THE EFFECT OF SEASON AND SHRUB-GRASS COMBINATION ON THE FODDER QUALITY OF THREE AGROFORESTRY PLANT SPECIES GROWN IN MASENO, WESTERN KENYA

BY

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ABSTRACT

An experiment to study the effect of season and shrub-grass combinations on the fodder quality of leucaena (Leucaena leucocephala), calliandra (Calliandra calothyrsus) and Napier grass (Pennisetum purpureum) was established at Maseno, western Kenya.

The species were managed as hedgerows on field bunds in a randomized complete block design with seven treatments and four replications. Fresh and dry leafy biomass assessments, and sample collection were done at two-month harvesting intervals for 18 months. Percent dry matter was determined by oven-drying approximately 500 g of fresh samples at 60 ^{0}C for 48-72 hours. Dried samples were ground to pass a 1 mm sieve and analysed for N (used for crude protein estimation), P, Ca, K, Mg, Zn, Cu and ADF (acid detergent fibre). Statistical analysis was done using SAS 6.04 at α=0.05 significance level.

Napier grass was highest in fresh and dry biomass productivity. Biomass productivity, however, dropped significantly in the second year. Biomass productivity of shrubs was lower, but was maintained at similar levels throughout the study period. Leucaena was highest in crude protein, Ca and Cu, but lowest in Zn and ADF. Calliandra was highest in P, Zn and ADF, but was lowest in K and Mg. Napier grass was highest in K and Mg, but was lowest in crude protein, Ca, P and Cu.

Except in the leucaena-Napier grass mixture, where differences were not significant, establishment in shrub-grass combinations caused significant increases in the biomass yields of Napier grass. Biomass yields of the woody perennials were either increased significantly or were not affected. Nutrient concentrations of the legume plants were not significantly changed by shrub-grass combinations. The same is true of the Napier grass for most nutrients except K and Mg. The former was increased significantly in combination with both legumes, while the latter was significantly reduced in combination with calliandra, but remained unchanged in combination with leucaena.

Except for K content in Napier grass ($r=0.750$), biomass and nutrients were not significantly correlated with rainfall. Other correlations were not significant and varied with species and parameter. It is suggested that the presence of at least some rainfall in all months maintained a reasonable level of moisture in the soil, so that adverse effects caused by prolonged drought in other areas were not observed at Maseno.

Napier grass is suitable for providing the basic ration, while trees and shrubs have a significant potential as high nutrient supplements to conventional animal feeds. These can conveniently be established as tree or shrub-grass combinations. Attempts to diversify the genetic base of fodder trees and shrubs should be made to overcome problems related to toxicity, poor digestibility and the occurrence of pests and diseases.

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1. INTRODUCTION

Livestock production is an integral part of all landuse systems in the highlands of western Kenya. Population densities in this part of the country have increased significantly since early in this century. Land holdings are now too small to provide all the needs of individual households. This has caused considerable changes in the traditional lifestyles of the local people (Conelly, 1992). Among other things, there is a general tendency to put more land under crops, leaving little or none for free grazing. Farmers have shifted their livestock management practices from tethering and herding on communal and fallow land to zero grazing, the most intensive livestock production system, involving the cut-and-carry method. Zero grazing with an average of 2-3 animals is currently being practised by many of the farmers. The manure from the animals is utilized to improve soil fertility in crop plots and the crop residues (maize stover, sweet potato (Ipomoea batatas) vines, stem and foliage of banana plants, sugarcane tops and bean leaves) are used as feed supplements during periods of diminished fodder supply. Crop residues, however, are low in digestibilities and are deficient in fermentable energy, fermentable nitrogen, crude protein and several of the required mineral elements (Nangole et al., 1983; Butterworth, et al., 1984; Escobar and Parra, 1980, cited by Preston, 1982).

Napier grass (Pennisetum purpureum), a popular fodder species in the high-potential areas of Kenya (Abate et al. 1985), is the major livestock feed supplying the zero-grazing units. Together with maize (Zea mays) stover, it accounted for 80% of all cut-and-carry feeds in Hamisi during the 1986-87 period (Conelly, 1992). Many farmers have established Napier grass either on terrace bunds (low-lying ridges of soil constructed along the contour) or as fodder banks. Napier grass is high in biomass production per unit area, but like many tropical pasture grasses, has a few shortcomings: 1) the protein content of the grass is not high (Gohl, 1981) and drops significantly during the dry season (Sands et al., unpublished data, 1982), 2) during the dry season, availability of grass fodder is reduced because of a slow-down in growth and an increase in the crude fibre content, 3) biomass production from the grass starts to decline over time unless nutrients are added (Snyders, 1991).

