hochst, *Bothriochloa radicans* (Lehm.) A. Camus and *Ischaemum afrum* (J.F. Gemel.) Dandy were studied at Illala-sala grassland plain to asses their nutrient status and productivity as influenced by season and simulated grazing. Seasonal and annual biomass production of the grasses, seasonal effects on grass moisture content and on accumulation of N, P, K and Na were studied. The effect of grazing, simulated by clipping, was followed under glasshouse condition.

Seasonal and annual biomass production was estimated from four 6 x 6 m fenced quadrates, the grass stand of which was mowed at the beginning to a height of two cm. The three quadrates were systematically selected and placed such that each species had one quadrat where it homogenously covered the entire quadrat, whereas the fourth quadrat was established in such a way that it included mixed stands of the three species. In each quadrat, there were a total of 36, 50 x 50 cm sub-quadrates. Biomass production was estimated from nine sub-quadrates within each quadrat after allowing the grass to grow for 3, 6, 9 and 12 months. Moisture and nutrient content of grasses was determined seasonally (every three months) from six plant samples for each species collected randomly from the area. All the data were statistically analyzed by one way Analysis of Variance using Tukey's Family Error Rate test.

Nine clipping treatment combinations, differing in cutting height and cutting frequency, were applied. The grasses were clipped to 4, 8 and 12 cm every 15, 30 and 45 days interval. Two-way Analysis of Variance was performed to test for significant effects of cutting frequency and cutting height on shoot and root biomass production and nitrogen content of the species.

The biomass production showed significant seasonal variation following rainfall. Peak biomass was obtained during the wet periods, April-June and July-September. It ranged from 116 g m^{-2} to 409 g m^{-2} for *B. radicans* and *I. afrum* stands, respectively. There was very little growth in the dry period (October-December). The annual biomass production ranged from 397 to 792 g m^{-2} for *B. radicans* and mixed species stands, respectively. The biomass production of *B. radicans* stands were significantly lower than *I. afrum* and the mixed species stands.

Significant seasonal changes in the amount of moisture and nutrient (N, P, and K) content were observed in relation to the amount of rainfall. The moisture and N, P and K content of the species decreased with the dry season. The crude protein content of the grasses fell below the maintenance level required for ruminants during dry periods, indicating that herbivore populations may be limited by shortage of nutritionally adequate food during the dry season.

The clipping experiment showed that both cutting frequency and cutting height affected biomass accumulation and nitrogen content of the three grass species. For all the three species, increasing cutting frequency and decreasing cutting height decreased shoot and root biomass accumulation but increased nitrogen content. In general, clipping decreased shoot and root biomass production but increased the nitrogen content of the species. Except for two values obtained with *B. radicans*, root/shoot ratio was generally lower in clipped plants; and no consistent effect of clipping on tillering was observed. The experiment indicated that low intensity grazing may improve the nutritional quality of the grasses without reducing biomass production.

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1 INTRODUCTION

1.1 Scope of the problem

Ethiopia possesses diverse and unique wildlife. Some of these are protected within national parks, sanctuaries, wildlife reserves and other conservation zones. These areas are distributed over the country where wildlife concentration occur. Awash National Park (ANP), the first to be protected and legally gazetted together with the Simen Mountains National Park in 1969, is one of the most important conservation centres the country has.

The area delineated as Awash National Park and its surroundings was known for its high population of grazers. However, the population of grazers such as oryx (*Oryx gazella* (Linn. 1758)), soemmering's gazelle (*Gazelle soemmerringi* (Cretzschmar 1882)) and swayne's hartebeest (*Alcelaphus buselaphus swayni* (Pallas 1766)) has been declining from time to time. Park records show that some of the grazers such as grevy's zebra (*Equus grevyi* Oustalet 1882), bush duiker (*Sylvicarpa grimmia* (Linn. 1758)), orbi (*Ourebia ourebi* (Zimmermann 1783)), buffalo (*Syncerus caffer* (Sparrman 1779)), rhinoceros (*Diceros bicornis* (Linn. 1758)) and even African elephant (*Loxodonta africana* (Blumenbach 1797)) have disappeared from the area completely (Jacobs and Schloeder, 1993). It is difficult to find grazers such as oryx and soemmering's gazelle in some areas of the park that used to be grasslands as a result of which the areas have been encroached with shrubs.

Several factors could contribute for the decline and disappearance of these grazers such as poaching, predation, interference by pastoralists and town people, competition with livestock for grazing land and changes in quality and quantity of forage. The contribution of some of these factors to the decline of the grazer population has been looked at in the management plans of the park and in numerous reports of park wardens. However, the ecology of forage species of the park vis-a-vis the requirements of the grazers has never been studied. Nor has there been a quantitative assessment of the overall potential of the area to support wildlife. In general, there is little quantitative information concerning the seasonal and spatial variation in plant biomass and nutritive quality of east African grasslands (Boutton *et al.*, 1988b). For grasslands of ANP in particular, the quality and quantity of forage, the nutrient status and productivity of the major range grasses are among the least known ecological aspects.

Competition of grazers with livestock for grazing land is one of the factors which causes overgrazing resulting in shrub encroachment of a previously grassland area. The introduction of cattle as the predominant grazing species can change the valuable fodder-grass vegetation to impenetrable thickets, mainly consisting of *Acacia* species (Tolsma *et al.,* 1987). Thus, currently, grazers in ANP such as oryx and soemmering's gazelle are forced to concentrate in a narrow plain known as Illala-sala grassland which has an area of about 43 km^2.

The relative preference of grazers for plant communities is generally a linear function of the relative abundance and/or nutritive quality of the preferred plants in the communities (Senft *et al.,* 1987). Illala-sala has relatively high grass cover. This does not, however, necessarily mean that food source for grazers is plentiful. The variation in nutrient content occurring among different grass species can regulate herbivore population (Ben-Shahar, 1994). Shortage of nutritionally adequate food during dry seasons, for instance, may limit the performance and the population number of herbivores (Sollenberger *et al.*, 1987; Boutton *et al.*, 1988b).

As there is variation in nutrient content among the grass species, herbivores may select their food to obtain a nutritionally balanced diet (Westoby, 1974). Thus grazers are expected to select plants which have high levels of a particular element (Georgiadis and McNaughton, 1990). However, there is no single species that is known to accumulate high levels of all nutrients (Ben-Shahar, 1994).

The value of a pasture is largely determined by three factors: the quantity (biomass production), the energy and the protein content of forages that are eaten by herbivores (Soneji and Musangi, 1972; Boudet, 1975; Field, 1976). However, the most critical limiting factor for herbivores is the nitrogen (crude protein) content of the forages available in the area (Boudet, 1975; Field, 1976; Prins and Beekman, 1989). Nitrogen is the best indicator for explaining the palatability of forage. There are reports that grazers show preference for those plants which have the highest crude protein value (Eadie, 1970; Von Richter and Osterberg, 1977) which can be estimated from the percent nitrogen content. Also, phosphorus, energy and low crude fibre content may be used as indicators of the quality of forages (Heady and Child, 1994). Together with these factors, high moisture content of forages could also be a good indicator of the nutritional value of grasses (Ben-Shahar, 1994).

One of the criteria for range development planning is assessment of the carrying capacity of the community to meet the feed requirements of the animals at any point in time and on a long term sustained basis (Le Houerou *et al.*, 1988). Specially for a proper management of an area that is primarily maintained for its population of large herbivores, it is important to understand the availability of resources for grazing (Ridder *et al.*, 1982). Thus, biomass production is considered as an important ecological characteristic since it reflects the functional significance of grass species in a plant community. Determination of biomass production of species in different areas is a pre-requisite to identify the ecologically important grass species of the area (Theunissen, 1995). Therefore, a study on total biomass production of an area will give information on the capacity of the area since grazing animals adjust their densities in relation to grassland productivity (McNaughton, 1985). However, in tropical African grasslands, there have been few studies of primary production and there is a lack of quantitative information on the contribution of individual species to the primary production (Kinyamario and Imbamba, 1992).

In general, both chemical composition and quantitative yield of forages are important determinants of grassland production (Soneji and Musangi, 1972). Since diet selection by large herbivores is aimed at obtaining maximum quality and adequate quantity (Senft *et al.*, 1987), it is important to understand the potential of an area to support grazers. Ben-Shahar (1994) suggested that differences in nutrient levels among the available species in different seasons can be used to indicate nutritious forage species particularly at the peak of the dry season. Thus, acquiring knowledge on the nutrient status of the dominant grass species of a wildlife concentration area, its variation in different seasons as well as on overall productivity of the area is an essential requirement for a proper assessment of the suitability and capacity of an area to support grazers (Tolsma *et al.*, 1987).

The primary determinants of the quantity and quality of forage in east African grasslands are the long and short rains which are in turn determined by the pattern of movement of a low pressure system known as the Inter-Tropical Convergence Zone (Hesla *et al.*, 1985; Boutton *et al.*, 1988a; 1988b). However, the onset, magnitude and duration of these rains vary greatly between years and locations (Boutton *et al.*, 1988b; Veenedaal *et al.*, 1996). The amount of these two rains structure both the plant and animal components of east African grasslands (Boutton *et al.*, 1988a). Thus, variation in primary production is closely linked to variation in the amount of rainfall and its distribution (Le Houerou *et al.*, 1988).

Another important determinant of grassland productivity is the intensity of grazing, the main reason why range management is based on a knowledge of the responses of the range vegetation to grazing influences (Jameson and Huss, 1959). Grazing or clipping experiments are often used to examine how individual plants respond to different intensity of grazing (Middleton, 1982; Archer and Detling, 1984) since the influence of grazing depends on the degree, time and frequency of removing their leaves (Edroma, 1981b).

Intensity of grazing on an area not only affects the nutrient quality and the production of forage species (McNaughton, 1985; Georgiadis and McNaughton, 1990), but also the species composition of the area (Edroma, 1981a). The effect of grazing on both quality and quantity of forage species can be simulated in glasshouse experiments (Polley and Detling, 1989). Artificial grazing (clipping) has been shown to have similar effects as natural grazing. Although it may not reproduce all of its influences (Rockwood, 1973), it attempts to produce some aspects of the influences on the grass species (Jameson and Huss, 1959). According to Georgiadis and McNaughton (1990), the first principal component that separates samples according to their nutritional quality is the intensity of grazing. Thus, experiments on quality and quantity of species as influenced by simulated grazing are important components of studies of grassland production dynamics. The present study stems from this understanding. The study aims to characterize the nutrient levels and biomass production of the three major grass species of ANP (Schloeder and Jacobs, 1993) namely *Bothriochloa radicans* (Lehm) A. Camus, *Chrysopogon plumulosus* Hochst, and *Ischaemum afrum* (J.F.Gmel.) Dandy under field condition as influenced by season. The three species were identified as the major range grass species of the area from a preliminary survey. The influence of simulated grazing on growth pattern, nutrient status and biomass production of the three species was also studied to characterize individual plant response to the same.

1.2 Objectives of the study

General objective:

To asses the nutrient status and productivity of the three dominant grass species: *Bothriochloa radicans, Chrysopogon plumulosus* and *Ischaemum afrum* as influenced by season and simulated grazing.

Specific objectives:

- To estimate seasonal and annual biomass production of grasses.
- To examine the nutrient and moisture content of the grasses at different periods of the year.
- To examine the effect of simulated grazing on productivity and nutrient content of the three grass species.
- To examine the effect of the three grass species on the soil moisture and nutrient content.
- To evaluate the quantitative and qualitative importance of the species to grazers.

2 DESCRIPTION OF THE STUDY AREA AND THE STUDY GRASSES

2.1 Description of the study area

2.1.1 Location

The study was conducted at Awash National Park which is located in the Ethiopian Rift Valley between latitudes 8° 45' N and 9° 15' N and longitudes 39° 45' E and 40° 5' E. ANP covers approximately 756 km^2 and its altitude ranges between 970 and 2000 m. The park is bordered to the west by the edge of the Sabober plain, to the south and east by the Awash River and to the north by Kessem River and Filwoha Springs. The Assab-Addis Ababa highway passes through the National Park. The main entrance gate and the headquarters are 207 and 217 km from Addis Ababa, respectively. The study was conducted at Illala-sala grassland plain which is north of the Addis Ababa-Assab road, approximately 13 km from the headquarters and 3 km from the main entrance gate (see map of the area).

2.1.2 Climate

Climate of ANP may be characterized as semi-arid. The annual rainfall ranges between 400 and 700 mm (Daniel Gemechu, 1977). Rainfall is bimodal with two distinct seasons: the small rains which usually begins in February and extends to the end of April and the big rains which extends from July to September. Since the area is located within the Inter-tropical Convergence Zone, there is both temporal and spatial variability in rainfall, humidity and

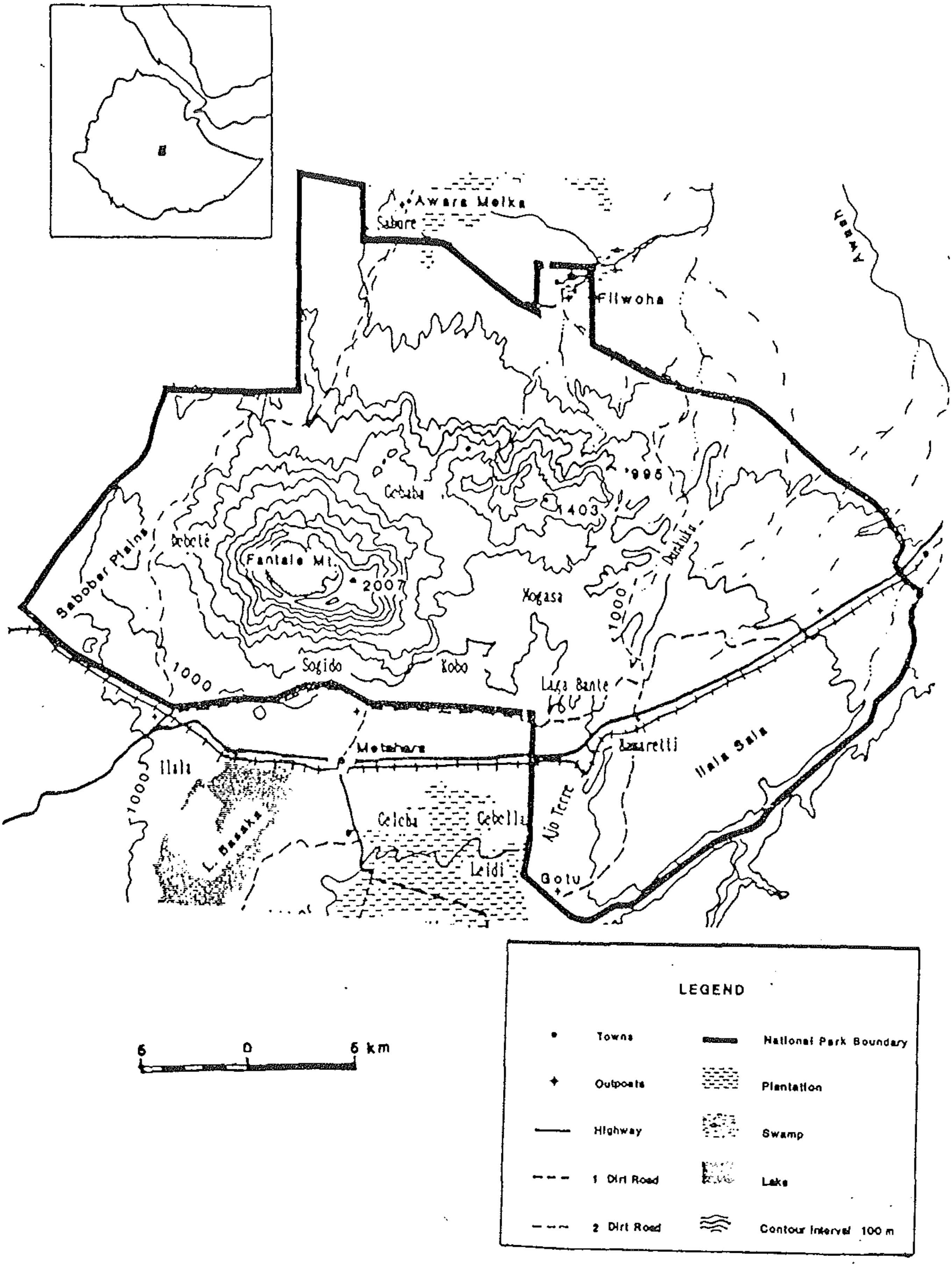

Fig. 1. Map showing location of the study area.

temperatures (Daniel Gamechu, 1977). Data collected at Metehara Sugar Plantation between 1966 and 1991 show that the mean annual rainfall is 555 mm. The least rainfall occurs during October, November and December and maximum rainfall fall during the months of July and August. There is only one really distinct dry season in which there is usually no or low rainfall recordings. This extends from late October to January.

The lowest monthly day time and night time temperatures occur during October - January and the highest of these temperatures occur during May and June. The maximum and minimum temperatures vary from 37.4° C in June to 28.6° C in November and from 22.3° C in June to 7.5° C in December, respectively.

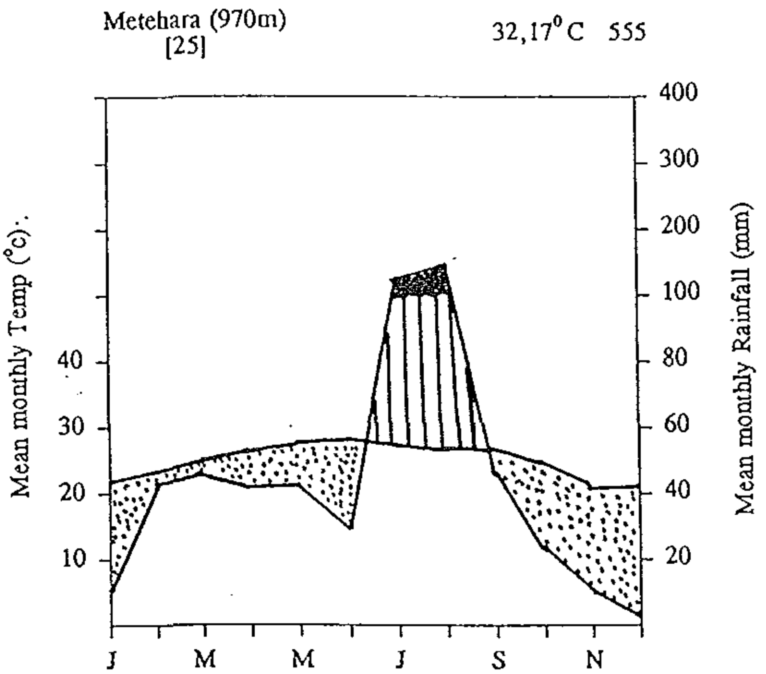

Fig. 2. Climate diagram of the study area.

2.1.3 Vegetation

According to the Ethiopian Mapping Authority Vegetation Map, there are eight major vegetation types or categories found in the conservation area: grassland, open grassland, shrub-grassland, shrubland, bushland/woodland, dense tree canopy and wooded grassland. The grasslands are dominated by *Chrysopogon plumulosus, Bothriochola radicans* and *Ischaemum afrum* in the lower elevations (Illala-sala) and *Hypharrhenia hirta* and *Themeda triandra* at higher elevations (on the slopes of Fantale Mountain). The shrubland type occurs in areas where there is moderate to heavy grazing pressure. It is dominated by *Acacia nubica* and *A. senegal* species. The bushland and woodland types are also dominated by *Acacia tortilis* and *A. senegal*. However, in some places *Balanites aegyptiaca* becomes dominant in the woodland vegetation type. The dense tree canopy is dominated by *Ficus* and *Acacia* trees.

2.1.4 Soil

Based on an FAO survey (FAO, 1965 cited in Jacobs and Schloeder, 1993), the following soil types have been identified from the study area:

1. *Eutric Regosol* - soil which is found at the base of Fentale; high silt content and stoniness; pH, 7.6 - 7.7 and depth, 0-140 cm.
2. *Mollic Andosol* - soil which is found throughout Metahara area; pH, 5.4 - 5.5 and depth, 0-100 cm.
3. *Gleyik Solonchak* - soil found around the marsh area of the warm springs (Filwoha); depth, 0-100 cm.