Resources to purchase high protein concentrates such as bone meal, and meat-and-bone meal (Butterworth et al., 1984) for supplementing livestock feeds are limited, and the majority of the farmers find these feeds expensive and outside their financial capabilities. Kenya, like many other third world countries, is looking for a cheaper source of protein (Semenye, 1990). Herbaceous legumes such as desmodium and lucerne (Snyders, 1991) could improve the situation, but do not have the capacity to withstand periods of extreme moisture stress. Tropical leguminous woody forages are rich in protein and minerals (Gohl, 1981) and may be possible alternatives.

The dry matter yield, protein quality and in-vitro digestibility of Leucaena leucocephala, for example, compare well with those of the finest forage legumes such as alfalfa (NAS, 1977). Reports by Siebert et al. (1976), in which steers fed chopped sugarcane (Saccharum officinarum) supplemented with Leucaena leucocephala gave the same liveweight gains (0.61 kg per head per day) as those supplemented with meat meal, supports this hypothesis. Studies involving the use of multipurpose trees and shrubs (MPTS) as livestock feed supplements have yielded similar results.

Consequently, agroforestry research focusing on the identification of potential fodder species and suitable management options has been intensified. Due to the land tenure situation in western Kenya, and to reduce labour requirements, fodder production systems in which components are established as tree-grass mixtures are prefered to pure planting arrangements. Earlier research has shown that Napier grass and some leguminous shrubs increase significantly in biomass production when grown in mixtures (Gill et al., 1990; Otieno et al., 1991). However, information regarding the effect of these mixed plantings on the feeding value of the species involved is not available. The effect of seasonal changes on the nutrient composition (particularly of the shrub species) has also not been investigated.

The objectives of this study were to: 1) compare the fresh leafy biomass, dry matter, crude protein, acid detergent fibre (ADF) and macronutrient element contents of *Leucaena leucocephala*, *Calliandra calothyrsus* and *Pennisetum purpureum* grown in western Kenya; 2) study the fluctuations in the nutrient values of the three fodder crops with season; 3) study the nutrient content changes when the species are established as tree-grass mixtures or as pure stands.

2. LITERATURE REVIEW

2.1. Agroforestry: concepts and potentials

2.1.1. An overview

Agroforestry is a new term for an old landuse system that has been in existence for many years (King, 1987). A preliminary overview for a global inventory on agroforestry systems (ICRAF, 1983) revealed many examples of prominent agroforestry systems and practices in developing countries. Agroforestry permits multiple cropping in which woody perennials are integrated with crops and/or animals/pastures on the same unit of land where they interact ecologically and economically (Somarriba, 1992; Agroforestry systems, vol. 1, pp. 7-12, 1982).

Agroforestry and its potentials attracted the interest of scientists and development planners in late 1960's and the 1970's when increased population densities called for immediate remedies to pressing landuse problems. It has been pointed out that the increase in world population during the 20 years between 1965 and 1985 was equal to the total world population in 1900 and that 90% of this increase was in developing countries (Kidd and Pimentel, 1992). Despite declining birth rates in many developing countries, this population (about 4.8 billion in 1985) is estimated to increase by 37% to about 6.6 billion by about 2005.

In tackling problems associated with reduced land sizes and diminished per capita income, agroforestry is generally seen as a promising option, albeit a complex enterprise requiring knowledge and skills of experts and scientists from a diversity of academic disciplines (forestry, agriculture, soil science, animal science, etc.).

The establishment of the International Council for Research in Agroforestry (ICRAF) in 1977 to promote and catalyse research in agroforestry (King, 1977) was a milestone in the history of Agroforestry. After joining the Consultative Group on International Agricultural Research (CGIAR), with global responsibility for research on agroforestry, ICRAF recently changed from a council to a centre. With its headquarters in Nairobi, Kenya, ICRAF'S institutional goals are to mitigate tropical deforestation, land depletion and rural poverty through improved agroforestry systems (ICRAF, 1991).

The success of any agroforestry practice depends on the choice of plant species. Huxley (1981a) provided a list of technical, managerial and socio-economic factors to be considered when trees (and other woody perennials) are being considered for agroforestry. Many leguminous woody perennials have an advantage over other multipurpose trees and shrubs (MPTS) because of their ability to fix atmospheric nitrogen. Consequently, a literature survey conducted by ICRAF prior to a global inventory of agroforestry systems indicated that the majority of the species currently used in tropical and subtropical agroforestry belong to the family Leguminosae [Fabaceae] (Nair et al., 1984). Nitrogen fixation improves the nitrogen status of the soil and increases the yield of associated crops (Dommergues, 1987).

2.1.2. Agroforestry in Kenya

Kenya is a developing country lying on the equator and having a land area of about 580,000 sq. km. A large proportion of the country is dominated by arid and semi-arid climate. The high-potential area which consists of the Kenya highlands, the coastal strip and much of the Lake Victoria Basin occupies less than 20% of the area (Getahun, 1989), but supports the majority of the country's 25 million people. In recent years, land use problems associated with increasing population densities (and subsequent intensification of agriculture and livestock production) have been experienced, particularly in the medium-to high-potential zones.

The period between 1970 and now (1994) has been one of accelerated agroforestry awareness, research and development in Kenya. This achievement has been attributed to the joint efforts of the Kenya government, donor agencies, the non-governmental (NGO) community and the Kenyan farmers (Getahun, 1989). As Getahun further stated, the Kenya government's initial attention and interest in agroforestry came as a result of energy supply problems and environmental degradation.

In 1981, the then Ministry of Energy and Regional Development (MOERD), in close collaboration with the Ministry of Agriculture (MOA), the Ministry of Environment and Natural Resources (MENR), the Ministry of Livestock Development (MOLD) and selected NGO'S such as Kenya Energy Non-Governmental Organizations (KENGO), began a national effort to implement a coordinated programme of agroforestry research, training and extension (Getahun, 1989). By 1985, there were 13 major national organizations and 63 others active in agroforestry/social forestry and general tree planting activities in Kenya and this number has been on the increase (Energy Development International, 1985; cited by Getahun, 1989).

The location of the International Centre for Research in Agroforestry (ICRAF) in Nairobi has made a significant contribution to Kenya's progress in agroforestry. ICRAF's 40-ha field station at Machakos provides facilities for field experimentation and demonstration (ICRAF, 1991). Since its creation in 1986, ICRAF's Collaborative Programmes Division (COLLPRO), has conducted joint field research vis a vis the agroforestry research network for Africa (AFRENA) with the Kenya Forestry Research Institute (KEFRI) and the Kenya Agricultural Research Institute (KARI) at Maseno and Embu. AFRENA is a programme established by ICRAF and is mandated to develop appropriate agroforestry technologies for selected land use systems and to develop the regional and national capability to plan, formulate and implement agroforestry research in the participating African countries and regions. The programme covers, among other African regions, the highlands of East and Central Africa.

ICRAF continues to play a leading role in coordinating, catalysing, promoting and encouraging agroforestry research, training and/or extension among local institutions. It also participates actively in the quest for appropriate agroforestry technologies for the farming community. Agroforestry is now taught as part of the curriculum in some of the universities and agricultural institutions. Agroforestry research is undertaken at Moi University, University of Nairobi and Egerton University. Experiences from agroforestry extension agencies indicate great interest and enthusiasm among small-scale farmers. Impact evaluation of the CARE-KEFRI extension project in the Siaya and South Nyanza districts showed considerable increases in tree planting activities among the target groups (Scherr, 1992; Scherr and Alitsi, unpublished data, 1991).

2.2. The role of woody perennials and their configurations in agroforestry

Depending on the intended principal end-uses, farmers integrate trees and shrubs with their crops and livestock in various ways (Burley, 1987). Individual woody plants may occur regularly or randomly at wide spacing on productive agricultural land. They may also be found as linear single or multiple-row plantings along boundaries, contours, roads, riverbanks or railways. Trees and shrubs may be established as shelterbelts, windbreaks, or as live fences. Community and farm woodlots are common features in some areas. In many highly populated humid and subhumid tropics, woody perennials are established as hedgerows in small scale farms, where they are maintained at low cutting heights.