4. *Orthic Solonchak* - soil found throughout Kessem/Kebena plain; highly saline silty clay loam in severely eroded areas; depth, 0-100 cm.
5. *Eutric Histosols* - soil found in the Illala-sala plain; depth, 0-300 cm.
6. *Eutric Fluvisol* - soil found along the bank of Awash River; pH, 7.5-8.5
7. *Calcaric Fluvisol* - soil found near warm springs in Filwoha/Metahara area; saline soils on calcareous material; depth, 50-70 cm.

2.2 Description of the study grasses

2.2.1 *Chrysopogon plumulosus* Hochst

C. plumulosus is a loosely tufted perennial grass that grows from a short stout rootstock. Culms are numerous, thin but hard, branching and bushy above the base and form loose clumps. The culms are 20-80 cm high and leaves are up to 15 cm long and 2-3 mm wide. Panicle 5-10 cm long; spikelet 6 mm long with an awn of 2-4 cm long and straight plumose bristle. Side spikelets are with two plumose bristle each which are 10-12 mm long. The plants do not form dense stands but rather grow scattered by leaving a considerable space between the tufts. *C. plumulosus* grows on stony or black clay soils in semi-desert grassland areas and open Acacia bushlands at an altitude ranging from 400 to 1600 m.

The species is distributed in some parts of Ethiopia (Tigray, Shewa, Sidamo, Arsi and Harerge regions), western part of Eritrea, Northern Kenya, Somalia, Sudan, Niger, Egypt, S. Arabia and in Iran.

C. plumulosus is an important drought resistant perennial grass which is readily grazed by all kinds of stock (Bogdan, 1977).

2.2.2 *Bothriochloa radicans* (Lehm.) A. Camus (1931)

B. radicans is a perennial grass which forms loose tussocks of 25 to 100 cm high which are much branched with dense leafy above ground parts. Leaves are glabrous or sparingly hairy with a length ranging between 6 and 20 cm, and 2 and 5 mm wide. The inflorescence consists of clusters of 3-12 racemes which is 3-7 cm long, slightly scented, subdigitate or on a short axis up to 5 cm long. Sessile spikelet are 2.5-4.0 mm long, unpitted or occasionally with a single pit with an awn of 5-9 mm long. The plant grows on various soils but mainly on dark volcanic or black soils in grasslands or in thin bush.

B. radicans is distributed in various regions of Ethiopia (Shewa, Afar, Arsi, Harerge, Sidamo and Tigray) and other African countries at an altitude ranging from 600 to 1900 m.

B. radicans is liked by cattle and has according to Bogdan (1977) high nutritive value.

2.2.3 *Ischaemum afrum* (J.F.Gemel.) Dandy (1956)

I. afrum is a tufted perennial with rhizomes, branched stem up to 1.5 m high. The leaves are linear, tough, 20-40 cm long and 4-8 mm wide tappering to a long setaceous tip. Racemes 2-5, subdigitate with 9-20 cm length. The grass is found on clay soils at an altitude ranging from 600 to 1500 m.

I. afrum is distributed in dry Acacia bushland or savanna region of Ethiopia (Shewa, Afar, Hararge, Sidamo, Tigry, Gondar and Gojam), and other African countries.

I. afrum is grazed when it is young and its crude fibre content is also high even in young leaves (Bogdan, 1977).

A complete description of the features and distribution of the three grasses studied is given by Bogdan (1977) and by S. Phillips in *Flora of Ethiopia and Eritrea* (Hedberg and Edwards, 1995).

3 MATERIALS AND METHODS

3.1 *In situ* field studies: Experimental design for the estimation of seasonal and annual biomass production

Above ground seasonal and annual biomass production of the grass species was estimated according to Singh and Yadava (1974). At the beginning of the study, four 6 m x 6 m quadrates were established and fenced at Illala-sala grassland to exclude large grazers. Each of the three quadrates were established systematically in such away that only pure stands of the individual grass species were included whereas the fourth quadrat was established in such a way that it included mixed stands of the three grass species. Each quadrat was divided into 36, 50 cm x 50 cm sub-quadrates (plots) which were numbered.

At the beginning of the study (first week of January, 1996), all the grass in the quadrates was mowed up to 2 cm level above the ground. Portions of the sub-quadrates were mowed at three months interval (based on the rainfall distribution of the area) to estimate the seasonal and annual biomass production of the grass species. On each sampling occasion, nine, 50 cm x 50 cm sub-quadrates were randomly selected from each quadrat and mowed at 2 cm level from the ground. Sampling was done such that it allowed a three, six, nine and twelve months of growth for each species. Mowing was performed manually with the help of sharp sickles. The harvested grass from each harvested plot was packed in plastic bags and brought to the laboratory separately. Then the samples were dried in an oven at 80°c for 48 hours and dry matter was determined.

3.2 Seasonal variation in moisture content and nutrient levels of grass species

The seasonal variation in moisture content was determined from samples collected for estimation of biomass production. Nutrient levels of the three grass species was investigated by taking about 500 g above ground parts for each of the three species from good grass stands outside the quadrates at Illala-sala plain. Samples were collected in six replicates per species at three months interval starting from April 1996 to January 1997. Each samples was wrapped tightly in a plastic bag to avoid moisture loss. The samples were weighed in the laboratory before opening the bags and the fresh weight was recorded after subtracting the weight of the plastic bag. The samples were dried in an oven at 80°c for 48 hours and weighed again. Percent plant moisture content was then calculated as the difference between the fresh and dry weights.

The levels of the important minerals such as N, P, K, and Na were determined for each sample following Yerima (1992) as described in section 3.5.3.

3.3 Seasonal variation in moisture content and nutrient levels of soil samples

To relate variation in grass moisture and nutrient content with soil conditions, soil samples (four replicates) were collected parallel with grass sample collections under each of the three grass species both from the surface (0-3 cm) and from a depth of 25-30 cm. The soil samples were packed in air tight polythene bags and transported to the laboratory. Then the soil was weighed and dried at 80° C for 48 hours and the dried soil was weighed again. The percent soil moisture content was calculated from the difference between the wet weight and dry weight as follows:

$$\text{Percent soil moisture} = \frac{\text{field soil weight - oven dry weight}}{\text{field soil weight}}$$

The soil physical and chemical characteristics were determined as described in section 3.5.1 and 3.5.2, respectively.

3.4 Greenhouse experiment to study the influence of simulated grazing on grass biomass production and nitrogen content

Experimental design

A clipping experiment was conducted to examine the effect of cutting height and frequency on biomass accumulation and nitrogen concentration of the three grass species. The experiment was carried out from July 1996 to February 1997 under glasshouse conditions with plants grown from seeds. The experimental design was a randomized complete block lay out with two blocks and three replications per treatment for each of the three species (*C. plumulosus*, *B. radicans* and *I. afrum*). Treatments consisted of three cutting frequencies (15, 30 and 45 days intervals) and three cutting heights (4, 8 and 12 cm) following Middleton (1982). The seeds were sawn in plastic pots of 15 cm diameter and 20 cm depth filled with sand, peat and soil mixture (2:2:1) in well watered condition. The plants were thinned to one plant per pot and the grasses were allowed to grow for 66 days before the start of clipping. Clipping was done evenly using scissors. Clipped parts were saved for determination of nitrogen level and biomass records. The nitrogen level for each treatment and for each species was determined following Yerima (1992) (see section 3.5.3). At the end of the experiment tillering, total shoot and root biomass were recorded.

3.5 Soil and plant analysis

3.5.1 Determination of soil physical characteristics

3.5.1.1 Soil texture

The texture of the soil samples was determined following Hydrometer Method of Mechanical Analysis (Juo, 1978). Fifty ml of 5 % sodium hexametaphosphate along with 100 ml of distilled water was added to 51 g of two mm sieved soil samples. After stirring, the suspension was allowed to stand for 30 minutes. The soil suspension was stirred for 15 minutes with a multi-mix machine and then transferred to one litter measuring cylinder. Then the cylinder was filled with distilled water up to the mark. This was mixed by covering the top of the cylinder with hand and inverting several times until all soil was in suspension. The first hydrometer and temperature readings were taken in 40 seconds after the cylinder was put on a table. The second hydrometer and temperature readings were taken three hours later. The percentage of different soil particles were calculated following (Juo, 1978) as follows:

% sand = $100 - [H_1 + 0.2\ (T_1 - 68) - 2.0]2$

% clay = $H_2 + [0.2\ (T_2 - 68 - 2]2$

% silt = 100 - (% sand + % clay)

Where

H_1 - the first hydrometer reading

H_2 - the second hydrometer reading

T_1 - the first temperature reading

T_2 - the second temperature reading

3.5.1.2 Bulk density

Bulk density was determined following Wilde *et al.* (1979). Soil samples were taken by pressing a core cylinder downward. Then the cylinder together with the surrounding soil was removed by a spade and the surplus soil was cut away with a knife. The samples were then dried to constant weight in an oven and weighed. Bulk density was recorded as the weight of the soil sample divided by its volume.

3.5.1.3 Porosity

According to Wilde *et al.* (1979), it is possible to determine porosity of soils from the bulk density without the pycnometric determination of specific gravity of the soil material, since specific gravity of soil particles varies in most instances within the narrow limits of 2.60 and 2.70. The error introduced by taking specific gravity as 2.6 or 2.7 does not exceed 5 % and is sufficiently accurate for comparative studies (Wilde *et al.*, 1979). Porosity was therefore calculated in the present study by taking the average specific gravity of the soil as 2.65 g cm^{-3} (Chopra and Kanwar, 1976; Thompson and Troeh, 1978; Wild, 1993). Thus,

$$P = \frac{S - D}{S} \times 100$$

$$P = \frac{2.65 - D}{2.65} \times 100$$

Where, S - specific gravity

D - bulk density

3.5.2 Determination of soil chemical characteristics

3.5.2.1 Soil pH

The pH of the soil was determined using a 1:1 soil water ratio (Jackson, 1973; Juo, 1978). Twenty grams of soil, passed through a two mm sieve was mixed with 20 ml of distilled water in 50 ml beaker. The suspension was stirred occasionally and after 30 minutes the pH was determined using a Beckman pH meter after standardizing with buffer solutions of pH 4 and 7.

3.5.2.2 Total nitrogen

Total nitrogen was determined following the macrokjeldahl method as described below. The kjeldahl method for nitrogen determination involves three processes: digestion, distillation and titration. During digestion, organic nitrogen is converted to ammonium-nitrogen with the help of potassium sulphate (K_2SO_4) to raise the temperature and cupric sulphate ($CuSO_4.5H_2O$) is used as catalyst.

$$\text{Organic nitrogen} + H_2SO_4 \xrightarrow[CuSO_4.SH_2O]{K_2SO_4} (NH_4)_2SO_4 + H_2O$$

Then the amount of nitrogen is estimated from the amount of ammonia liberated by distilling the digest with alkali (NaOH).

$$2(NH_4)_2SO_4 + 4\ NaOH \longrightarrow 2Na_2SO_4 + 4NH_3 + 4H_2O$$

The ammonia liberated is trapped by boric acid and titrated using HCl.

$$NH_3 + H_3BO_3 \longrightarrow NH_4H_2BO_3$$

$$NH_4H_2BO_3 + HCl \longrightarrow NH_4Cl + H_3BO_3$$

To one g of soil sample, passed through a 0.5 mm sieve, seven g of potassium sulphate and 0.8 g of cupric sulphate was added into macrokjeldahl tubes. The mixture was digested at 420° C for about three hours until a clear green solution developed. After cooling, 75 ml of distilled water was added and let to stand overnight. Then the digest was distilled by dispensing 50 ml of 40 % sodium hydroxide. The distillate was received in 25 ml of 4 % boric acid mixed indicators and titrated with 0.1 N hydrochloric acid until the green colour of the distillate changed to neutral grey. Similarly the blank was passed through all the process like that of the samples to compensate for any contribution from the reagents used. Then the percentage of nitrogen present in the soil samples was calculated as follow:

$$\%\ N = \frac{(T - B) \times N \times 14.007 \times 100}{\text{Weight of sample in mg}}$$

Where, T - titration volume for the sample

B - titration volume for the blank

N - normality of the acid

3.5.2.3 Available phosphorus

Available phosphorus in the soil was determined following Bray No. 2 method of Olsen and Sommers (1982) and Tamirie Hawando *et al.* (1986). To one gram of soil sample, passed through 2 mm sieve, 7 ml of the extracting solution was added. This was shaken for 40 seconds on a mechanical shaker and the suspension was centrifuged at 2,000 RPM for 15 minutes. Then 2 ml of the clear supernatant was pipetted into 20 ml test tubes. Into the 2 ml supernatant 5 ml distilled water and 2 ml of ammonium molybdate solution was added and the content mixed. Then one ml of diluted stannous chloride ($SnCl_2.2H_20$) was added and after 5 minutes the transmittance of the resulting complex was determined using spectrophotometer (Spectronic 1001) at 660 nm. The concentration of available phosphorus in the soil was calculated from the standard curve obtained with known concentrations of phosphorus.

The concentration of dilute fluoride - diluted acid extractable phosphorus in the soil was calculated as follows:

$$\text{ppm of P in soil} = \text{ppm of P in solution} \times \frac{\text{vol. of the mixture}}{\text{vol. of the extract}} \times \frac{\text{vol.of extracting soln.}}{\text{wt. of sample}}$$

$$\text{ppm of P in soil} = \text{ppm of P in solution} \times 10/2 \times 7/1$$

$$= \text{ppm of P in solution} \times 35$$

3.5.2.4 Exchangeable potassium and sodium

Exchangeable potassium and sodium of the soil were determined flame-photometrically following Juo (1978). Thirty ml of 1 N ammonium acetate solution (pH=7) was added to 5 g of soil sample passed through a 2 mm sieve and shaken for 2 hours on a mechanical shaker. The suspension was centrifuged at 2,000 RPM for 10 minutes. The clear supernatant was decanted in 100 ml volumetric flasks. Another 30 ml of ammonium acetate solution was added and shaken for 30 minutes. This was centrifuged and the clear supernatant was decanted into the same volumetric flask. This last step was repeated once more. The flask was filled up to the mark with the ammonium acetate solution. Potassium and sodium were determined on a flame photometer and the amount of exchangeable potassium and sodium was calculated from the standard curve of known concentrations of potassium and sodium salts.

3.5.2.5 Organic carbon

Organic carbon of the soil was determined following the Walklay and Black wet oxidation method under standardized conditions with potassium dichromate in sulphuric acid medium (Chopra and Kanwar, 1976). However, it should be noted that the values obtained by this method are only approximate, since only 60-90% of all the carbon is oxidized with a mean value between 75 - 80%. Ten ml of 1 N potassium dichromate and 20 ml of sulphuric acid was added to one g of soil sample passed through 0.5 mm sieve in a 250 ml Erlenmeyer flask. The mixture was shaken for two minutes and allowed to stand for 30 minutes. Then 150 ml of distilled water, 10 ml of 85 % phosphoric acid and 1 ml of diphenylamine indicator solution was added and titrated with 0.5 N ferrous ammonium sulphate solution. Similarly blank determination was also carried out to standardize the dichromate solution. Then the % organic carbon was calculated using the following formula:

$$\% \text{ organic carbon} = \frac{(X-Y) \times 0.003 \times 100}{2 \times W}$$

Where X = volume of 0.5 N ferrous ammonium sulphate required for reducing 10 ml $K_2Cr_2O_7$ solution (blank reading)

Y = volume of 0.5 N ferrous ammonium sulphate required for reducing the excess of dichromate in the sample

W = weight of soil taken in grams

3.5.2.6 Electrical conductivity

Electrical conductivity of the soil solution (the concentration of soluble salts) was determined by preparing a 1:2 soil water suspension following Chopra and Kanwar (1976). Fifty g of soil, passed through a 2 mm sieve, was mixed with 100 ml of distilled water in 250 ml Elrenmeyer flasks and the mixture was shaken for 20 hours. Then the suspension was filtered through a Buchner funnel and the conductivity of the filtrate was determined by Crison CDTM-523 conductivity meter. The conductivity in 1:2 soil water suspension multiplied by two gives the values for the original soil samples. Then,

Ec.25° C = Ect x Ft

Where, EC.25° C - electrical conductivity at 25° C

Ect - Electrical conductivity at temperature t

Ft - Correction factor at temperature t

3.5.2.7 Cation Exchange Capacity (CEC)

CEC was determined by measuring the total equilibrating the charge of the exchanger by neutral sodium acetate following Juo (1978). To 5 g of soil, passed through 2 mm sieve, 30 ml of sodium acetate solution (pH=7) was added and shaken for one hour. Then the solution was transferred completely using a small amount of distilled water into a Buchner funnel fitted with a moist filter paper. The soil on the filter paper was leached with 60 ml of sodium acetate solution by adding about 15 ml portion at a time and the leachate was discarded and the soil was then washed by 30 ml of 95 % ethanol six times until the leachate gave an electrical conductivity which was less than 50 m mhos cm^{-1}. Then the exchangeable sodium was displaced from the samples by leaching with 20 ml portions of 1 N NH_4OAC (pH=7) five times. Finally, the sodium was determined flame photometrically and the amount of sodium was calculated from the standard curve of known concentrations of sodium.

CEC, me/100 g soil = me Na/100 g soil.

3.5.3 Determination of N, P, K, and Na in plant tissues

For the determination of the concentrations of N, P, K, and Na in plant tissues a similar process of digestion was used for all the elements with concentrated sulphuric acid and hydrogen peroxide at elevated temperature under the influence of selenium as a catalyst (Yerima, 1992). Digestion was initiated by transferring 0.3 g of plant material (which has been dried and grounded and passed through 0.5 mm sieve) and 2.5 ml of the digestion mixture (sulphuric acid-selenium-salicylic acid) to a digestion tube and allowed to stand for two hours including the blank digest. Then the tubes were placed in the heating digestion block and heated at 100° C for two hours. After heating, the tubes were removed from the block and allowed to cool, then 1 ml of hydrogen peroxide was added three times successively by mixing thoroughly after each addition. Again the tubes were placed in the preheated block at 330° C until the digest turned to colourless or light yellow. After cooling 50 ml of distilled water was added and the contents were mixed. This was allowed to stand overnight. Then the digests were filtered into 100 ml volumetric flasks and filled up to the mark with distilled water. This digest was used to determine total nitrogen, phosphorus, potassium and sodium.

3.5.3.1 Total nitrogen

Total nitrogen from plant samples was determined by distillation of the aliquot (50 ml) from the digest with 40 % sodium hydroxide which was received in 25 ml of boric acid and then titrated with 0.1 N HCl to the end point of mixed indicators. The distillation, titration as well as calculation of percent nitrogen from plant sample was done in the same way as for the soil (see section 3.5.2.2).

3.5.3.2 Phosphorus

The amount of phosphorus in the digest was determined colorimetrically by using molybdate and metavanadate for colour development. Five ml of the sample digest was pippeted into 50 ml volumetric flask and 10 ml of molybdate and vanadate solution was added. Then the flasks were filled with distilled water up to the mark. After 10 minutes absorbance was determined using a spectrophotometer at 460 nm wavelength. The concentration of phosphorus in the sample digest was calculated from the standard curve of known concentrations of phosphorus.

$$P\ pmm = \frac{C.V1.V2}{S.A}$$

Where, C = P concentration in sample digest obtained from the standard curve, ppm

V1 = volume of the digest (100 ml)

V2 = volume of the dilution (50 ml)

S = weight of the plant material digested (0.3 g)

A = aliquot (5 ml)

Thus, P ppm = C x 3333.3

3.5.3.3 Potassium and Sodium

Sodium was determined by aspirating the diluted digests directly to the flame photometer, while potassium was determined by diluting the extract with 4 % nitric acid before reading. Then the concentration of sodium and potassium in the sample digest were extrapolated from the standard curve. The concentration of K and Na were calculated as follows:

$$K, Na\ (ppm) = \frac{(a - b) \times v \times df}{s}$$

where, a = concentration reading (K, Na) for sample from curve (ppm)

b = concentration reading (K, Na) for blank from curve (ppm)

v = volume of the digest adjusted to the mark (100 ml)

df = dilution factor

s = sample weight, g

3.6 Statistical analysis

All collected data were subjected to statistical analysis using the MINITAB statistical package version 10. Variance analysis (one way ANOVA) using Tukey's Family Error Rate was used to test for significant differences among the biomass and nutrient data sets. One-way and two-way analysis of variance tests were used to identify the significant effects of the three different cutting heights and cutting frequencies on shoot and root biomass accumulation and nitrogen concentration of the three grasses as well as to determine the interaction of treatment factors.