In all these configurations, the products and services derived from woody perennials are manifold and include direct advantages and both environmental and socio-economic benefits (Burley, 1987). Extensive reviews concerning the role of woody perennials in agroforestry have been undertaken (Huxley, 1981b; Nair et al., 1984). These roles can be categorized into productive and protective (Nair et al., 1984); some species play both roles simultaneously. Trees and shrubs are productive as sources of consumables such as food, fodder, firewood, timber, green manure, fruits and medicine. The protective (service) role of woody perennials in agroforestry stems from their soil improving and soil conserving functions, and their role as live fences, shelterbelts and windbreaks. Woody perennials improve and enrich soil conditions through nitrogen fixation, addition of organic matter, and improvement of soil structure and efficiency of nutrient cycling (Young, 1989). Physical soil conservation is the main protective function of woody perennials and can be conveniently exploited in agroforestry if the chosen species can provide additional benefits and outputs such as fodder, fuel, etc. (Nair et al., 1984). A large number of multipurpose woody perennials are being used as effective live fences at CATIE (Centro Agronomico Tropico de Investigacion y Ensenanza), Turrialba, Costa Rica (Budowski, 1983). Similarly, very encouraging results on shelterbelts and windbreaks have been obtained at the Pakistani Forestry Research Institute, Peshawar (Sheikh and Khalique, 1982).

In animal agroforestry, fodder production is one of many productive and service roles played by woody perennials in systems supporting either or both domestic and wild herbivores (Torres, 1983). Browse in silvopastoral systems provides stability and productivity of livestock production, the major source of livelihood and income in arid and semi-arid African zones (Le Houerou, 1987).

2.3. Woody plants for fodder in agroforestry

2.3.1. Rationale

Grasses form the main portion of tropical and sub-tropical pastures. These pastures support the majority of the world's herbivores: 66% of the cattle, 64% of the sheep and goats, 80% of the equines, and almost all the camels and the buffaloes (Jones, 1988). Individual grasses differ in growth habits, ecological requirements and utilization (Judd, 1979). When their fodder potentials are considered, grasses are generally highly productive and nutritious under favourable conditions; but are highly susceptible to environmental changes.

There are several factors that have been found to limit the potentials of tropical fodder grasses. Grasses are generally low in protein and minerals (Gohl, 1981). Compared to temperate grasses, tropical grasses have lower feeding values because of lower protein levels which sometimes fall below 6-8% (depressing dry matter intake) and higher fibre contents, which lower voluntary intake and dry matter digestibility (Minson, 1981). The lower digestibility of tropical grasses is caused by differences in anatomical structure associated with the different photosynthetic pathways (Laetsch, 1974) and the higher temperature at which tropical grasses are normally grown (Minson, 1990). These features limit long-term animal performance to 0.7 kg liveweight gain per head per day for beef cattle, or 12 kg milk per head per day for dairy cattle (Humphreys, 1991). Fluctuations in productivity and nutritive values associated with environmental and growth changes are noteworthy. While grasses attain high productivity during periods of moisture sufficiency, there is a significant drop in quality (Sands et al., unpublished data, 1982) and quantity during the dry season. Animal feed requirements on the other hand remain relatively constant and must be met continuously.

Leguminous trees and shrubs are high in protein and minerals and are able to withstand adverse environmental conditions compared to grasses. Le Houerou (1980) found grasses in the dry season to be extremely deficient in protein, phosphorus and carotene, while these nutrients were adequate for livestock maintenance requirements in a wide range of browse plants.

Unlike grasses, the dry matter digestibilities of tropical and temperate legumes are similar because both categories have the same photosynthetic pathway and leaf anatomy (Minson, 1990). Woody perennials can provide alternative feeds during the dry season when grasses are scarce or absent. In the face of high population densities, agroforestry systems in which suitable woody perennials are managed along side crops and/or animals/pastures to serve this purpose are, therefore, being promoted among many small-scale farms in the tropics.