4 RESULTS

4.1 Biomass production of grasses at Illala-sala grassland plain

The seasonal variation in aboveground biomass production of the grasses was estimated after removing all the biomass at 2 cm aboveground at the start of the experiment. The quantity of seasonal biomass production of grasses at Illala-sala grassland varied in different periods of the year (1996) in response to the seasonal variation in rainfall amount (Fig. 3a and Appendix 1). Rainfall at Awash National Park during the study period is shown in Fig. 5b. The highest rainfall was recorded in July whereas there was very little rainfall from October to December.

Maximum values of biomass (within a growth period of three months) were obtained during the period from April to June and July to September. These values ranged from 113.5 ± 35.4 g m^{-2} to 408.7 ± 92.2 g m^{-2} from *B. radicans* and *I. afrum* stands, respectively. The second but much smaller peak biomass was accumulated during the period from January to March which corresponds with the small amount of rainfall during the period. However, the biomass produced during the period from October to December, the typical dry period of the year, was very little.

The increase in biomass production of the grasses from all the four types of stands at different growth intervals (i.e., after 3, 6, 9 and 12 months of growth) is shown in Fig. 4. The biomass produced with three, six and nine months growth intervals were significantly different ($p < 0.05$) from each other but the biomass produced after 12 months growth was

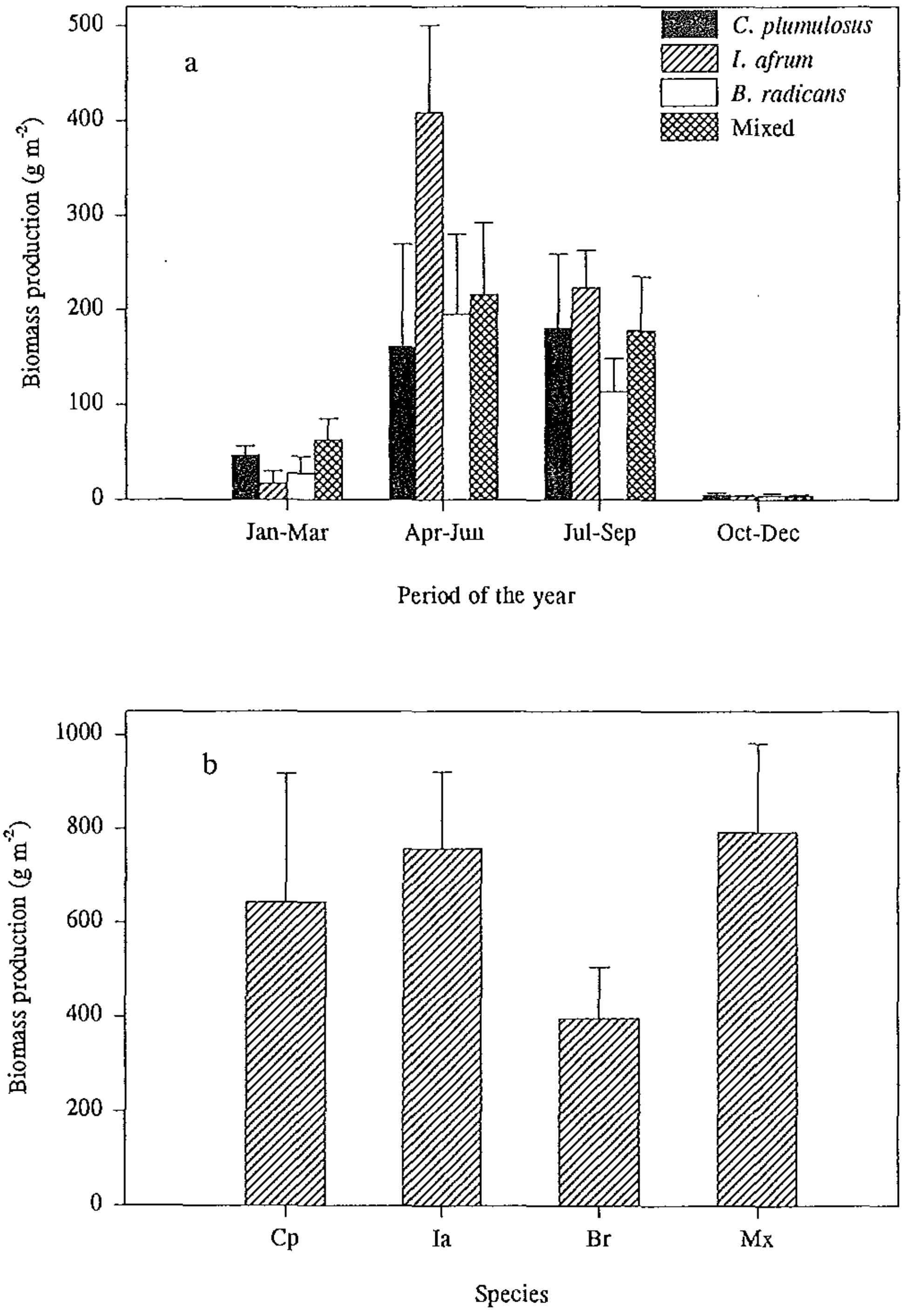

Fig. 3. **Seasonal (a) and annual (b) biomass production of the three grass species.** (Cp, *C. plumulosus*; Ia, *I. afrum*; Br, *B. radicans* and Mx, Mixed).

not significantly different from the biomass produced after nine months growth for all the stands (Appendix 2). Biomass value after 12 months growth was slightly lower than the biomass obtained after 9 months growth for all the stands due to defoliation.

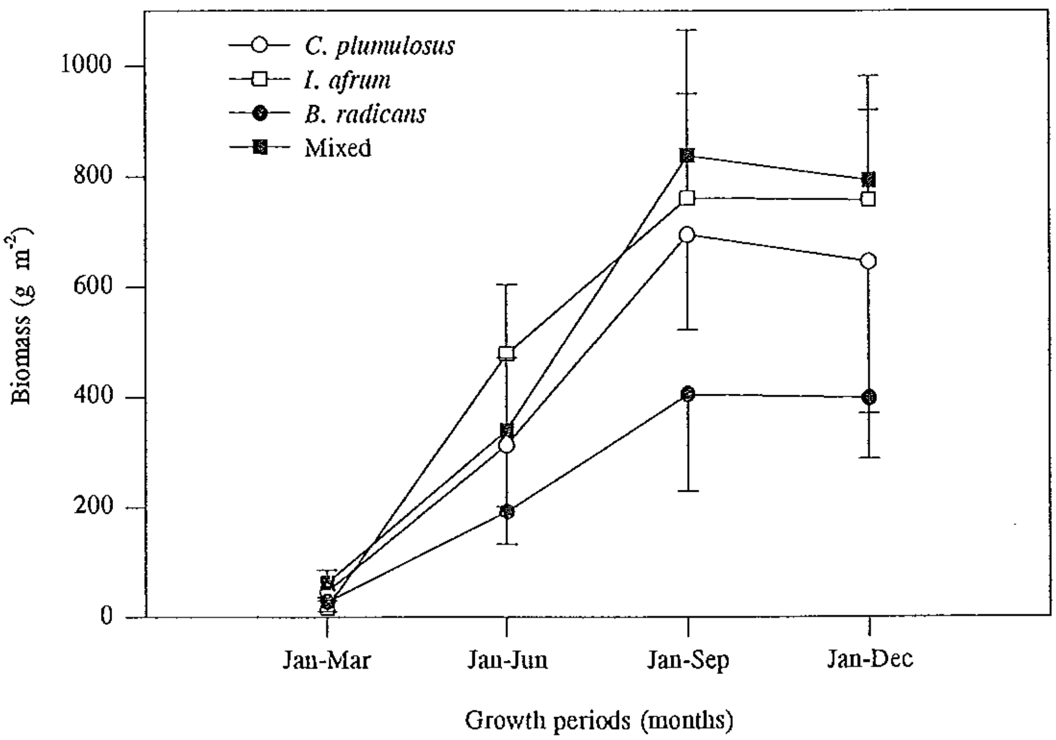

Fig. 4. Biomass production of the three grass species and the mixed stands in different growing intervals. The values were obtained after allowing the stands to grow for three (January-March), six (January-June), nine (January-September) and 12 (January-December) months. Significant differences among the growing intervals and among the species are shown in Appendix 2.

When the values of biomass of the four groups of stands were compared (Appendix 2), *B. radicans* had significantly lower biomass than *I. afrum* and the mixed species stands after six and twelve months growth. It had also significantly lower biomass value than the other three stands after nine months growth.

The annual biomass production was estimated after removing the biomass produced before January 1996 and allowing all the stands to grow for 12 months. The annual biomass production of the different stands is shown in Fig. 3b. It ranged from 396.7 $\pm$ 108.6 g m^{-2} for *B. radicans* stands to 791.8 $\pm$ 189.8 g m^{-2} for mixed species stands. As it can be seen from Fig. 3b, the biomass production of *B. radicans* stands was significantly lower than that of *I. afrum* and the mixed species stand (Appendix 2).

4.2 Nutrient and moisture content of the three grass species

Table 1-4 and Appendix 3 and 4 present the effect of season on the moisture and nutrient (nitrogen or crude protein, phosphorus, potassium and sodium) contents of the three grass species. Differences in moisture and nutrient contents among the grass species in different periods is also presented in the same tables.

4.2.1 Moisture content

The percent moisture content of the grasses (obtained from the samples collected for estimation of biomass production) decreased from April, 1996 to January, 1997 (Fig. 5a). The highest moisture content was obtained in April after the small rains and the lowest in

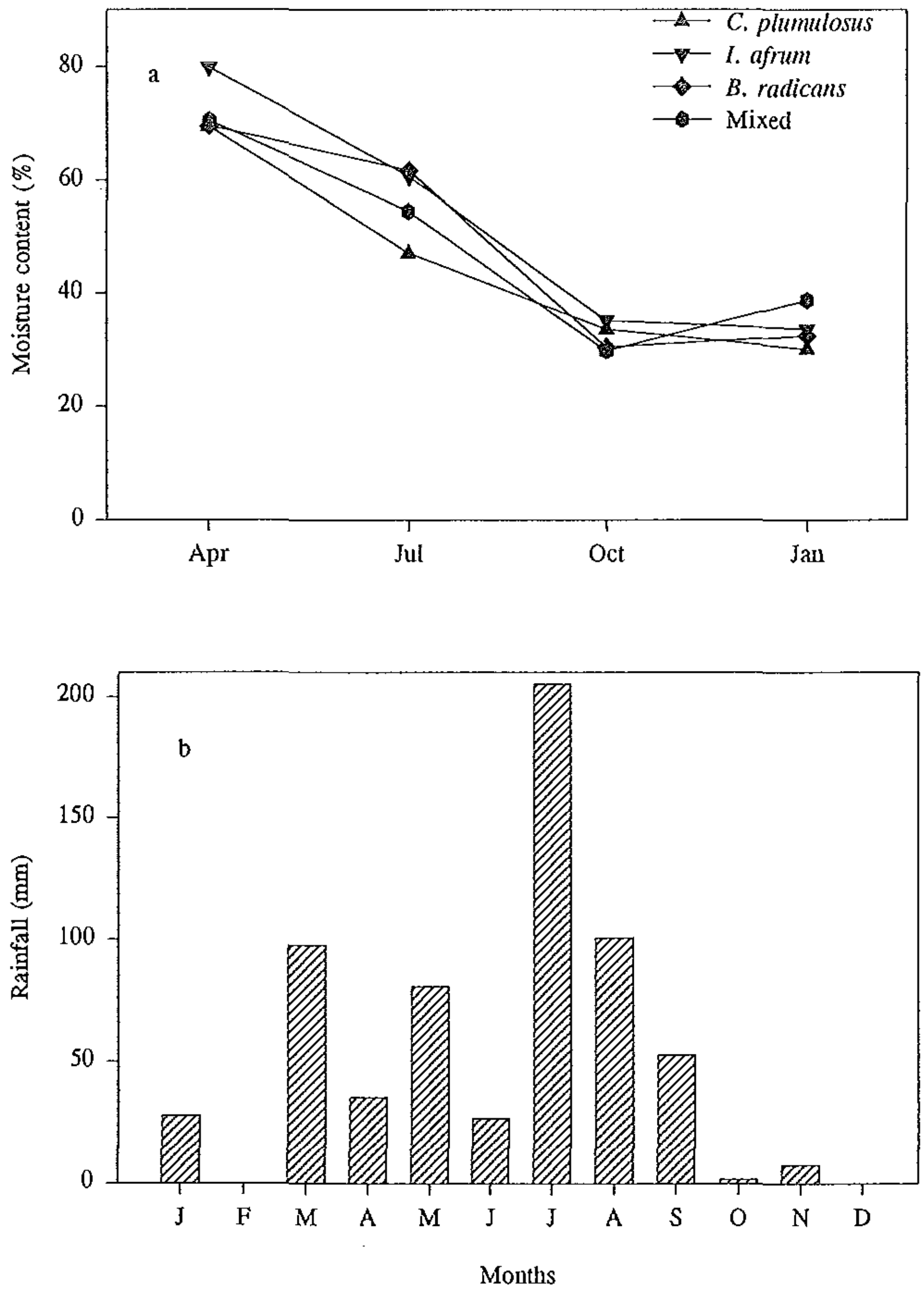

Fig. 5. Moisture content of the grasses as determined in different periods of the year (a) and monthly rainfall data (b) (1996). The moisture content of the grasses was determined towards the end of the months indicated.

October and January during the beginning and the peak of the dry period, respectively. It ranged from 29.9 ± 2.2 percent in October for the mixed species stands to 79.9 ± 6.1 percent for *I. afrum* stands in April. The percent moisture content of the grasses in the three consecutive sampling periods (April, July and October) were significantly different from each other at $p < 0.05$. However, the moisture content of the grasses in October was not significantly different from that of January for all the stands (Appendix 3).

When the moisture content of the different stands in the same sampling period is compared, *I. afrum* stands had significantly higher moisture content than the other three groups of stands in April and *I. afrum* and *B. radicans* stands had significantly higher moisture content than that of *C. plumulosus* and the mixed stands in July. But the mixed species stands had significantly higher moisture content than *C. plumulosus* stands. Here *C. plumulosus* stands had the least moisture content in July. However, there were no significant differences in moisture content among the four stands in October and January (Appendix 3).

4.2.2 Nitrogen

Significant seasonal differences in concentration of nitrogen occurred in all the grass species (Table 1). Values for percent nitrogen in the three grass species decreased with precipitation. It ranged from 0.397 ± 0.06 to 1.106 ± 0.211 % with the maximum value occurring in April during the small rains for *B. radicans* and the minimum value occurring in January during the peak of the dry period in *I. afrum*. The percent nitrogen value of the species is also presented as percent crude protein content in Appendix 4.

As shown on Table 1, *C. plumulosus* and *B. radicans* had significantly higher % N in April and July (wet periods) than in January (the typical dry period). But *I. afrum* had significantly higher % N only in April than that of % N in January. When the nitrogen values of the three species were compared, there was no significant difference among the species in April and October. However, *I. afrum* had significantly lower nitrogen values than that of *C. plumulosus* and *B. radicans* in July and January, respectively. From the mean values, *I. afrum* had lower % N in all the periods as compared to the other two species.

Table 1. Mean nitrogen content (%) of the three grass species in different periods of the year (n=6, mean ± sd).

Period	*C. plumulosus*	*B. radicans*	*I. afrum*
April, 1996	0.964 ± 0.043^{aA}	1.106 ± 0.211^{aA}	0.820 ± 0.288^{aA}
July, 1996	0.961 ± 0.250^{aA}	0.912 ± 0.122^{abA}	0.671 ± 0.056^{bAB}
Oct., 1996	0.683 ± 0.232^{aAB}	0.528 ± 0.052^{aB}	0.497 ± 0.143^{aAB}
Jan., 1997	0.534 ± 0.123^{abB}	0.609 ± 0.140^{aB}	0.397 ± 0.060^{bB}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

4.2.3 Phosphorus

The grasses showed significant seasonal changes in their phosphorus concentration (Table 2). The concentration of phosphorus in the grasses ranged from 257.2 ± 73.0 to 1140.3 ± 327.0

ppm. Maximum values were recorded in April for *B. radicans* and the minimum value in January for *I. afrum*. There were no significant differences in phosphorus contents among the species in April and October. However, *C. plumulosus* had significantly higher phosphorus content than *B. radicans* and *I. afrum* in July, whereas, *B. radicans* had significantly higher phosphorus content than *C. plumulosus* and *I. afrum* in January.

Table 2. Phosphorus content (ppm) of the three grass species in different periods of the year (n=6, mean ± sd).

Period	*C. plumulosus*	*B. radicans*	*I. afrum*
April, 1996	1069.7 ± 247.2^{aA}	1140.3 ± 327.0^{aA}	810.9 ± 278.8^{aA}
July, 1996	1064.0 ± 305.3^{aA}	619.0 ± 248.2^{bB}	624.1 ± 280.6^{bA}
Oct., 1996	772.7 ± 251.3^{aA}	892.7 ± 253.3^{aB}	624.4 ± 192.7^{aA}
Jan., 1997	363.3 ± 51.3^{abB}	440.9 ± 140.23^{aB}	257.2 ± 73.0^{bB}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

4.2.4 Potassium

The potassium concentration of the grasses also showed significant seasonal variation (Table 3). It ranged from 2224 ± 389 ppm in January (dry period) for *I. afrum* and 9366 ± 2929 ppm in July (wet period) for *B. radicans*, similar to the variation in nitrogen and phosphorus values. In January, the values of potassium in *C. plumulosus* and in *B. radicans* were significantly lower than in the other three periods. But *I. afrum* had significantly higher potassium concentration in July and October than in April and January (Table 3). There were no significant differences in potassium content among the grasses in April, July and October. However, in January, *I. afrum* had significantly lower potassium concentration than *B. radicans*.

Table 3. Potassium content (ppm) of the three grass species in different periods of the year (n=6, mean ± sd).

Period	*C. plumulosus*	*B. radicans*	*I. afrum*
April, 1996	6732 ± 1338^{aA}	6169 ± 2798^{aA}	2721 ± 2559^{aA}
July, 1996	6385 ± 1653^{aA}	9366 ± 2929^{aA}	6989 ± 1670^{aB}
Oct., 1996	6534 ± 2094^{aA}	7317 ± 1141^{aA}	7121 ± 1811^{aB}
Jan., 1997	2596 ± 556^{abB}	3106 ± 304^{aB}	2224 ± 389^{bA}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

4.2.5 Sodium

Unlike for the other mineral elements, there was very little seasonal variation in sodium content among the grass species. *C. plumulosus* and *I. afrum* had almost the same sodium content in all the four periods. But *B. radicans* had significantly higher sodium concentration in October than in April. The concentration of sodium ranged from 1091.3 ± 112.4 ppm in

April for *I. afrum* to 1612.9 ± 75.7 ppm in October for *B. radicans*. However, there were no significant differences among the species in their sodium content in all the four periods of the year (Table 4).

Table 4. Sodium content (ppm) of the three grass species in different periods of the year (n=6, mean ± sd).