2.3.2. The role of nutrients

A nutrient is a feed constituent, or group of feed constituents that are classified together, which contribute to the support of animal life. All nutrients in feeds are contained within the dry matter and include crude protein, energy, minerals, and vitamins. The quantity of each nutrient absorbed depends on (1) the quantity of forage dry matter eaten each day, and (2) the concentration and availability of that particular nutrient in each kilogram of forage dry matter (DM) (Minson, 1990). Detailed information on individual nutrients and their functions in the animal body are provided in many standard texts. The following summary is an overview condensed from Huston and Pinchak (1991).

Crude protein

Crude protein is the basic structural material from which many animal body tissues are formed (e.g. muscles, nerves, skin, connective tissues and blood cells). It supplies nitrogen (as ammonium) and amino acids for intraruminal microbial activity and cellular-level tissue metabolism. Twenty-four amino acids are generally thought to be constituents of proteins; some of these are "essential" because they cannot be formed in body tissues, and must be provided in the diet (Pomeranz and Meloan, 1987). Protein requirements in ruminants include protein and/or nitrogen requirements of the ruminal microbial population. Generally, microbial requirements are met at 6-8% crude protein in the diet. Animal requirements range from 7-20% in the diet depending upon species, sex and physiologic state.

Energy

Energy is required primarily in making (anabolism), and sometimes breaking (catabolism), chemical bonds in metabolic processes which include muscle contraction, nerve impulses, and tissue synthesis.

Ruminants derive energy primarily from plant carbohydrates, lipids and proteins, though not all of it is captured in a form usable to the animal. The energy value of feeds and forages can be expressed in many ways. Net energy is the amount of energy available for maintenance and production.

Minerals

Minerals are required for tissue growth, repair, and the regulation of body functions. Twenty-two elements are important for animal nutrition and are normally categorized into two groups. Those required in relatively large amounts (grams/day) are refered to as "Macro" and include Na, Cl, Ca, P, Mg, K and S. Those required in small amounts are refered to as "Micro" (milligrams/day or less). They include Cu, Zn, Mn, Mo, Se, I, Fe, Co, F, V, Sn, Ni, Cr, Si, As (Little, 1985). Individual minerals have special functions as components of certain tissues or as cofactors for certain metabolic reactions.

Vitamins

Vitamins are "cofactors" or catalysts in metabolic reactions, in that they do not appear in the products of reactions, but must be present for reactions to occur. All vitamins or their precursors must be absorbed from the digestive tract as they cannot be synthesized by mammalian tissue. With few exceptions, vitamin A is the only vitamin that is likely to limit the productivity of grazing ruminants. Vitamin A does not occur in plant tissue, but is synthesized by the animal from chemical precursors in plants, mainly beta carotene, but other plant pigments as well. Vitamin A deficiency is most likely to develop during an extended period of low temperature and/or drought when green plants are unavailable to the animal.

2.3.3. Species

Not all woody perennials available in the tropics and subtropics are suitable for fodder (see section 2.5). A number of species have been identified and occur naturally or are widely cultivated in many ecological zones. A few of these species, the majority of which are legumes, have proved successful and have been introduced for wider adaptation throughout the tropics. Some introduced tree legume species such as *Gliricidia sepium*, *Leucaena leucocephala*, *Sesbania grandiflora*, *Albizia falcataria* and *Calliandra calothyrsus* have shown the greatest potential as a forage resource for increased animal production in Indonesia (Panjaitan, 1988).

In attempts to widen the genetic base of browse, recent research has indicated the existence of many more potential fodder trees and shrubs (especially those indigenous to particular regions) that are traditionally used by local communities. Comparative studies into the fodder potentials of indigenous as opposed to exotic species are being carried out to address potential problems that would result from continued dependence on the few known species. Out of eight indigenous and two exotic species evaluated for browse in southeastern Nigeria, mbom (Alchornea cordifolia) was highest in dry matter production, while Leucaena leucocephala and Glyphaea brevis were the most prefered by goats (Larbi et al., 1993b).

Though cultivated browse species are mainly members of the family Leguminosae, experience of cattle owners and researchers has shown that some non-legumes may have tremendous potential as well. Observations of browsing cattle and interviews with pastoralists revealed that 39 plant species identified as browse in central Nigeria alone belonged to several different plant families and varied greatly in appearance (Bayer, 1990). They included semi-woody legumes such as Adenodolichos paniculatus, twiners such as Mucuna poggei, large trees such as the savanna mahogany (Khaya senegalensis) and even a member of the graminae family (a bamboo species: Oxytenanthera abyssinica). Some species such as Tamarindus indica and Faidherbia albida were observed closer to the humid areas, but are usually more prominent in the drier parts of Africa.

Since there are many species of fodder trees and shrubs, it is impossible to list all of them, and only examples are given here. In the Guinea and Sudan zones of Northern Nigeria, nutritious pods and seeds of the locust bean trees, Parkia clappertonia and Parkia filicoidea are utilized as livestock fodder and human food in the dry season when other supplies are scarce in the region (Ichire, 1993).

Indigenous vegetation providing foliage or fruit to supplement intake from pasture in Australia include mulga (Acacia aneura), saltbrush (Atriplex spp.) and kurrajong (Brachychiton spp.) (Pratchett, 1989). Useful introduced species include tagasaste (Chamaecytisus palmensis), paulownia (Paulownia spp.), poplar (Populus spp.) and sub-tropical shrubs such as leucaena (Leucaena leucocephala), carob (Ceratonia siliqua) and honey locust (Gleditsia triacanthos) (Wilson, 1969). Of these species, only leucaena (Leucaena leucocephala) and tagasaste (Chamaecytisus palmensis) have achieved any degree of commercial acceptance (Lefroy et al., 1992). Agroforestry with red calliandra (Calliandra calothyrsus) in Bogor, Indonesia provides favourable economic opportunities, particularly as a source of fuelwood, feed for bee keeping and cattle fodder (Satjapradja and Sukandi, 1981).

2.3.4. Benefits to livestock

Trees and shrubs form a significant portion of the livestock diets in many tropical and subtropical zones. This is more so in arid and semi-arid areas compared to humid and subhumid climates, where dry seasons are relatively shorter and viable alternatives to browse are available (Le Houerou, 1987). Trees and shrubs in the silvopastoral production systems of Africa constitute the basic feed resource of more than 500 out of 660 million head of livestock (FAO, 1985; cited by Le Houerou, 1987). When carefully fed to livestock, tree fodder has been shown to improve feed quality, availability, intake, digestibility, and animal production per se (Lefroy et al., 1992; Kang et al., 1991).

Quality and availability of feed resource

In addition to their relatively low nutritional status, grasses are adversely affected by drought and are not available during prolonged dry seasons. Trees and shrubs explore deep soil layers for moisture and nutrients and can better withstand dry periods. Some of these species, the legumes in particular, are excellent sources of high quality green fodder during periods of nutritional stress. In the arid and semi-arid silvopastoral systems of Africa, woody species are the only source of protein, carotene and phosphorus for livestock and wildlife during the long dry season (Le Houerou, 1987).

Effect on food intake and digestibility

The quantity of net energy absorbed each day is the main factor controlling the growth rate and milk production in ruminants. The intake of net energy is controlled by the quantity of food energy eaten (intake), the proportion of each unit of feed that is digested (digestibility) and the efficiency of utilization of the products of digestion (Minson, 1981). Intake is determined by, among other things (sward structure, availability, type of animal, etc.), the feed quality. The appetite of animals, for example, is depressed by protein deficiency when the crude protein content of feeds falls below 6-8%, a common feature in tropical grass pastures (Minson, 1981).

The availability of energy in forage is usually measured as dry matter digestibility (DMD), which is closely related to other energy parameters: organic matter digestibility, digestible organic matter, total digestible nutrients, digestible energy, and metabolizable energy (Minson, 1990; Huston and Pinchak, 1991). Digestion of forage organic matter is dependent, among other things, on the activities of rumen micro-organisms. These organisms require a supply of protein, amino acids or their precursors, including nonprotein nitrogen and sulfur (Hungate, 1966). Phosphorus, in addition to being important for skeletal formation, is also essential for proper functioning of rumen micro-organisms, especially those which digest plant cellulose (McDowell et al., 1983). Deficiency of these substances may limit digestibility.