Period	*C. plumulosus*	*B. radicans*	*I. afrum*
April, 1996	1288.7 ± 216.7^{aA}	1175.9 ± 124.5^{aA}	1091.3 ± 112.4^{aA}
July, 1996	1175.9 ± 422.6^{aA}	1316.9 ± 306.1^{aAB}	1175.9 ± 376.1^{aA}
Oct., 1996	1471.9 ± 115.6^{aA}	1612.9 ± 75.7^{aB}	1443.7 ± 278.0^{aA}
Jan., 1997	1429.6 ± 98.6^{aA}	1463.5 ± 158.8^{aAB}	1373.3 ± 124.5^{aA}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

4.3 Influence of grass species on nutrient and moisture content of soil in different seasons

The soil immediately beneath the grass species was investigated to study the effect of species and season on soil moisture content and on the levels of total nitrogen, available phosphorus, exchangeable potassium and sodium. Table 5a and 5b show the results of this investigation.

4.3.1 Moisture

The amount of moisture in the soil under each species decreased with the dry season both at 0-3 cm and at 25-30 cm depth (Table 5a). In April and July, the soil at 0-3 cm depth under *C. plumulosus* and *B. radicans* had significantly higher moisture content than in October and January. But moisture content of soils at 0-3 cm depth under *I. afrum* measured at the different seasons were significantly different from each other. Values of moisture content at 25-30 cm depth under each of the three species were significantly different from each other in all the different periods. Thus, seasons and the depth from which the soil samples were taken were more important than the species under which the samples were collected.

4.3.2 Total nitrogen

Season of collection and species under which the soil samples were collected had very little influence on nitrogen content. There was no significant difference among soils taken from the same depth in nitrogen content in all the four periods of the year under each species except that of the soil at 25-30 cm depth under *B. radicans* (Table 5a). Species had no significant effects on the nitrogen content of the soil under them in all four periods of measurements except in April between soil nitrogen content under *C. plumulosus* and under *I. afrum* at 25-30 cm depth. However, the depth from which the soil samples were taken had more effect on nitrogen content than the season and the species under which the species were collected. In general, most of the differences observed were due to depth but not due to season or species.

4.3.3 Available phosphorus

As is the case with nitrogen, the effect of seasons on the levels of available soil phosphorus was also very minimal. There were no significant differences among the soils in their available phosphorus content in all the four periods of the year under each species except for the soil at 25-30 cm depth under *B. radicans*. Comparison of available soil phosphorus among the three species showed that there were no significant differences in all the four periods. However, depth had much more effect on the soil available phosphorus in wet periods than in the dry periods. Also, in both the wet and the dry periods, the mean available soil phosphorus at 0-3 cm depth was relatively higher than that of the soil at 25-30 cm depth.

4.3.4 Exchangeable potassium and sodium

Unlike the other nutrients, season had an effect on the exchangeable potassium content of the soils collected under each of the three species with the exception of soil at 0-3 cm depth under *I. afrum* (Table 5b). Although in general soil exchangeable potassium content was not influenced by the grass species, the value obtained in October for soil at 0-3 cm depth under *B. radicans* was significantly lower than the soil samples collected under the other two species. Depth of collection had a very significant effect on the exchangeable potassium content in all the periods under each species. In all the periods the amount of exchangeable potassium at 0-3 cm depth was significantly higher than that of the soil at 25-30 cm depth under the three species.

Both season and species did not have significant effect on the amount of exchangeable sodium at 0-3 cm and at 25-30 cm depth (Table 5b). However, the amount of exchangeable sodium at 0-3 cm depth was significantly lower than that of the soil at 25-30 cm depth ($p < 0.001$).

The soil physical and chemical characteristics of the study area are shown in Table 6. The bulk density of the soil and percent pore space ranged from 1.14 to 1.28 g cm^{-3} and 51.7 to 57.0%, respectively. Soils at 2-3 cm depth had a sand, clay and silt percentage of 24.7 - 40.7, 22.0 - 39.6 and 25 - 42, respectively. Soil at lower depth (25 - 30 cm) had a higher clay percent which ranged between 48 to 64 %. For comparison percent sand and silt at the same depth ranged between 15.0 and 25.6% and 20.4 and 30.0%, respectively. The pH values of aqueous extracts of soils from 1:1 soil water ratio was alkaline. It ranged from 7.4 to 8.22 in the surface soil and from 7.97 to 8.71 in soil at 25-30 cm depth. The electrical conductance of the soils was high; it ranged from 0.73 to 0.81 m mhos cm^{-1} at the surface and from 0.85 to 2.76 m mhos cm^{-1} at 25-30 cm depth. Cation Exchange Capacity (CEC) of the soils at 2-3 cm and at 25-30 cm depth was almost the same. It ranged from 51.7 to 65.0 me/100 g soil at 2-3 cm and from 45.6 to 66.2 me/100 g soil at 25-30 cm depth. Higher percentages of total nitrogen, available phosphorus, exchangeable potassium and lower percentage of exchangeable sodium were obtained from soils at 2-3 cm depth when compared with soil at 25-30 cm depth.

Table 5a. Seasonal moisture and nutrient content of the soil under the three grass species (S = surface (0-3 cm) & D = depth (25-30 cm).

Species		Moisture (%)				Nitrogen (%)				Phosphorus (ppm)			
		Apr., 1996	Jul., 1996	Oct., 1996	Jan., 1997	Apr., 1996	Jul., 1996	Oct., 1996	Jan., 1997	Apr., 1996	Jul., 1996	Oct., 1996	Jan., 1997
CP													
	S	17.5^{aA}	22.7^{aA}	11.1^{bA}	8.50^{bA}	0.149^{aA}	0.200^{aA}	0.164^{aA}	0.161^{aA}	54.97^{aA}	102.4^{aA}	118.5^{aA}	54.78^{aA}
	D	22.7^{aA}	17.0^{bB}	15.1^{bB}	13.7^{bB}	0.102^{aB}	0.112^{aB}	0.105^{aB}	0.117^{aB}	25.01^{aB}	33.74^{aB}	37.71^{aA}	26.47^{aB}
Br													
	S	19.6^{aA}	23.2^{aA}	10.5^{bA}	7.6^{bA}	0.218^{aA}	0.188^{aA}	0.134^{aA}	0.218^{aA}	118.4^{aA}	89.39^{aA}	150.6^{aA}	103.0^{aA}
	D	25.4^{aB}	16.8^{bB}	15.3^{bB}	12.7^{cB}	0.123^{acB}	0.117^{acB}	0.094^{abB}	0.130^{cA}	17.93^{aB}	37.91^{bB}	33.54^{abA}	30.44^{abA}
Ia													
	S	17.7^{aA}	26.2^{bA}	13.1^{cA}	6.70^{dA}	0.190^{aA}	0.205^{aA}	0.200^{aA}	0.184^{aA}	109.5^{aA}	82.6^{aA}	105.5^{aA}	104.2^{aA}
	D	23.1^{aA}	18.0^{abB}	18.2^{abB}	13.7^{bB}	0.136^{aB}	0.129^{aA}	0.124^{aA}	0.117^{aA}	29.08^{aB}	29.28^{aB}	41.59^{aA}	39.85^{aA}

Means followed by the same lower case letters in rows and means followed by the same upper case letters in columns for the two depths under each species are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.(Cp, *C. plumulosus*; Br, *B. radicans*; Ia, *I. afrum*).

Table 5b. Seasonal nutrient content of the soil under the three grass species (S = surface (0-3 cm) & D = depth (25-30 cm).

Species		Potassium (ppm)				Sodium (ppm)			
		Apr., 1996	Jul., 1996	Oct., 1996	Jan., 1997	Apr., 1996	Jul., 1996	Oct., 1996	Jan., 1997
Cp									
	S	49.1^{aA}	54.7^{abA}	49.1^{aA}	59.3^{bA}	3.11^{aA}	2.87^{aA}	2.47^{aA}	5.00^{aA}
	D	30.7^{abB}	29.6^{abB}	26.8^{aB}	36.3^{bB}	48.8^{aB}	67.6^{aB}	26.8^{aB}	93.8^{aB}
Br	S	48.8^{aA}	51.4^{abA}	36.0^{aA}	65.8^{bA}	3.57^{aA}	4.97^{aA}	2.33^{aA}	4.72^{aA}
	D	24.2^{aB}	29.6^{abB}	25.9^{aB}	37.5^{bB}	69.4^{aB}	65.1^{aB}	30.1^{aB}	72.0^{aB}
Ia									
	S	46.9^{aA}	54.8^{aA}	47.7^{aA}	55.6^{aA}	4.13^{aA}	5.04^{aA}	4.39^{aA}	5.14^{aA}
	D	27.7^{aB}	29.6^{aB}	29.2^{aB}	38.8^{bB}	54.7^{aB}	53.9^{aB}	71.6^{aB}	74.3^{aB}

Means followed by the same lower case letters in rows and means followed by the same upper case letters in columns for the two depths under each species are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.(Cp, *C. plumulosus*; Br, *B. radicans*; Ia, *I. afrum*).

Table 6. **Physical and chemical characteristics of soil of Illala-sala grassland plain (n=12, mean ± sd).**

Depth	Texture (%) Sand	Texture (%) Clay	Texture (%) Silt	Pore space (%)	Density. (g/cm^3)	pH	EC	CEC	C (%)	N (%)	C/N	P (ppm)	K (ppm)	Na (ppm)
0-3cm	33.1^{a}	31.8^{a}	36.2^{a}	54.8	1.20	7.97^{a}	0.78^{a}	58.8^{a}	1.86^{a}	0.188^{a}	10.33^{a}	87.3^{a}	60.2^{a}	4.96^{a}
	±4.6	±6.6	±3.3	±2.0	±0.05	±0.25	±0.03	±3.74	±0.45	±0.061	±2.49	±61.52	±6.76	±2.00
25-30cm	18.7^{b}	56.3^{b}	25.6^{b}	_	_	8.45^{b}	1.35^{b}	57.9^{a}	1.10^{b}	0.121^{b}	9.45^{a}	32.26^{b}	37.52^{b}	80.03^{b}
	±4.1	±5.6	±3.5	-	-	±0.22	±0.59	±6.62	±0.15	±0.024	±2.56	±17.88	±3.27	±50.41

Means followed by the same letter in columns are not significantly different at $p<0.05$.

4.4 The effect of simulated grazing on biomass production and nitrogen content of the grasses

The biomass production of the three species increased and nitrogen concentration decreased with increase in cutting interval and cutting height (Fig. 6 and Fig. 8, respectively).

The significant responses of the grasses to different cutting heights and cutting frequencies and the interaction of the two in shoot and root biomass production and percent nitrogen concentration are shown in Appendix 5. Both cutting height and cutting interval (frequency) had influence on both biomass production and nitrogen concentration of the three grass species. However, cutting interval (frequency) had much more effect on nitrogen content of *C. plumulosus* and *I. afrum* than cutting height.

Comparison of nitrogen content and shoot and root biomass production in the three species showed no significant differences in their root biomass production and percent nitrogen concentration among the three species. However, *C. plumulosus* accumulated significantly lower shoot biomass than the other two species (Fig. 7).

In general, shoot and root biomass accumulation increased with increase in cutting height and a decrease in cutting frequency. However, when the root and shoot biomass accumulated under each treatment was compared with the controls, clipping decreased the accumulation of biomass in most cases for all species. Comparison of shoot biomass of clipped plants (treatments) with that of unclipped plants (controls) showed that the shoot biomass of *C. plumulosus* produced under all cutting heights with 45 days cutting interval, and 12 cm

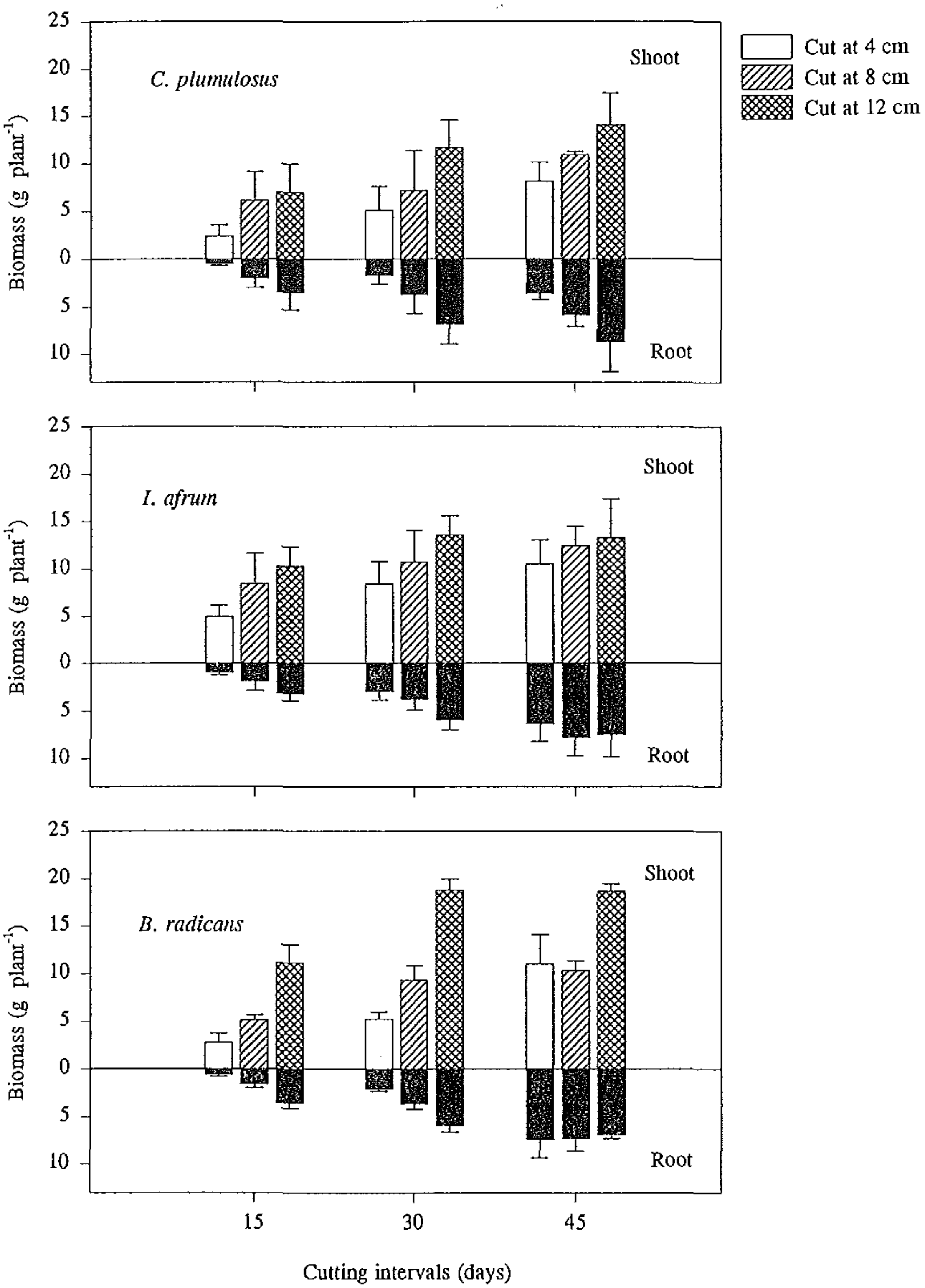

Fig. 6. Shoot and root biomass production in the three grass species as influenced by different cutting heights (4, 8 and 12 cm) and cutting intervals. The dark bars represent the root biomass for each treatment group. Biomass cut at every sampling occasion was saved for nitrogen analysis for each group and added to obtain the cumulative biomass.

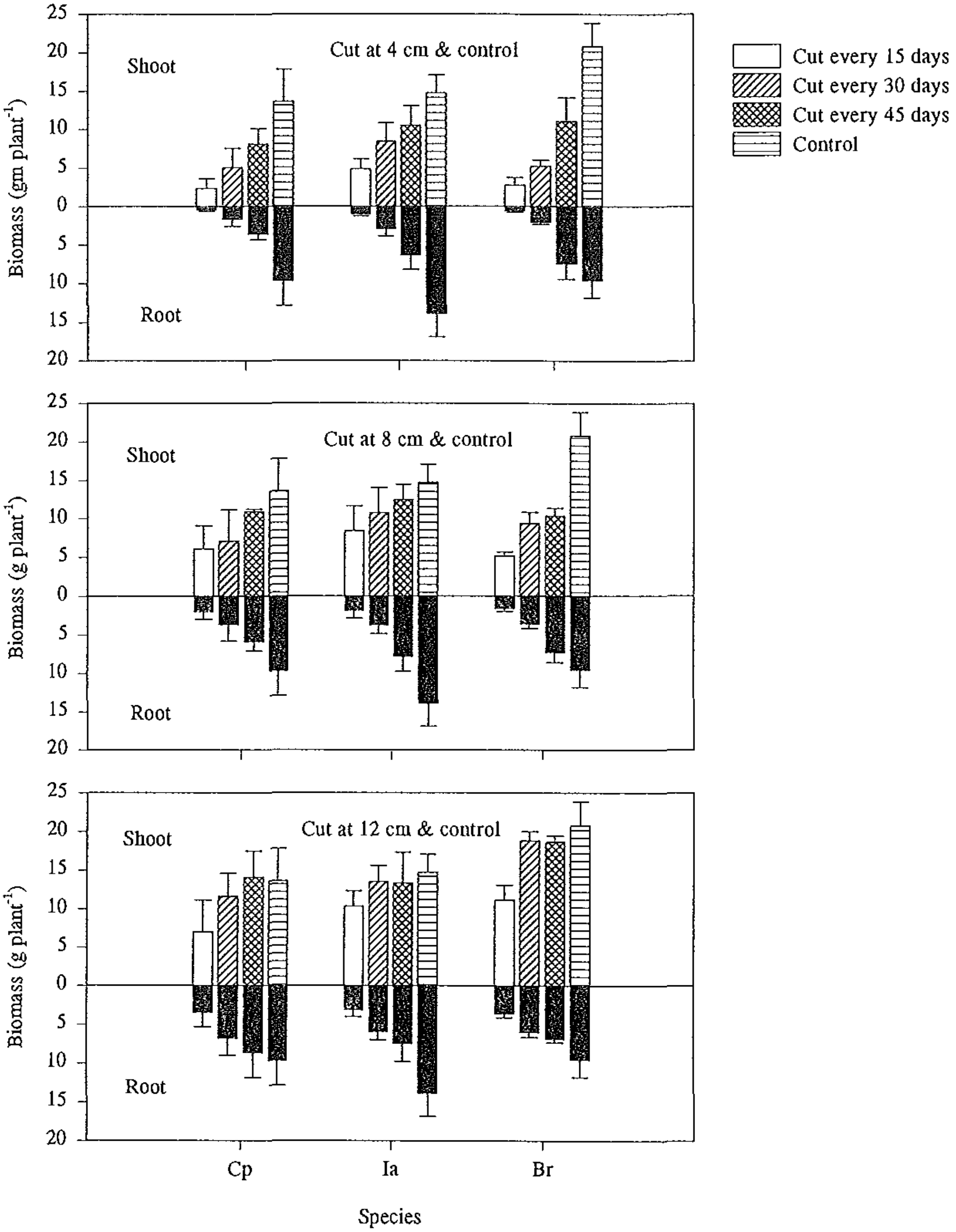

Fig. 7. Comparison of the influence of cutting height and cutting frequency in the grass species with the controls. (Cp, *C. plumulosus*; Ia, *I. afrum* and Br, *B. radicans*). The dark bars represent the root biomass for each treatment group and the controls. The cumulative biomass of each group was compared with the controls.

cutting height and 30 days cutting intervals were not significantly different from the controls. The shoot biomass of *I. afrum* produced at 12 cm cutting height and 15 and 30 days cutting intervals, at 8 cm cutting height and 30 days cutting interval and with 45 days cutting interval and with all cutting heights were not significantly different from controls. However, in *B. radicans* only the shoot biomass produced with 12 cm cutting height and with 30 and 45 days cutting intervals were not significantly different from the controls (Fig. 7).

When the accumulation of root biomass under each treatment (clipped plants) was compared with that of the controls (unclipped plants), clipping decreased root biomass accumulation in all the three species except for *C. plumulosus* where the root biomass produced with 12 cm cutting height and with 30 and 45 days cutting frequency were not significantly different from that of the controls. The root biomass of the controls were significantly higher than that of the treatments ($p < 0.001$) for both *I. afrum* and *B. radicans*. Thus, simulated grazing decreased the root biomass of both *I. afrum* and *B. radicans* (Fig. 7).

The increase in cutting height and the decrease in cutting frequency resulted in lowered nitrogen concentration in the three grass species (Fig. 8). However, the value of nitrogen concentration of unclipped plants was much more lower than that of the treatments for all the species: clipped plants of all the species had significantly higher nitrogen content than that of the unclipped plants at $p < 0.001$.

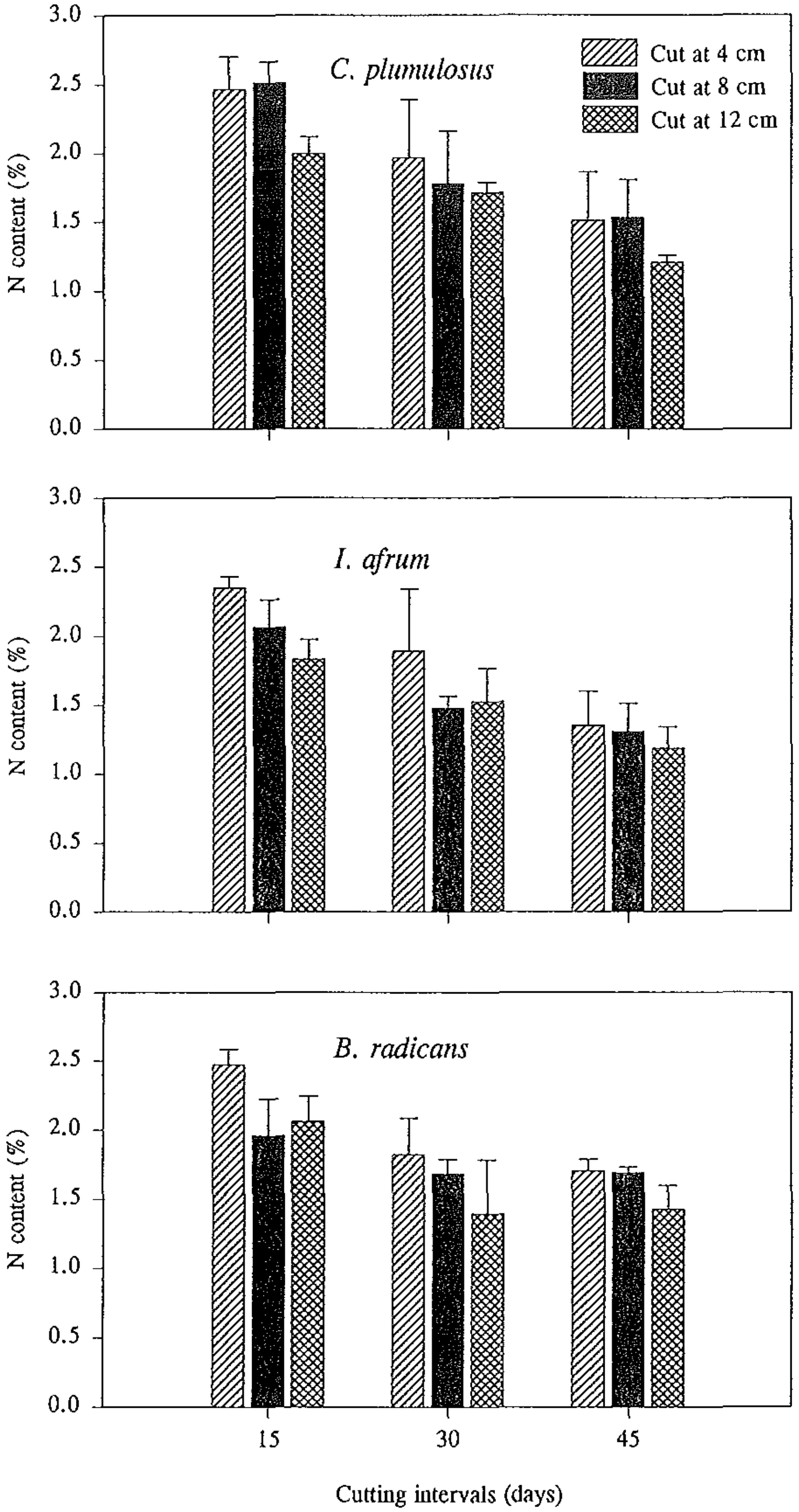

Fig. 8. Nitrogen content of the three grass species as influenced by cutting height and cutting frequency.

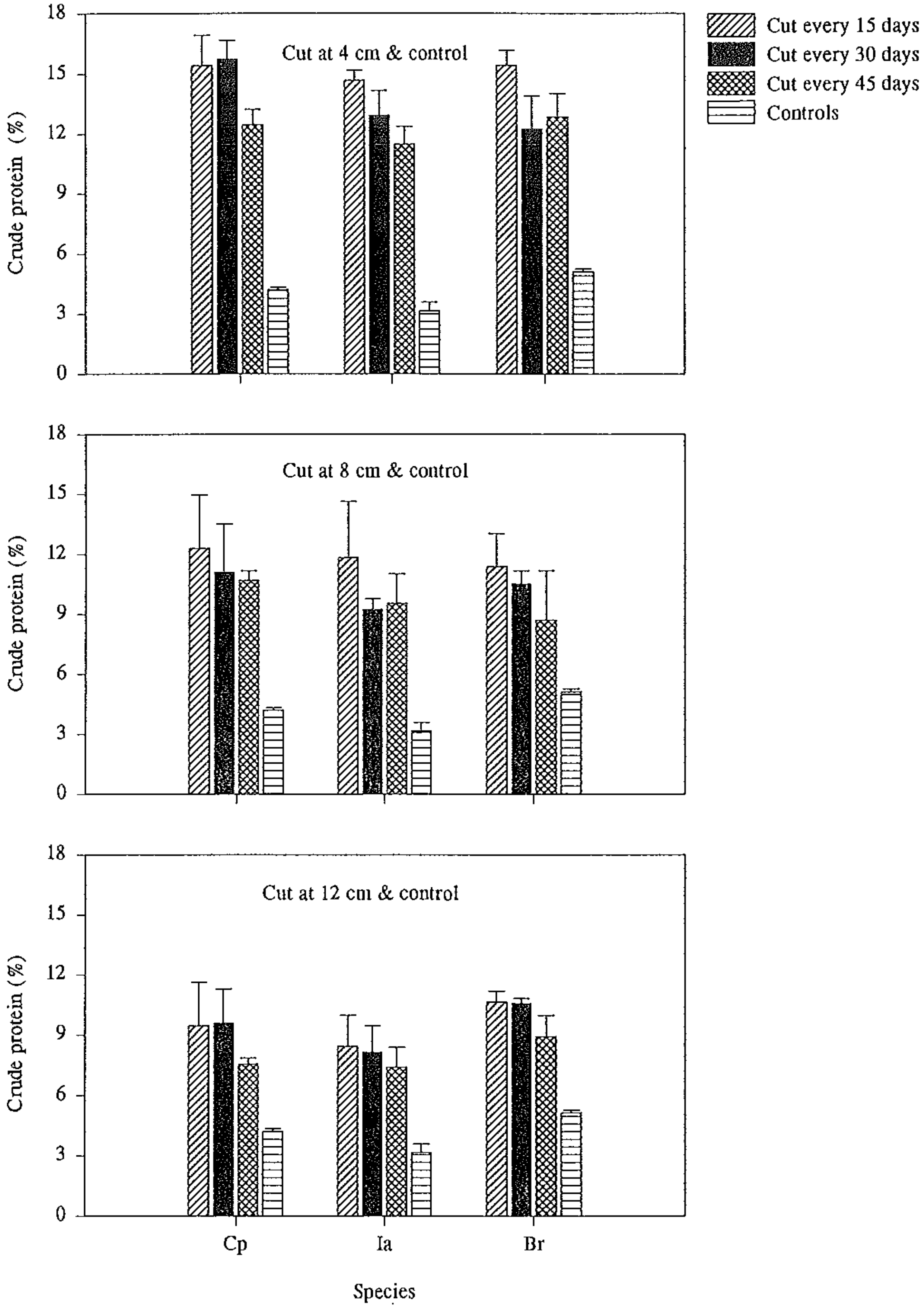

Fig. 9. Comparison of crude protein content of the three grass species as influenced by cutting height and cutting frequency and the controls. (CP, *C. plumulosus*; IA, *I. afrum* and BR, *B. radicans*).

Percent crude protein content (% crude protein = % Nitrogen x 6.25) is presented in Fig. 9. The unclipped plants of the three species had significantly different crude protein value ($p < 0.001$), i.e., *B. radicans* had the highest and *I. afrum* had the lowest crude protein values.

The root/shoot ratio of the grasses increased with the increase in cutting height and cutting interval (Fig. 10). When root/shoot ratios of the clipped plants were compared with that of the unclipped ones, the clipped plants had lower root/shoot ratios than the unclipped ones except for *B. radicans* at 4 and 8 cm cutting heights and 45 days cutting interval. The readers might note to the root/shoot ratio of the controls: 0.716, 0.946 and 0.458 for *C. plumulosus*, *I. afrum* and *B. radicans*, respectively. Here *B. radicans* allocated more to the shoot than the other two species.

The final counts of tillers from both clipped and unclipped plants are presented in Fig. 11. There was no consistent trend following the treatments in the number of tillers of *C. plumulosus* and *I. afrum*. Eventhough treatments did not show significant differences, tillering in *B. radicans* increased with the increase in cutting height and with the decrease in cutting frequency. In all the cases, *I. afrum* had higher number of tillers than the other two species. Clipping also increased the number of tillers of *I. afrum* as compared to the number of tillers of the unclipped plants. But clipping decreased the number of tillers of *C. plumulosus* and *B. radicans* at the shortest cutting height and the highest and medium cutting frequency and with the medium cutting height and the highest cutting frequency in *B. radicans* (Fig. 12).

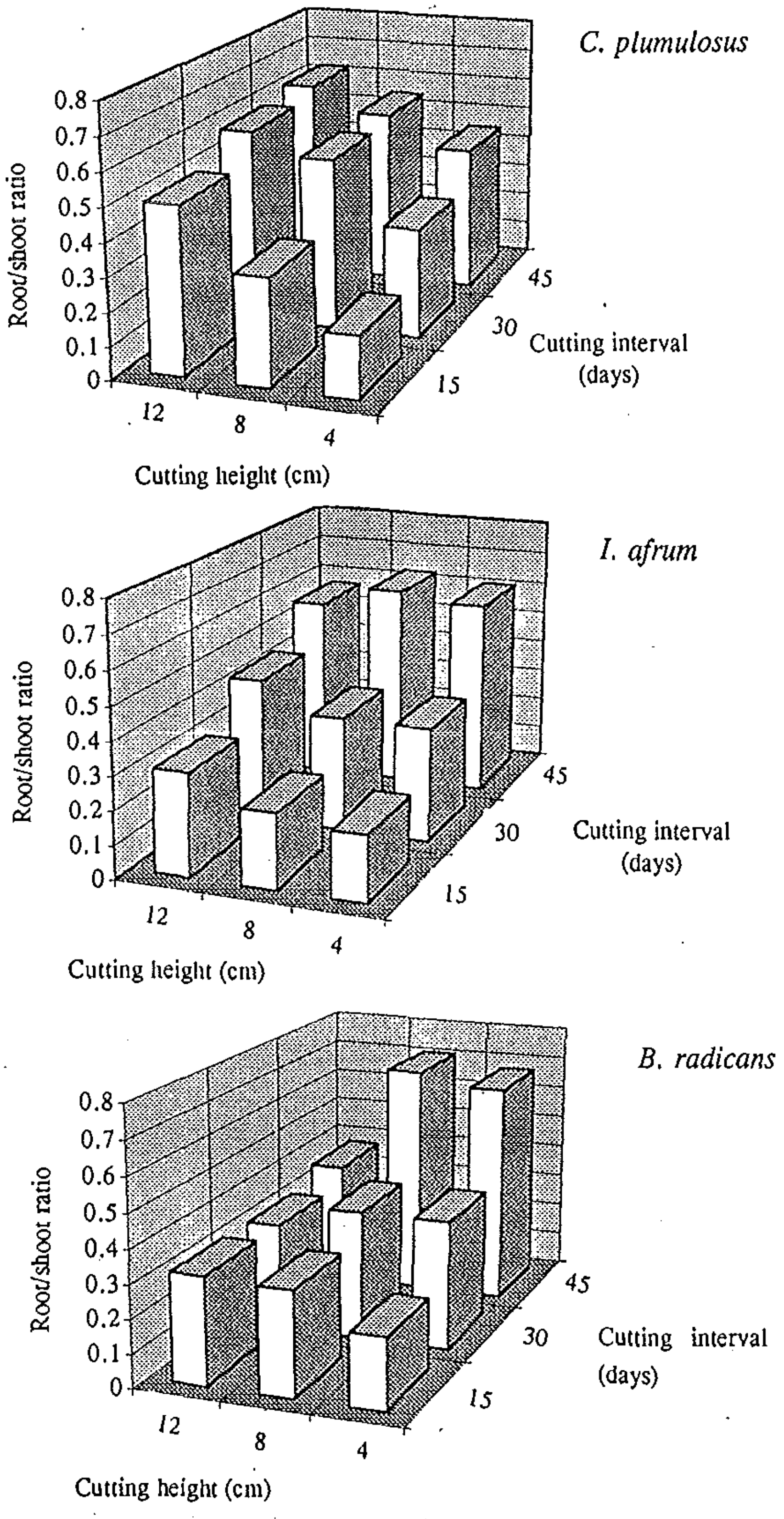

Fig 10. Root/shoot ratio of the three grass species as influenced by different cutting heights and cutting frequencies.

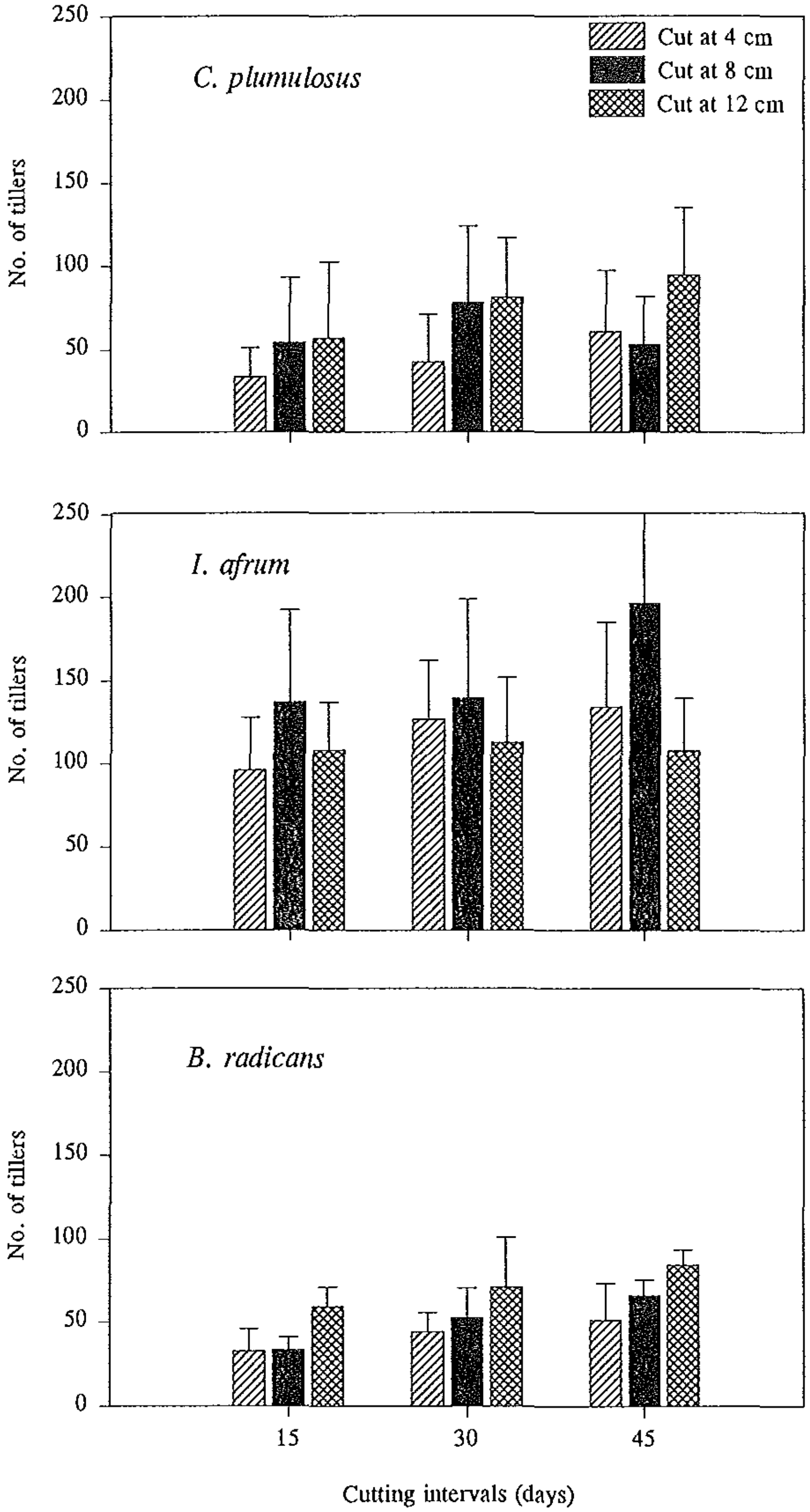

Fig. 11. Influence of cutting height and cutting frequency on tillering of the three grass species.

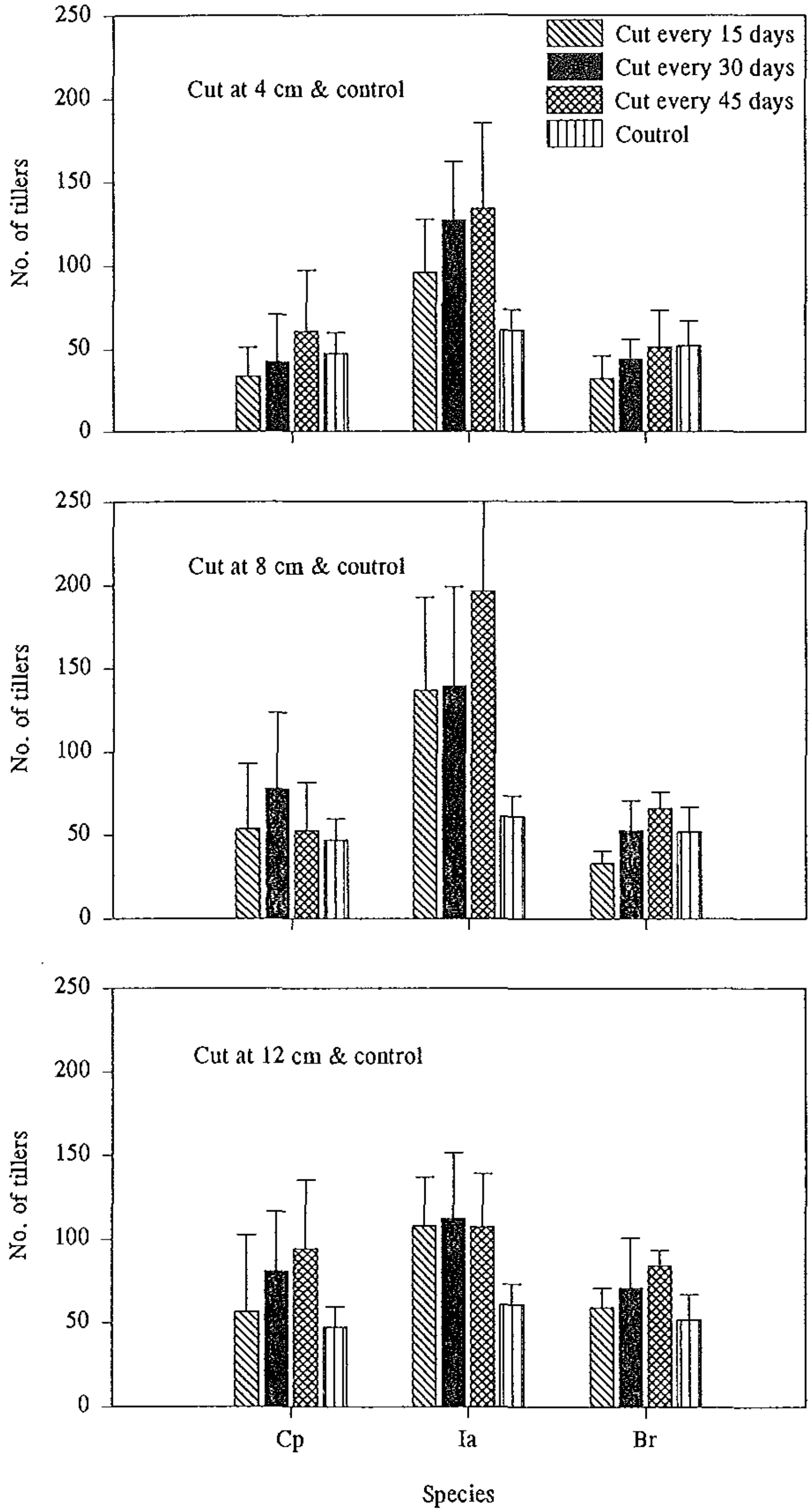

Fig. 12. Comparison of tillering of the three grass species as influenced by cutting height and cutting frequency with controls for each species. (Cp, *C. plumulosus*; Ia, *I. afrum* and Br, *B. radicans*).