Apart from chemical treatment of forage (e.g., with NaOH, ammonia or Magadi soda), and plant breeding, voluntary intake and digestibility can be improved cheaply and safely by including small quantities of high protein legumes as feed supplements (Minson, 1990). Rees et al. (1974) reported large increases in the appetite of sheep when as little as 10% legume was added to a grass diet containing 3.6% protein. At ILCA in Addis Ababa (Butterworth and Mosi, 1985), average dry matter digestibility of the crop residue (oat, wheat, teff and maize straws) when fed alone was 48.3% and the intake was 49.8 g/(kg liveweight)$^{0.75}$. The provision of an average of 45% legume (Trifolium tembense) hay improved digestibility to 65% and intake by 16% to 58 g/(kg liveweight)$^{0.75}$. Digestibility of nitrogen and energy were improved in all cases, while the cell wall constituents, ADF, NDF, cellulose and hemicellulose, were each improved in at least one type of crop residue. Where both the grass and the legume component of a mixture contains sufficient crude protein and minerals, voluntary intake is linearly related to the proportion of legume in the mixture and there is no synergism between the two species (Moseley, 1974; cited by Minson, 1990). Synergism will occur where one species in a mixture is deficient in an essential nutrient and the other species contains a high level of this nutrient (Minson, 1990).

The effects of legume supplementation on forage intake and digestibility have also been demonstrated by other research workers. Supplementing a basic diet of Pennisetum purpureum with increasing levels of Erythrina abyssinica leaves resulted in reduced intake of the grass, but increased total organic matter intake in both species (Larbi et al., 1993a). Phiri et al. (1992) observed significant increases in total dry matter intake, diet dry matter digestibility, and diet organic matter digestibility when maize husks were fed together with individual and mixed supplements of leucaena and calliandra. Bamualim _et al_. (1984) reported significantly greater organic matter intake when spear grass was supplemented with fresh leucaena leaf. Van Eys _et al._ (1986) observed no difference among diets in total dry matter intake, intake of cell wall constituents, and digestibility when foliage from gliricidia, leucaena, and sesbania were used as supplements to Napier grass for growing goats. No significant differences in dry matter intake were observed when cross-bred heifers were fed _Gliricidia maculata_ leaves (Dharia _et al._, 1987).

Effect on production

Foliage from multipurpose trees and shrubs can be fed either as sole feeds or as supplements to conventional livestock diets, though the former approach appears to have been accepted to a lesser extent. The increased animal productivity achieved when tree foliage is included in the diet is likely due, at least in part, to high intake of N and energy resulting from the increased total organic matter intake. Cattle feeding on leucaena near Brisbane in Australia gained an average of almost 1 kg each day for more than 200 days (NAS, 1979). Live weight gains of bull calves were significantly higher in animals fed leucaena _ad lib_. than in those fed a restricted amount of the forage (Sobale _et al_., 1978). In central Java (NRC, 1983), dried calliandra leaves are often pulverized, pelleted (either alone or mixed with leucaena leaves) and used for feed on Javanese chicken farms, while calliandra leaf meal has successfully been used as chicken feed in amounts up to 5%. No significant differences in body weight gains were observed when cross-bred heifers were fed Gliricidia maculata leaves, but the cost of feeding was reduced (Dharia et al., 1987).

Browse supplementation is popular and widespread among small-scale livestock owners in the tropics. A feed consisting of Leuçaena leucocephala alone caused loss of hair in sheep within 10 days, but combination with Setaria sphacelata grass up to about 60% shrub (DM) caused no ill effects even after 2 months (Joshi and Upadhyaya, 1976). The suggestion by Joshi and Upadhyaya (1976) that leucaena can be used as animal feed when fed in combination with any ordinary fodder is applicable to some other woody perennials as well. Liveweight gains of sheep and goats increased linearly with increasing levels of Erythrina abyssinica leaf supplementation (Larbi et al., 1993a). In sheep trials using mixed diets of grass and calliandra, best growth was obtained with 40-60% calliandra (NRC, 1983). In Zambia, goats feeding on maize husks supplemented with leucaena, calliandra and leucaena plus calliandra had significantly higher liveweight gains than the control (Phiri et al., 1992).