5 DISCUSSION

5.1 Biomass production, moisture and nutrient content

A major objective of the present work was to estimate the biomass production of Illala-sala grassland plain. The biomass produced was estimated after removing the oldest shoots and stems, since with perennial grasses, where dry matter accumulates over the years, the standing biomass can not be used to estimate primary production (Desmukh, 1986).

The biomass production of Illala-sala grassland plain showed significant seasonal differences. All the stands showed a highest production peak during the rainy seasons and the lowest during the dry season (Fig. 3a), when the highest values were recorded during the April-June and July-September sampling periods. It ranged from 114 ± 35 g m^{-2} to 409 ± 92 g m^{-2} per three month growth intervals. However, during October-December the biomass produced was insignificant. Results obtained during this investigation showed that seasonal changes in the aboveground biomass production in all the species and the mixed stands was related (as expected) to the amount of rainfall and thereby to the amount of soil moisture .

Many investigators from various parts of the world have attempted to relate range production to rainfall, either on a seasonal or on annual basis (Oyenuga, 1960; Soneji and Musangi, 1972; Murphy, 1975; Strugnell and Pigott, 1978; Edroma, 1981b; Boutton *et al.*, 1988a; Le Houerou *et al.*, 1988; Prins and Beekman, 1989; Kinyamario and Imbamba, 1992). In grasslands of Uganda which is dominated by *Hyparrhenia filipendula* and *Themeda triandra*, Strugnell and Pigott (1978) found that monthly biomass production and protein content of grasses are significantly correlated with rainfall. Boutton *et al.* (1988a) and Kinyamario and Imbamba (1992) also found peak values for live biomass at Nairobi National Park at the end of the long rains. They obtained strong correlation between biomass and rainfall and between biomass and soil moisture. According to Soneji and Musangi (1972), the grasses in Australia, India, eastern and southern Africa had a rapid growth rate in the wet seasons and little or no growth during the latter parts of the wet seasons. Unlike these reports Devidas and Puyravaud (1995) found that monthly aboveground productivity of herbaceous layer in the savanna woodland ecosystem of Bandipur National Park of southern India did not have significant relationship with rainfall and soil moisture. They reported more significant relationship between belowground productivity and temperature.

Negligible rainfall during dry periods limits production through reduced soil moisture (Shrimal and Vyas, 1975). Rainfall is a major source of available soil moisture in semi-arid areas (Muleba, 1987) and soil moisture is one of the most important factors which limit production in the semi-arid regions of Ethiopia (Getachew Alem, 1987). The amount of rainfall received in one month not only affects production in the same month but also in the following month as well (Afolayan, 1978; Edroma, 1981b).

The annual biomass production ranged from 396.7 $\pm$ 108.6 g m^{-2} (*B. radicans*) to 791.8 $\pm$ 189.8 g m^{-2} (mixed stands). This range is within those reported by Strugnell and Pigott (1978), 500-700 g m^{-2} from grasslands of Rwenzori National Park in the western Rift valley of Uganda and higher than the value obtained by Boutton *et al.* (1988a) which ranged from 368-466 g m^{-2} from Masai Mara Game Reserve in Kenya.

As is indicated in Appendix 2 and Fig. 3a and 3b, the seasonal and annual biomass production estimated from *B. radicans* stand was significantly lower than that of the *I. afrum* and mixed stands after 6 and 12 months growth period. It was also lower than all the other three groups of stands after 9 month growth period. This indicates that the contribution of *B. radicans* to the area's primary production was relatively lower than the other two species.

The quantity of forage is determined not only by climatic factors but also by edaphic factors such as texture, fertility etc., (Thompson and Troeh, 1978; Ridder *et al.*, 1982; Clayton and Renvoize, 1986; Agboola, 1987). Thus, the chemical and physical characteristics of the soil of a study area play an important role. As shown in Table 6, the bulk density of the soil of the study area is low (1.20 ± 0.05 g cm^{-3}). This indicates the suitability of the soil for good root growth and water penetration. Root growth and water penetration is slowed significantly by soils with bulk density of 1.5 - 1.6 g cm^{-3} and root growth is generally stopped by soil layers with bulk densities of 1.7 - 1.9 g cm^{-3} (Thompson and Troeh, 1978; Wilde, 1993). According to Wilde (1993), such low bulk density could be due to higher pore space between the granules. Also, low bulk density may also indicate low grazing intensity on the area (Zerihun Woldu, 1985; Heady and Child, 1994), as compaction increases the bulk density of soil increase thereby decreasing production (Agboola, 1987).

The textural classes of the soils at the surface at Illala-sala belonged to loam and clayloam, while at depth there was more clay soil (Table 6). Such type of soils have sufficient water-holding capacity and a high supply of nutrients for the growth of plants (Wilde *et al.*, 1979), since clay fraction has the capacity to store water and plant nutrients (Thompson and Troeh, 1978).

The pH of the soil is one of the most indicative measurements of the chemical properties of a soil as it indicates the relative availability of plant nutrients (McLean, 1982; Moore and Chapman, 1986). The soil pH of ANP grassland (7.97 $\pm$ 0.25 - 8.45 $\pm$ 0.22) is within the maximum availability range for most nutrients (N, P, Ca and Mg) except for K which is not readily available at pH range of 7.6 - 8.4 (Thompson and Troeh, 1978). Total nitrogen in all soils falls within the required range for most plant growth (Murphy, 1959). However, the amount of organic carbon in the soils was generally low resulting in a low C/N ratio. Low levels of organic carbon in savanna soils are a result of the relatively lower amount of rainfall, and the narrow C/N ratio may be due to high rate of organic matter decomposition (Singh, 1987). According to Killham (1994), the C/N ratio may be used to describe resource quality. Generally, low C/N ratios are associated with high resource quality and rapid rates of decomposition and high C/N ratios are associated with low resource quality and slow decomposition.

The available phosphorus content both at surface and at depth was above the required concentration for plant growth (above 20 ppm) and plants grown on such soils do not usually show a phosphorus deficiency (Murphy, 1959; Olsen and Sommers, 1982; Tamire Hawando *et al.*, 1986).

Exchangeable potassium both in soil samples at surface and at depth was in the range described as low concentration for plant growth (Thompson and Troeh, 1978). However, the values were not below the critical limit of potassium (0.13 meq/100 g soil) (Singh,1987). The low amount of exchangeable potassium in the soils was probably caused by the higher pH which makes potassium less available to plants (Thompson and Troeh, 1978).

From the foregoing, it may be concluded that, the productivity of Illala-sala grassland may not be limited by low concentration of soil nutrients but rather, as many authors agree by the limited amount of rainfall.

To improve planning for range management, an estimation of the amount of primary production alone is not sufficient. Knowledge of the quality of forage available in the area and the seasonal variation in the levels of nutrients of the grass species is very important in the management of grazing habitats (Afolayan and Fafunsho, 1978).

Grazers generally show preferences for the plants with the highest crude protein value (Von Richter and Osterberg, 1977). Thus, it is important to compare the nutrient (crude protein) and moisture content of the three grass species under investigation in different periods of the year to rate their qualitative importance for grazers. The present study showed significant seasonal fluctuations in the concentrations of most nutrients (except for sodium (Table 1-4) among all the grass species. These changes appeared to be directly related to the seasonal moisture content of the grasses and thereby to the seasonal variation of rainfall of the area (moisture and crude protein had r^2 value of 0.712, 0.974 and 0.962 for *C. plumulosus, B. radicans* and *I. afrum*, respectively). Moisture contents, crude protein, phosphorus and potassium contents of the grasses decreased from April to January. The seasonal input of moisture from the rain is very important in structuring both the plant and animal components of the East African grassland communities (Hesla *et al.*, 1985). The moisture content of the grasses decreased with the dry season. However, most perennials overcome periods of drought either by conserving water or withstanding desiccation (Pratt and Gwynne, 1977). In the present study, as shown in Table 1 and Appendix 3, the amount of nitrogen in the grasses was higher in periods of the year with higher plant moisture content and the values decreased with a decrease in plant moisture content. Georgiadis and McNaughton (1990) found out that two of the variables which are positively correlated with forage quality were crude protein and water. Additionally, Ben-Shahar (1994) suggested also high digestibility and low crude fibre (high crude protein) content as good indicators of the overall nutritional value of grass species.

The highest percentage of nutrient levels (nitrogen, phosphorus and potassium) in the grasses were obtained in April after the short rain period because the grass sampled during April had recently been produced and did not have large proportion of stems to leaves. However, in October and January when the grass became fully mature and accumulated more biomass, the percentage concentration of these nutrients dropped. This shows that the three grass species are best suited for the game animals at the beginning of the growing season (wet periods) while the grass is still wet with high nutritive value. During the dry periods when the grasses become tall, coarse and low in moisture and nutrient content, the animals will be able to utilize very little percentages of these grasses (Afolayan and Fafunsho, 1978).

The results of the present study are supported by reports of similar trends in grasses found in Nairobi National Park and Masai Mara Game Reserves whereby peak nutrient concentrations were observed during the short rainy season than in the long rains (Boutton *et al.*, 1988b). Afolayan and Fafunsho (1978) found that grasses in Serengeti National Park had higher protein contents at the beginning of the growing season than at the end when they became tall, coarse and thus unpalatable. Ben-Shahar (1994) also reported that the levels of nutrients in 10 grass species in Sabi-Sand Wild Trin Game Reserve in South Africa were below the minimal requirements for ruminants during the peak of the dry period. The reason for the decrease in the concentration of nutrients during dry periods was not due to net nutrient translocation out of the shoots. It may rather be due to more vegetation being produced as a result of the long rains that is matured and increased in structural carbohydrate content thereby diluting the nutrient concentrations in contrast to the vegetation produced during the short rains that didn't have a large proportion of stems (Eadie, 1970; Boutton *et al.*, 1988b). Thus, the digestibility of forages declines with the passage of time as the grass matures (Soneji and Musangi, 1972). Many authors concluded that the nutritional value of grasses declined steadily as leaves aged (Soneji and Musangi, 1972; Boudet, 1975; Field, 1976; Isichei, 1981; Owen-Smith and Novellie, 1982; Woldu Tekle Debessai, 1984; Boutton *et al.*, 1988b; Prins and Beekman, 1989; Georgiadis and McNaughton, 1990; Ben-Shahar, 1991; Heady and Child, 1994)

As shown in Appendix 4, the crude protein content of the two grass species: *C. plumulosus* and *B. radicans* in wet periods of the year (April and July) was above the maintenance levels of crude protein content of forages required for ruminant, i.e., 5% crude protein (Von Richter and Osterberg, 1977; Boutton *et al.*, 1988b). However, that of *I. afrum* was below the level except in April. In samples collected in the dry periods (October and January), the crude protein content of the three grass species was below the maintenance levels. McNaughton (1979) and Prins and Beekman (1989) also reported that during the post rainy season, the quality of the grasses they studied fell below the maintenance level for the grazers.

From the above comparison, it may be concluded that *C. plumulosus* and *B. radicans* have more nutritional value than *I. afrum* both in the wet and the dry periods. *I. afrum* had a value of CP greater than the maintenance level required for grazers only in April thus reducing its significance. However, the quality of forage is not only affected by its nutrient contents but also by the inhibitory chemicals present in the species (Georgiadis and McNaughton, 1990). For instance, Field (1976) reported that *Bothriochloa* spp was avoided during dry season by most grazers and was only tolerated by buffalos when the grass was young. He suggested that the aromatic smell of *Bothriochloa* leaves may be the reason for the reduced preference. Thus, although numerous unpalatable species may contain as much as or more nutrients than those readily grazed plants (Heady and Child, 1994), their quality as fodder may be affected by the concentration of inhibitory chemicals (Georgiadis and McNaughton, 1990).

According to Boutton *et al.* (1988b) and Ben-Shahar (1994), the significant seasonal changes in the concentrations of nitrogen, phosphorus and potassium is related to seasonal moisture inputs which make conditions favourable for the growth and nutrient uptake of plants. Thus, the primary determinants of the quantity and quality of forage in east African grasslands are the long and short rains (Boutton *et al.*, 1988a).

The three species were compared to evaluate their influence on the nutrient concentration and moisture content of the soil under which they grow. The results indicate that neither the species nor the season had little effect on the concentration of soil nutrients. While there was an obvious influence of seasons on soil moisture. Most of the differences in nutrients were rather due to difference in depth of the soil: the surface soil was rich in nitrogen, available phosphorus and exchangeable potassium and poor in exchangeable sodium content and the soil at depth was rich in sodium content and poor in other nutrients.

As already discussed the concentration of crude protein in the three grasses in October and January fell below the maintenance level required by ruminants. This indicates that grazers in Awash National Park experience seasonal shortage of nutritionally adequate fodder (Hesla *et al.*, 1985; Boutton *et al.*, 1988b). They overcome the problem of low levels of nutrients in the grasses during dry periods partly by diversifying their food intake. Otherwise, they will be obliged to feed upon these lower quality foods in quantity in order to supplement their diet with specific essential nutrients (Ben-Shahar, 1994). There are reports that during dry periods large generalist herbivores adapt to using food which is abundantly available but low in nutritional value (Westoby, 1974). However, Illala-sala grassland plain is dominated by perennial grasses and part of the vegetative biomass of these perennials is always alive. Thus, the grassland can still provide forage of limited quality even at the peak of the dry season for herbivores though their activity could be limited (Ridder *et al.*, 1982)

Afolayan and Fafunsho (1978) reported that the highest percentage of the grass species were grazed in periods when their crude protein content were highest whereas in periods when the percentage crude protein contents of the grasses dropped, little grazing took place. Thus, during these dry periods they recommended that any management practice that totally remove trees, shrubs and herbs in favour of grass should be avoided. This management practice is important since during dry periods, when the grass is completely dry and low in nutritive values, herbivores need to supplement their grazing with browse plants until the beginning of the next growing season.

From observation on the area for several years it can be said that Illala-sala grassland has good grass cover all year round, except when there is fire, due to also low intensity of grazing. The latter is indicated by the low bulk density of the soil (Heady and Child, 1994). In some areas of the grassland large quantities of dead grass are accumulated due to lower herbivore pressure. Also it is observed that oryx and sommering's gazelle ignore areas with large accumulation of standing dead grass. Instead they concentrate on areas which have been burnt recently and with young sprouts. Because burning removes the nutritionally poor forages and stimulates growth of fresh palatable forage (Edroma, 1981a). Thus, areas with large accumulation of dead tissue are poor quality habitat for grazing animals (Boutton *et al.*, 1988b) and carefully managed burning need to be considered.

5.2 The effect of simulated grazing on biomass accumulation and nitrogen content of the three species

The results of the experiment on influence of grazing on grass growth (simulated by clipping plants) showed that both cutting frequency and cutting height affected biomass production and nitrogen accumulation by the species (Appendix 5). Clipping decreased the shoot and root biomass production but increased the nitrogen concentration of the species. When the accumulated biomass of the three species subjected to a treatment combination of three cutting frequencies at three cutting heights were compared, the yield of all species increased with a decrease in cutting frequency and an increase in cutting height. The result clearly showed that both cutting height and cutting frequency influenced grass biomass production.

The experiment also revealed that *C. plumulosus* was more sensitive to clipping frequency than *I. afrum* and *B. radicans*, as the former species accumulated less biomass and even had mortality cases with the shortest cutting height and highest cutting frequency. The amount of plant material removed influences the species response pattern, regrowth and biomass accumulation capacity of the plant. Zerihun Woldu (1985) showed that in protected areas biomass gets concentrated in a few species and the total biomass may be lower than that accumulated in grazed areas. He mentioned, however, that this may be compensated by better palatability of the species. Repeated clipping results in the reduction of biomass production since the remaining biomass of grazed plants become unable to produce healthy roots and may die earlier (Evers and Holt, 1972; Edroma, 1981b). Edroma (1981a) also found that less palatable species such as *Sporobolus pyramidalis* were more resistant to the effects of repeated clipping than palatable species such as *Themeda triandra*. This characteristic affects species composition of an area as grasses which are grazed too frequently are eliminated and replaced with unpalatable species.

Similar results have been reported by other authors on other species that as cutting frequency increases grass biomass accumulation decrease (Van Voorthuizen, 1972; Middleton, 1982; Fennema and Briede, 1990). Unlike our results, Coughenour *et al.* (1985b) found that clipping of *Themeda triandra* reduced the biomass of most plant components with no significant differences between 3 and 6 cm cutting heights.

The root shoot ratio of the grasses studied was reduced by clipping, i.e., clipped plants had lower root shoot ratio than unclipped plants. This indicated that clipping stimulated shoot growth at the expense of root growth since clipping enhanced tillering which diverted more photosynthate from roots to shoots (Coughenour *et al.*, 1985b). However, according to Oesterheld (1992), experiments on allocation of above and belowground growth of potted plants may be biased by limitations of the pot size on the growth of the root. Oesterheld (1992) found that the root density of the plants grown in pots was much lower than that of the field. He concluded that defoliation intensity increased the proportional allocation of biomass to leaf as compared to that of the root thus decreasing root/shoot ratio. Conflicting results on the effect of grazing on root/shoot ratio have been obtained by other investigators. Georgiadis and McNaughton (1990) for instance found that clipping increased the root shoot ratio of *Themeda triandra* evidently a result arising from the difference in the responses of the species and the grazing intensity.

The shoot and root biomass production of some of the treatments, especially the least severe clipped ones were not significantly different from that of the unclipped plants. This might indicate that cutting (clipping) above a certain level of intensity does not influence the shoot and root biomass production of the species.

McNaughton (1986) cited in Bastrenta and Belhassen (1992) proposed that plant fitness may be increased by compensation growth which resulted from a reduction in leaf surface area due to grazing. The present study also provides evidence supporting the hypothesis that the shoot and root biomass of some of the treatments were not significantly different from that of the controls. This suggests that there may be a compensatory effect at these intensities (Bastrenta and Belhassen, 1992).

Tiller production was reduced by the shortest cutting height and cutting frequency, i.e., at 4 cm cutting height and 15 days cutting frequency. Under all treatment conditions *I. afrum* had a higher number of tillers than the two other species and thus resulted in having higher biomass accumulation than *C. plumulosus*. Tillers serve as the origin of new growth and constitute a large percentage of the yield of grasses (Evers and Holt, 1972). In *C. plumulosus* and *B. radicans* tiller production was reduced with low cutting height only with short and medium cutting frequency and clipping increased tillering at all intensity of cutting for *I. afrum*. Similar results have also been reported by other workers (Jameson and Huss, 1959; Evers and Holt, 1972) but with different species. An observation worth noting from the present experiment was that eventhough clipped plants produced more number of tillers they were generally smaller than those of the controls (unclipped plants). Similar observations have also been made by Oesterheld and McNaughton (1988); Georgiadis and McNaughton (1990); Evers and Holt (1972) still with other grass species.

The concentration of nitrogen and crude protein of the clipped plants of the three species are shown in Fig. 9 and Fig. 10, respectively. The results clearly show that N concentration in all the species increase with an increase in cutting frequency and decrease in cutting height, i.e., both cutting frequency and cutting height affected the nitrogen concentration of the species (Appendix 5). However, the crude protein content of unclipped plants was much lower than that of clipped plants, perhaps because there is a steady decline in the crude protein percentage (%N) with successive stages of growth of plants (Soneji and Musangi, 1972).

The decrease in yield (shoot and root biomass) and increase in nitrogen content observed in the present study followed similar trends reported by many authors for other species (Middleton, 1982; Coughenour *et al.*, 1985a; Oesterheld and McNaughton, 1988). Middleton (1982) reported that % N of *Panicum maximum, Setaria sphacelata* and *Brachiaria decubens* increased with an increase in cutting frequency. However, unlike the present study, the effect of cutting frequency was much greater than that of cutting height. Oesterheld and McNaughton (1988) also found that the concentration of leaf N of clipped *Briza subaristata* was higher than the unclipped plants. Under natural condition, Georgiadis and McNaughton (1990) found that all the samples from high herbivore use intensity had a higher nutritional quality than those from low herbivore use intensity but the quality of the grass declined with the dry season.

After reviewing a number of publications which are related to herbivory, Belsky (1986) concluded that there is no much evidence supporting beneficial effects of defoliation. However, this conclusion does not agree with the results of the present study, as the leaf nitrogen content of unclipped plants of the three species was much lower than that of the clipped ones. Thus, although frequent clipping decreased the yield of plants, it increased their nutritional quality indicating a compromise between low yield and high quality.

In a grassland management system one should strike a compromise between frequent clippings which result in low biomass yield and high N content and infrequent clipping which results in high biomass yield but low N content (Middleton, 1982). Defoliation releases plants from the limitation imposed by the accumulation of old and dead tissue (Oesterheld and McNaughton, 1991) to produce new shoots which have good quality. Although the present experiment may not exactly simulate the natural condition, following Middleton (1982), it may be suggested that about six to eight weeks regrowth intervals (after grazing) may produce biomass with more or less adequate crude protein levels. It may also be concluded that an infrequent cutting intensity would give adequate quantity and still good quality forage for grazers. However, these conclusions have to be examined under natural conditions.

6. SUMMARY AND RECOMMENDATIONS

This study was carried out to estimate seasonal and annual productivity of three range grasses at Awash National Park namely, *C. plumulosus, B. radicans* and *I. afrum*. It was also designed to evaluate the quantitative and qualitative importance of the three grass species as forage for wildlife. The study showed that the productivity of Illala-sala grassland plain falls on the higher range of productivity for similar ecosystems. Productivity was mainly limited by the amount of rainfall during the dry seasons. It was also found out that there were significant seasonal variations in moisture and nutrient (N, P and K) contents of the grasses. The highest values for biomass, moisture and nutrient content were obtained during the rainy seasons and these values declined during the dry periods of the year. The contribution of *B. radicans* for annual biomass production of the Illala-sala grassland plain was comparable to that of *C. plumulosus* but was lower than *I. afrum* and the stands which contained mixed species. However, although its biomass production was relatively high, the crude protein content of *I. afrum* was generally below the maintenance level required for grazers except in April after the short rains. *C. plumulosus* and *B. radicans* had crude protein contents above the maintenance level during the wet periods. However, the preference of grazers for *B. radicans* may be reduced due to its smell as shown to be the case for some wildlife. During the dry periods these two species had crude protein values which were all below the required maintenance level. Thus, it may be concluded that grazers in Awash National Park face shortage of nutritionally adequate forage during the dry periods.

The effect of grazing on grass production and nutrient content was investigated by simulating it with clipping plants at different time intervals and at different heights. The response of all the three species to the treatment was generally similar. In general, it may be concluded that shoot and root biomass decreased with an increase in cutting frequency and a decrease in cutting height. However, contrary to biomass production, nitrogen content of the clipped plants increased with an increase in cutting frequency and a decrease in cutting height. Also, the nitrogen content of clipped plants was significantly higher than the unclipped plants (controls), indicating that these grasses may have a better nutritional value when grazed moderately. There is, however, a need to conduct controlled grazing experiments under natural condition to identify optimum grazing levels so that adequate quantity and quality forage is obtained. Such information should also be supported by planned and controlled late burning programmes that will remove the nutritionally poor grasses and stimulate growth of nutritious forages.

Comparing the three rauge species in terms of their crude protein content, *I. afrum* had values below the required maintenance level in most cases. The preference of grazers for *B. radicans*, although it has higher crude protein content, may be lower because of its smell. Therefore, *C. plumulosus* may be the forage of choice for much of the year. But selective grazing of this species might change the species composition of the area giving a chance to unpalatable species to dominate. The sensitivity of *C. plumulosus* to high intensity grazing has also been indicated by our experiment. Thus, in order to acquire better knowledge for the effective management of Illala-sala grassland plain, the competitive aggressiveness of these grass species and the effect of fire on the species composition need to be investigated.

7. REFERENCES

Afolayan, T.A. 1978. Grass biomass production in Northern Guinea Savanna Ecosystem. *Oecologia Plantarum* 13:375-386.

Afolayan, T.A. and Fafunsho, M. 1978. Seasonal variation in the protein content and the grazing of some tropical savanna grasses. *East African Wildlife Journal* 16:97-104.

Agboola, A.A. 1987. Solving the problem of soil fertility in the African semi-arid zone. In: *Food grain production in semi-arid Africa.* Proceedings of an international drought symposium held at the Kenyatta conference centre, Nairobi, Kenya. 19th to 23rd May 1986, pp. 429-444, (Menyonga, J.M., Taye Bezuneh and Youdeowei, A., eds). OAU/STRC_SAFGRAD - Semi-Arid Food Grain Research and Development Publication. Ouagadougou, Burkina Faso.

Archer, S. and Detling, J.K. 1984. The effects of defoliation and competition on growth of tillers of two North American mixed-grass prairie graminoids. *Oikos* 43:351-357.

Bastrenta, B. and Belhassen, E. 1992. The effects of simulated grazing on survival and reproduction of *Anthyllis vulneraria*. *Acta Oecologica* 13:787-796.

Belsky, A.J. 1986. Does herbivory benefit plants? a review of the evidence. *The American Naturalist* 127:870-892.

Ben-Shahar, R. 1991. Selectivity in large generalist herbivores: feeding patterns of African ungulates in a semi-arid habitat. *African Journal of Ecology* 29:302-315.

Ben-Shahar, R. 1994. Patterns of nutrients in grasses of a semi-arid savanna. *African Journal of Ecology* 32:328-333.

Bogdan, A.V. 1977. *Tropical pasture and fodder plants*. Longman, London and New York.

Boudet, G. 1975. Pastures and livestock in the Sahel. In: *The Sahel: Ecological approaches to land use*. MAB Technical Notes, pp. 29-40. The UNESCO Press, Paris.

Boutton, T.W., Tieszen, L.L. and Imbamba, S.K. 1988a. Biomass dynamics of grassland vegetation in Kenya. *African Journal of Ecology* 26:89-101.

Boutton, T.W., Tieszen, L.L. and Imbamba, S.K. 1988b. Seasonal changes in the nutrient content of East African grassland vegetation. *African Journal of Ecology* 26:103-115.

Chopra, S.L. and Kanwar, J.S. 1976. *Analytical agricultural chemistry*. Kalyani Publishers, New Delhi.

Clayton, W.D. and Renvoize, S.A. 1986. *Genera Graminum. Grasses of the world.* Royal Botanic Gardens KEW. Kew Bulletin additional series xiii. Her Majesty's Stationary Office. London.

Coughenour, M.B., McNaughton, S.J. and Wallace, L.L. 1985a. Responses of an African tall-grass (*Hyparrhenia filipendula* Stapf.) to defoliation and limitations of water and nitrogen. *Oecologia* (Berlin) 68:80-86.

Coughenour, M.B., McNaughton, S.J. and Wallace, L.L. 1985b. Responses of an African graminoid (*Themeda triandra* Forsk.) to frequent defoliation, nitrogen, and water: a limit of adaptation to herbivory. *Oecologia* (Berlin) 68:105-110.

Daniel Gamachu 1977. *Aspects of climate and water budget in Ethiopia.* Addis Ababa University Press. Addis Ababa, Ethiopia.

Deshmukh, I. 1986. Primary production of a grassland in Nairobi National Park, Kenya. *Journal of Applied Ecology* 23:115-123.

Devidas, S. and Puyravaud, J-P. 1995. Primary productivity of the herbaceous layer in a grazed savanna woodland, Bandipur National Park, southern India. *Acta Oecologica* 16:491-505.

Eadie, J. 1970. Sheep production and pastoral resources. In: *Animal populations in relation to their food resources.* A symposium of the British Ecological Society, Aberdeen 24-28 March 1969, pp. 7-24, (Watson, A., ed.). Blackwell Scientific Publications.

Edroma, E.L. 1981a. The role of grazing in maintaining high species-composition in Imperata grassland in Rwenzori National Park, Uganda. *African Journal of Ecology* 19: 215-233.

Edroma, E.L. 1981b. Some effects of grazing on the productivity of grassland in Rwenzori National Park, Uganda. *African Journal of Ecology* 19:313-326.

Evers, G.W. and Holt, E.C. 1972. Effects of defoliation treatments on morphological characteristics and carbohydrate reserves in Kleingrass (*Panicum coloratum* L.). *Agronomy Journal* 64:17-20.

Fennema, F. and Briede, J.W. 1990. The effect of clipping and water stress on the production of selected species in the Yemen Arab Republic. *Journal of Arid Environments* 19:119-124.

Field, C.R. 1976. Palatability factors and nutritive values of the fodder of buffaloes (*Syncerus caffer*) in Uganda. *East African Wildlife Journal* 14:181-201.

Georgiadis, N.J. and McNaughton, S.J. 1990. Elemental and fibre contents of savanna grasses: variation with grazing, soil type, season and species. *Journal of Applied Ecology* 27:623-634.

Getachew Alem 1978. Soil and water management research in the semi-arid regions of Ethiopia. In: *Food grain production in semi-arid Africa*. Proceedings of an international drought symposium held at the Kenyatta conference centre, Nairobi, Kenya. 19th to 23rd May 1986, pp. 465-474, (Menyonga, J.M., Taye Bezuneh and Youdeowei, A., eds). OAU/STRC_SAFGRAD - Semi-Arid Food Grain Research and Development Publication. Ouagadougou, Burkina Faso.

Heady, H.F. and Child, R.D. 1994. *Rangeland ecology and management.* Westview Press, Inc. USA.

Hedberg, I. and Edwards, S. (eds). 1995. *Flora of Ethiopia and Eritrea,* Vol. 7. Poacea (Gramineae). Addis Ababa, Ethiopia and Uppsala, Sweden.

Hesla,B.I., Tieszen, H.L. and Boutton, T.W. 1985. Seasonal water relations of savanna shrubs and grasses in Kenya, East Africa. *Journal of Arid Environments* 8:15-31.

Isichei, A.O. 1981. Nitrogen concentration in the major grasses of the Derived and Guinea savanna zones of Nigerian in relation to season and site. *Trop. Agri.* 60:48-52.

Jackson, M.L. 1973. *Soil chemical analysis.* Prentice-Hall of India Private Limited. New Delhi.

Jacobs, M.J.M. and Schloeder, C.A. 1993. *The Awash National Park Management Plan (1993-1997).* NYZS and EWCO, Addis Ababa.

Jameson, D.A. and Huss, D.L. 1959. The effect of clipping leaves and stems on number of tillers, herbage weights, root weights and food reserves of Little Bluestem. *Journal of Rangeland Management* 12:122-126.

Juo, A.S.R.(ed.) 1978. *Selected methods for soil and plant analysis*. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Killham, K. 1994. *Soil ecology*. Cambridge University Press, New York.

Kinyamario, J.L. and Imbamba, S.K. 1992. Savanna at Nairobi National Park, Nairobi. In: *Primary productivity of grass ecosystems of the tropics and subtropics* (Long, S.P., Jones, M.B. and Roberts, M.J., eds). Chapman and Hall, London.

Le Houerou, H.N., Bingham, R.L. and Skerbek, W. 1988. Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. *Journal of Arid Environments* 15:1-18.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. *The American Naturalist* 113:691-703.

McNaughton, S.J. 1985. Ecology of grazing ecosystems: The Serengeti. *Ecological Monographs* 55:259-294.

McLean, E.O. 1982. Soil pH and lime requirement. In: *Methods of soil analysis*, Part II, Second edn., pp. 199-224. (Page, A.L., Miller, R.H. and Keeney, D.R., eds). American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Middleton, C.H. 1982. Dry matter and nitrogen changes in five tropical grasses as influenced by cutting height and frequency. *Tropical Grasslands* 16:112-117.

Moore, P.D. and Chapman, S.B. (eds) 1986. *Methods in plant ecology*. Second edition. Blackwell Scientific Publications, London.

Muleba, N. 1987. Rainfall characteristics at selected sites in Burkina Faso. In: *Food grain production in semi-arid Africa*. Proceedings of an international drought symposium held at the Kenyatta conference centre, Nairobi, Kenya. 19th to 23rd May 1986, pp. 385-392, (Menyonga, J.M., Taye Bezuneh and Youdeowei, A., eds). OAU/STRC_SAFGRAD - Semi-Arid Food Grain Research and Development Publication. Ouagadougou, Burkina Faso.

Murphy, P.G. 1975. Net primary productivity in tropical terrestrial ecosystems. In: *Primary productivity of the biosphere* (Lieth, H. and Whittaker, R.H., eds). Springer - verlag New York.

Murphy, H.F. 1959. *A report on the fertility status of some soils of Ethiopia*. Experiment station Bulletin No.1. Imperial Ethiopian College of Agriculture and Mechanical Arts. Addis Ababa, Ethiopia.

Oesterheld, M. 1992. Effect of defoliation intensity on aboveground and belowground relative growth rates. *Oecologia* 92:313-316.

Oesterheld, M. and McNaughton, S.J. 1988. Intra-specific variation in the response of *Themeda triandra* to defoliation: the effect of time of recovery and growth rates on compensatory growth. *Oecologia* 77:181-186.

Oesterheld, M. and McNaughton, S.J. 1991. Effect of stress and time for recovery on the amount of compensatory growth after grazing. *Oecologia* 85:305-313.

Oslen, S.R. and Sommers, L.E. 1982. Phosphorus. In: *Methods of soil analysis*, Part II, Second edn., pp. 403-430. (Page, A.L., Miller, R.H. and Keeney, D.R., eds). American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison, Wisconsin, USA.

Owen-Smith, N. and Novellie, P. 1982. What should a cleaver ungulate eat? *The American Naturalist* 19:151-178.

Oyenuga, V.A. 1960. Effect of stage of growth and frequency of cutting on the yield and chemical composition of some Nigerian fodder grasses - *Panicum maximum* Jacq. *J. Agric. Sci.* 55:339-350.

Polley, H.W. and Detling, J.K. 1989. Defoliation, nitrogen and competition: Effects on plant growth and nitrogen nutrition. *Ecology* 70:721-727.

Pratt, G.J. and Gwynne, M.D. (eds) 1977. *Rangeland management and ecology in east Africa.* Roberte E. Krieger Publishing Company. Huntington, New York.

Prins, H.H.T. and Beekman, J.H. 1989. A balanced diet as a goal for grazing: the food of the Manyara buffalo. *African Journal of Ecology* 27:241-259.

Ridder, N., Stroosnijider, L., Cisse, A.M. and Van Keulen, H. 1982. *A study of the soils, the vegetation and the exploitation of that natural resource.* Wageningen Agricultural University. Wageningen, The Netherlands.

Rockwood, L.L. 1973. The effect of defoliation on seed production of six Costarican tree species. *Ecology* 54:1363-1369.

Senft, R.L. Coughenour, M.B., Bailey, D.W., Rittenhouse, L.R., Sala, O.E. and Swift, D.M. 1987. Large herbivore foraging and ecological hierarchies. *BioScience* 37:789-799.

Shrimal, R.L. and Vyas, L.N. 1975. Net primary production in grasslands at Udaipur, India. In: *Tropical ecological systems, trends in terrestrial and aquatic research*. pp. 265-271, (Golley, F.B. and Medina, E., eds). Springer-Verlag Berlin. Heidelberg. NewYork.

Singh, L. 1987. Soil fertility and crop yields in the savanna zones of Nigeria. In: *Food grain production in semi-arid Africa*. Proceedings of an international drought symposium held at the Kenyatta conference centre, Nairobi, Kenya. 19th to 23rd May 1986, pp. 417-428, (Menyonga, J.M., Taye Bezuneh and Youdeowei, A., eds). OAU/STRC_SAFGRAD - Semi-Arid Food Grain Research and Development Publication. Ouagadougou, Burkina Faso.

Singh, J.S. and Yadav, P.S. 1974. Seasonal variation in composition, plant biomass, and primary productivity of a tropical grassland at Kurukshetra, India. *Ecological Monographs* 44:351-376.

Sollenberger, L.E., Quesenberry, K.H. and Moore, J.E. 1987. Forage quality responses of an Aeschynomene-Limpograss association to grazing management. *Agronomy Journal* 79:83-89.

Soneji, S.V. and Musangi, R.S. 1972. Digestibility and feed intake investigations at different stages of growth of *Brachiaria ruziziensis, Chloris gayana* and *Setaria sphacelata* using corriedale wether sheep. II - Chemical composition and yield. *East African Agricultural and Forestry Journal* 37:267-271.

Strugnell, R.G. and Pigott, C.D. 1978. Biomass, shoot production and grazing of two grasslands in the Rwenzori National Park, Uganda. *Journal of Ecology* 66:73-96.

Tamirie Hawando, Heluf G/Kidan and Yohannes Uloro. 1986. *Laboratory methods of soil, water and plant tissue analysis,* Part I. Alemaya University of Agriculture. Alemaya, Ethiopia.

Theunissen, J.D. 1995. Biomass production of different ecotypes of three grass species of the semi-arid grasslands of southern Africa. *Journal of Arid Environments* 29:439-445.

Thompson, L.M. and Troeh, F.R. 1978. *Soils and soil fertility.* Fourth edition. Tata McGrew-Hill Publishing Company LTD. New Delhi.

Tolsma, D.J., Ernst, W.H.O., Verweji, R.A. and Vooijs, R. 1987. Seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Botswana. *Journal of Ecology* 75:755-770.

Van Voorthuizen, E.G. 1972. The effects of cutting frequency and cutting height on four naturally occurring pasture grasses in Tanzania. *East African Agricultural and Forestry Journal* 37:258-264.

Veenedaal, E.M., Ernst, W.H.O. and Modise, G.S. 1996. Effect of seasonal rainfall pattern on seedling emergence and establishment of grasses in a savanna in south-eastern Botswana. *Journal of Arid Environments* 32:305-317.

Von Richter, W. and Osterberg, R. 1977. The nutritive values of some major food plants of Lechwe, Puku and Waterbuck along the Chobe River, Botswana. *East African Wildlife Journal* 15:91-97.

Westoby, M. 1974. An analysis of diet selection by large generalist herbivores. The *American Naturalist* 108:290-304

Wilde, A. 1993. *Soils and the environment.* An introduction. Cambridge University Press. London.

Wilde, S.A., Corey, R.B., Iyer, J.G., Voigt, G.K. 1979. *Soil and plant analysis for tree culture.* Oxford and IBH Publishing Co. New Delhi.

Woldu Tekle Debessai. 1984. *The mineral and crude protein contents of some feedstuffs produced in Jijiga Awraja and Gursum Woreda, eastern Ethiopia.* M.Sc. thesis, Addis Ababa University.

Yerima, B.P. 1992. *National soil service project, manual for plant analysis and interpretation.* Ministry of Agriculture. Addis Ababa, Ethiopia.

Zerihun Woldu. 1985. Variation in grassland vegetation on the central plateau of Shewa, Ethiopia, in relation to edaphic factors and grazing conditions. *Diss. Bot.* 84:1-114.

8. APPENDICES

Appendix 1. Biomass production (g m^{-2}) of the three species and the mixed stands in different periods of the year (n=9, mean ± sd).

Species	Growth periods			
	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
C. plumulosus	46.4 ± 10.1^{aAB}	161.2 ± 108.8^{bcA}	180.9 ± 78.0^{bAC}	5.2 ± 2.2^{cA}
I. afrum	16.9 ± 13.2^{aB}	408.7 ± 92.2^{bB}	223.6 ± 40.1^{cAB}	3.9 ± 1.3^{aA}
B. radicans	27.9 ± 17.1^{aB}	195.9 ± 84.9^{bA}	113.5 ± 35.4^{cC}	4.4 ± 2.5^{aA}
Mixed	62.5 ± 23.2^{aAC}	216.1 ± 76.6^{bA}	178.8 ± 57.1^{bBC}	3.5 ± 2.1^{cA}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 2. Biomass production (g m^{-2}) of the three species and the mixed stands in different growth periods of the year (n=9, mean $\pm$ sd).

Species	Growth time			
	3 months	6 months	9 months	12 months (1 year)
C. plumulosus	46.4 $\pm$ 10.1^{aAC}	312.8 $\pm$ 111.7^{bAC}	693.9 $\pm$ 172.6^{cA}	643.3 $\pm$ 273.7^{cAB}
I. afrum	16.9 $\pm$ 13.2^{aB}	478.0 $\pm$ 124.8^{bB}	760.2 $\pm$ 189.8^{cA}	756.3 $\pm$ 164.2^{cA}
B. radicans	27.9 $\pm$ 17.1^{aBC}	191.6 $\pm$ 58.9^{bA}	404.1 $\pm$ 175.1^{cB}	396.7 $\pm$ 108.6^{cB}
Mixed	62.5 $\pm$ 23.2^{aA}	339.5 $\pm$ 130.8^{bBC}	837.7 $\pm$ 227.6^{cA}	791.8 $\pm$ 189.8^{cA}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 3. Mean moisture (%) content of the grasses in different periods of the year (n=9, mean ± sd).

Period	*C. plumolosus*	*B. radicans*	*I. afrum*	Mixed
April, 1996	69.5 ± 4.1^{aA}	69.6 ± 3.0^{aA}	79.9 ± 6.1^{bA}	70.5 ± 1.6^{aA}
July, 1996	47.1 ± 4.8^{aB}	61.7 ± 3.0^{bB}	60.6 ± 2.1^{bB}	54.4 ± 2.8^{cB}
Oct., 1996	33.7 ± 5.8^{aC}	30.6 ± 5.9^{aC}	35.3 ± 3.8^{aC}	29.9 ± 2.2^{aC}
Jan., 1997	30.3 ± 12.5^{aC}	32.7 ± 8.9^{aC}	33.8 ± 10.0^{aC}	39.0 ± 15.9^{aC}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 4. Percent crude protein content of the three grass species in different periods of the year ($n=6$, mean $\pm$ sd).

Period	*C. plumulosus*	*B. radicans*	*I. afrum*
April, 1996	6.025 ± 0.269^{aA}	6.913 ± 1.319^{aA}	5.125 ± 1.800^{aA}
July, 1996	6.006 ± 1.563^{aA}	5.700 ± 0.763^{abA}	4.194 ± 0.350^{bAB}
Oct., 1996	4.269 ± 1.450^{aAB}	3.300 ± 0.325^{aB}	3.106 ± 0.894^{aAB}
Jan., 1997	3.338 ± 0.769^{abB}	3.806 ± 0.875^{aB}	2.481 ± 0.375^{bB}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p<0.05$ as determined by Tukey's, Family Error Rate.

Appendix 5. Results of two way ANOVA for test of significant difference between treatments in shoot and root biomass production and percent nitrogen content of the three grass species.

Species	Source	Shoot				Root				Nitrogen			
		DF	MS	F	P	DF	MS	F	P	DF	MS	F	P
C. plumulosus	Cutting height	2	146.73	17.850	<0.01	2	88.03	29.74	<0.01	2	0.3149	4.518	<0.05
	Cutting frequency	2	155.06	18.864	<0.01	2	74.83	25.28	<0.01	2	1.8627	26.725	<0.01
	Cut. ht. x cut. freq.	4	5.12	0.623	>0.05	4	2.36	0.797	>0.05	4	0.0407	0.584	>0.05
	Error	45	8.22			45	2.96			18	0.0697		
I. afrum	Cutting height	2	88.82	12.616	<0.01	2	20.13	10.167	<0.01	2	0.2928	5.653	<0.05
	Cutting frequency	2	85.68	12.170	<0.01	2	122.93	62.086	<0.01	2	1.4649	28.280	<0.01
	Cut. ht. x cut. freq.	4	3.70	0.526	>0.05	4	2.58	1.303	>0.05	4	0.0422	0.815	>0.05
	Error	45	7.04			45	1.98			18	0.0518		
B. radicans	Cutting height	2	483.16	210.07	<0.01	2	21.326	26.135	<0.01	2	0.3146	7.299	<0.01
	Cutting frequency	2	233.23	101.404	<0.01	2	127.836	156.662	<0.01	2	0.8813	20.448	<0.01
	Cut. ht. x cut. freq.	4	17.82	7.748	<0.01	4	8.377	10.266	<0.01	4	0.0602	1.397	>0.05
	Error	45	2.30			45	0.816			18	0.0431		

Appendix 6. Rainfall (mm) record at Metahara Sugar Plantation - ca 5 km southwest of the headquarters of ANP.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0	114	4	61	11	44	128	169	94	30	4	0	659
1967	0	0	68	58	51	52	119	231	51	44	119	0	793
1968	0	99	3	55	6	41	149	80	44	11	31	14	533
1969	65	123	34	37	45	25	144	177	21	0	6	0	677
1970	24	24	89	10	6	1	127	171	38	32	0	0	522
1971	0	0	1	22	28	38	160	185	23	0	24	16	497
1972	0	75	45	20	59	31	57	83	25	10	0	0	405
1973	0	0	0	8	21	26	113	95	42	9	0	0	314
1974	0	0	70	4	46	36	53	52	101	1	1	1	365
1975	0	31	52	50	52	58	186	195	50	4	0	0	678
1976	0	0	55	54	52	9	123	147	30	8	30	4	513
1977	110	46	7	68	88	103	74	70	18	233	18	0	825
1978	0	106	0	6	26	4	98	90	52	34	5	30	451
1979	76	0	52	5	59	42	135	75	53	14	0	3	514
1980	10	0	5	47	15	30	131	183	34	7	12	0	474
1981	0	1	130	72	4	0	174	190	62	11	0	0	644
1982	31	57	58	21	101	4	100	304	36	91	36	0	839
1983	6	49	64	49	93	21	139	143	19	8	0	0	591
1984	0	0	13	0	62	33	65	69	71	0	0	8	321
1985	6	0	20	90	72	5	173	131	43	9	0	0	549
1986	0	56	49	37	53	77	75	85	53	5	0	4	494
1987	0	11	70	46	75	0	36	124	10	5	0	0	377
1988	20	19	19	41	7	11	159	131	84	37	0	11	539
1989	0	28	89	102	3	63	55	163	25	0	0	19	547
1990	1	222	98	68	4	2	182	82	74	4	0	2	739
1991	0	54	65	27	52	14	171	109	81	0	0	0	573
Mean	13	43	45	41	42	30	120	136	47	23	11	4	555

Source: Metahara Sugar Plantation's Meteorological Station, Merti. (After Jacobs and Schloeder, 1993.)

Appendix 7. Temperature (° C) record at Metahara Sugar Plantation - ca 5 km southwest of the headquarters of ANP.

Year	Jan		Feb		Mar		Apr		May		Jun		Jul	
	max	min	max	min	max	min	max	min	max	min	max	min	max	min
1966	31.3	12.3	29.1	17.1	31.4	15.9	34.3	19.1	36.9	17.8	36.0	21.3	33.4	20.7
1967	28.3	10.5	31.4	14.8	33.6	18.5	32.8	18.3	33.8	18.5	34.7	19.1	29.1	20.2
1968	29.4	10.4	26.8	18.2	30.9	17.1	30.4	18.9	34.1	18.4	34.1	20.7	31.6	19.6
1969	30.4	18.3	29.1	16.9	31.6	18.5	33.5	19.3	35.4	20.9	36.5	22.3	33.3	22.1
1970	30.0	16.7	32.1	16.2	30.6	18.6	34.1	18.8	36.2	19.8	36.5	22.9	33.7	20.9
1971	28.6	13.4	31.4	11.4	32.9	15.9	34.0	17.9	33.8	19.4	34.7	21.2	31.7	19.5
1972	30.6	14.1	28.6	16.4	33.6	16.3	34.4	19.3	34.4	17.2	34.2	19.7	32.9	21.0
1973	30.7	14.7	32.8	13.9	35.0	17.8	35.8	20.5	35.2	20.2	35.8	21.7	32.7	21.1
1974	31.1	13.4	32.4	16.3	31.7	18.5	35.0	15.9	34.6	18.6	35.3	21.0	33.0	20.2
1975	30.9	11.9	32.1	16.3	34.6	18.1	34.3	19.0	35.3	19.3	34.6	20.7	31.3	19.3
1976	30.7	12.3	33.1	17.1	34.8	17.9	34.6	18.6	34.4	19.7	37.2	21.4	32.8	20.1
1977	29.7	18.4	29.1	14.3	33.6	17.7	34.4	18.6	34.9	19.3	35.5	21.4	33.4	21.0
1978	30.9	12.9	31.3	16.0	33.3	18.7	36.5	18.5	36.7	20.4	37.1	21.7	31.4	19.6
1979	27.8	16.9	30.9	15.6	33.0	16.9	33.9	17.8	33.7	18.8	34.4	20.8	33.1	19.8
1980	30.1	14.1	33.2	16.8	35.1	19.8	34.2	19.4	35.6	19.2	37.2	22.7	31.9	20.6
1981	31.9	13.3	32.0	15.1	29.8	17.7	30.5	17.7	34.1	17.5	36.3	20.8	32.4	20.5
1982	30.2	16.6	31.0	18.1	33.4	17.3	32.4	18.2	32.9	18.2	36.0	20.4	33.4	20.3
1983	29.2	13.5	30.2	18.1	32.7	20.2	33.7	19.8	34.2	20.1	35.3	20.0	34.2	20.7
1984	29.3	11.1	30.7	11.2	34.7	15.9	35.8	18.0	34.7	19.3	34.2	20.6	33.8	19.4
1985	31.1	13.8	30.8	14.4	34.4	18.2	32.1	19.4	33.2	18.7	35.8	20.9	31.6	19.4
1986	29.9	10.8	32.2	18.2	32.8	17.1	33.5	19.8	35.5	19.4	34.4	21.9	32.0	19.8
1987	29.5	14.0	32.7	15.9	32.1	20.0	32.9	18.1	33.1	19.6	36.2	22.7	36.0	21.0
1988	30.0	16.8	32.8	18.8	34.5	17.4	34.8	19.5	36.4	18.7	36.9	21.9	31.8	21.1
1989	29.4	13.8	30.2	16.1	32.7	18.0	31.0	19.0	34.8	16.2	36.0	20.4	32.2	20.5
1990	30.7	14.9	29.8	18.8	30.7	17.8	32.6	17.5	36.4	19.4	37.4	22.1	32.8	19.7
1991	31.9	16.4	32.0	17.5	34.3	19.1	33.9	18.5	34.5	18.9	36.6	21.0	32.5	20.8
Mean	30	14	31	16	33	18	34	19	35	19	36	21	33	20

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Year	Aug max	min	Sep max	min	Oct max	min	Nov max	min	Dec max	min	Annual max	Mean min
1966	32.2	19.3	32.7	15.1	32.7	16.2	ND	ND	29.7	8.7	33	17
1967	29.3	19.2	31.8	19.4	30.4	16.8	28.6	17.6	28.1	11.3	31	17
1968	31.2	18.5	32.5	18.4	32.1	15.2	29.3	14.8	30.0	13.4	31	17
1969	31.8	19.8	33.2	19.6	33.3	15.3	31.7	14.7	30.9	10.9	33	18
1970	30.7	19.8	32.2	18.4	32.3	16.2	30.3	10.2	28.8	10.7	32	17
1971	30.1	18.5	31.5	17.9	31.7	14.9	29.5	14.9	28.1	12.3	32	16
1972	32.2	19.6	32.8	18.5	32.2	16.0	31.1	15.6	30.1	15.0	32	17
1973	32.3	21.0	33.9	20.1	33.8	15.4	32.2	13.1	30.0	9.5	33	17
1974	33.2	20.3	33.7	19.3	35.1	15.8	31.6	11.1	30.9	11.9	33	17
1975	30.7	19.6	32.0	19.0	33.1	14.4	30.5	11.4	29.2	10.0	32	17
1976	30.8	18.6	33.2	18.4	33.3	15.3	30.5	14.1	31.0	13.6	33	17
1977	32.6	19.8	34.7	19.3	32.5	18.8	29.5	15.2	30.5	14.2	33	18
1978	31.9	19.1	32.9	18.5	32.2	16.5	31.2	13.7	29.2	14.1	33	17
1979	32.6	19.5	34.1	19.2	33.1	15.7	32.3	11.2	30.6	14.0	32	17
1980	32.3	19.6	34.2	19.4	33.9	16.5	32.4	14.7	30.5	11.3	33	18
1981	30.7	19.0	31.6	18.6	32.2	15.0	31.1	12.5	29.6	11.3	32	17
1982	30.1	19.1	32.7	18.4	30.1	15.1	29.9	15.6	29.3	15.4	32	18
1983	31.1	20.2	33.2	19.5	32.9	15.1	30.9	12.8	28.9	12.8	32	18
1984	33.8	20.1	32.9	18.3	33.1	13.9	31.9	15.5	29.7	14.4	33	16
1985	30.4	18.7	32.9	17.8	32.8	15.1	31.5	13.5	29.9	12.7	32	17
1986	32.8	19.4	33.6	18.6	32.9	15.7	31.9	14.0	29.9	14.6	33	17
1987	33.3	20.3	35.4	19.5	33.7	17.4	32.0	12.8	31.0	13.8	33	18
1988	31.8	19.8	32.7	19.4	32.4	16.5	30.9	10.6	30.0	12.7	33	18
1989	32.9	19.6	33.4	19.3	33.2	15.2	31.6	14.4	29.8	18.9	32	17
1990	32.8	19.9	33.7	19.7	32.2	15.1	32.1	14.8	30.1	12.5	33	18
1991	31.8	20.0	33.6	19.0	33.8	16.1	ND	ND	30.3	7.5	30	18
Mean	32	20	33	19	33	16	29	13	30	13	32	17

ND - no data

Source: Metahara Sugar Plantation's Meteorological Station, Merti. (After Jacobs and Schloeder, 1993.)

Appendix 8. Relative humidity (%) record at Metahara Sugar Plantation - ca 5 km southwest of the headquarters of ANP.

Year	Jan		Feb		Mar		Apr		May		Jun		Jul	
	max	min	max	min	max	min	max	min	max	min	max	min	max	min
1966	58	21	54	30	71	22	67	19	57	16	60	17	63	21
1967	61	24	51	22	54	21	65	21	60	17	59	18	63	33
1968	61	27	87	48	72	32	94	39	76	25	67	23	70	27
1969	83	34	86	35	85	32	89	33	84	28	76	29	80	35
1970	93	42	84	34	93	41	86	32	79	27	62	22	77	22
1971	85	30	87	23	82	24	81	22	80	24	73	22	84	27
1972	93	25	94	36	90	22	87	25	96	25	90	27	91	31
1973	97	34	93	28	75	16	67	16	70	13	71	21	85	31
1974	95	31	93	31	93	34	91	21	93	31	87	28	91	31
1975	92	25	89	28	83	25	86	24	83	22	84	25	91	34
1976	94	34	90	36	90	29	89	31	89	33	78	29	84	36
1977	87	44	87	36	84	33	85	31	85	30	78	30	82	36
1978	93	22	93	30	92	29	87	23	85	26	83	27	83	38
1979	86	46	85	37	85	33	85	26	83	26	82	26	82	28
1980	83	34	82	27	82	26	82	25	82	18	80	21	79	29
1981	81	28	81	29	80	37	80	33	83	25	80	22	81	27
1982	82	34	81	31	80	26	79	26	79	26	80	21	78	24
1983	80	30	79	34	80	29	79	23	80	24	78	19	78	23
1984	80	24	80	19	77	16	78	20	78	21	77	18	78	18
1985	77	22	76	25	78	21	79	25	78	19	76	18	ND	ND
1986	92	30	92	33	95	31	92	32	90	27	82	31	89	32
1987	95	37	96	35	97	43	95	37	95	39	80	32	90	32
1988	95	41	96	36	79	24	86	26	77	21	71	22	82	33
1989	88	31	91	34	90	33	94	35	92	24	ND	ND	82	34
1990	97	35	97	50	97	42	93	33	87	24	78	26	90	34
1991	92	33	93	35	92	29	93	28	91	28	83	24	88	33
Mean	85	31	85	32	84	29	84	27	82	25	77	24	82	30

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Year	Aug max	Aug min	Sep max	Sep min	Oct max	Oct min	Nov max	Nov min	Dec max	Dec min	Annual Mean max	Annual Mean min
1966	21	70	24	94	26	84	29	ND	ND	ND	68	23
1967	70	29	72	28	80	26	76	33	78	29	66	25
1968	85	32	95	34	81	29	76	32	83	28	79	31
1969	90	38	87	33	86	26	87	29	89	27	85	32
1970	82	31	88	26	85	23	90	21	91	25	84	29
1971	90	30	84	25	87	23	89	28	92	29	85	26
1972	95	33	96	30	95	27	94	30	98	35	93	29
1973	89	34	94	29	94	21	92	21	94	21	85	24
1974	90	33	93	30	92	24	96	22	93	27	92	29
1975	90	38	90	33	94	22	97	30	96	33	90	28
1976	89	40	88	34	89	29	93	34	90	32	89	33
1977	82	34	88	25	92	29	94	28	90	26	86	32
1978	84	34	83	29	85	27	84	29	89	35	87	29
1979	82	29	84	27	85	24	83	21	84	30	84	29
1980	80	31	81	28	82	23	83	26	82	27	82	26
1981	82	34	82	40	81	20	81	23	81	25	81	29
1982	79	35	80	26	79	26	81	29	80	33	80	28
1983	78	34	79	22	80	20	79	23	80	29	79	26
1984	77	18	79	20	77	17	77	27	78	25	78	20
1985	ND	ND	ND	ND	ND	ND	ND	ND	92	33	79	23
1986	93	32	95	28	93	26	95	31	96	38	92	31
1987	95	36	94	32	95	32	96	31	97	35	94	35
1988	88	33	90	30	92	25	94	24	91	28	87	29
1989	93	34	94	32	97	26	96	32	95	44	92	33
1990	89	33	91	28	91	24	93	31	93	28	91	32
1991	92	35	92	28	92	23	ND	ND	97	22	91	29
Mean	85	33	88	29	88	25	88	28	89	30	85	28

Source: Metahara Sugar Plantation's Meteorological Station, Merti. (After Jacobs and Schloeder, 1993.)