In Natal, goats offered 100% elephant grass lost weight at the rate of 19 g/day, but the trend reversed with increasing leucaena intakes, reaching a maximum liveweight gain of 43 g/day when the forage was provided ad lib (Yates and Panggabean, 1985). Flores et al. (1979) reported a significant increase in milk production and quality when leucaena was fed to cows selecting a Rhodes-grass (Gloris gayana cv. Pioneer) diet containing 18.2% crude protein. When foliage from gliricidia, leucaena and sesbania were used as supplements to Napier grass for growing goats, average daily weight gain (21 g/day) was significantly higher than for the control (-1 g/day) (Van Eys et al., 1986). At the Tumbi Research Institute in Tanzania, kids grazing on natural pasture showed higher liveweight gains than the control when provided fodder supplements from each of three multipurpose tree and shrub species (Cajanus cajan, Leucaena leucocephala and Sesbania sesban) (ICRAF, 1991).

On the Kenya coast, an increase of 37% in milk production was realized by a farmer who was feeding his dairy cows a mixture of leucaena and Napier grass in his zero grazing unit (Getahun and Reshid, 1988). Research in Rwanda has demonstrated that the weight gain of stall-fed livestock can be increased 60% (from 14 to 16 g/day to 20 to 30 g/day) by supplementing a ration of grasses with leaves from commonly used agroforestry species (Nyirahabimana, 1985; cited by Kidd and Pimentel, 1992). A farmer who substituted a mixture of calliandra/leucaena leaves and stems for dairy meal reported no decline in milk production after one week of daily feeding. He was using 2 kg of this mixture together with 4 kg of Napier grass on a Friesian cow (Getahun and Reshid, 1988).

2.4. Management for fodder

From the foregoing, there is no doubt that tree fodder, when provided as supplements to grasses, and sometimes when fed alone, can contribute favourably to animal performance. To sustain productivity and ensure quality and availability of fodder, appropriate management strategies must be identified and applied. Management options vary with the environment, plant species, growth characteristics, and planting arrangements.

2.4.1. Grasses

Free grazing and regular burning are two management practices applied to maintain productivity and quality of fodder in tropical grass pastures. The high protein levels of *Cynodon dactylon* and a roadside mixture of *Cynodon dactylon* and *Digitaria scalarum* were attributed to heavy grazing which maintained quality by preventing the production of substantial structural carbohydrates (Sands *et al*., unpublished data, 1982).

Grazing animals are selective and usually go for the young nutritious plants or younger top portions of the plant. In systems where land use is intensive and free movement of livestock is restricted, these practices are no longer applicable and cut-and-carry practices are more appropriate. As grasses mature, they become more stemmy and poorer in quality because there is an increase in the proportion of fibre and a decrease in the protein content, voluntary intake, and dry matter digestibility (Minson, 1981). The voluntary intake of _Digitaria_ _decumbens_ decreased with increased cutting interval (Chenost, 1975). The dry matter digestibilities (_in vivo_) of five species of tropical grasses, each cut as 1-month regrowths, were higher than when cut as mature regrowths (Minson, 1972). Consequently, the most effective way of maintaining quality is to maintain forage at a young vegetative stage of growth by regularly cutting or grazing at short intervals (Minson, 1990).

Grasses readily sprout when cut back and this is usually done at ground level (Otieno _et al._, 1991; ICRAF, 1991). There is very little information in the literature which demonstrates the productivity of grasses at higher cutting heights; however, it is expected that the practice may increase the presence of injurious and low-quality woody parts in the swards.

2.4.2. Trees and shrubs

In some silvopastoral and agrisilvopastoral systems of the arid and semi-arid tropics, trees and shrubs may be left to grow freely to provide seeds and pods for fodder or may be pollarded regularly to provide nutritious green foliage. The demand for browse increases during the dry season, when other forage is scarce, and diminishes during the rainy season. In a study of grazing activity and forage resource use by settled Fulani cattle herders in the subhumid zone of Nigeria, it was found that cattle in a grazing reserve spent more than 10% of annual feeding time browsing, with a peak of almost 30% of monthly feeding time in the late dry season (Bayer, 1990). In more intensive land use systems of the humid and subhumid areas, cultivated fodder trees and shrubs are integrated into arable farming systems and may be established as pure stands in pastures, pure hedgerows in agricultural land, or as tree-grass mixtures on hedgerows. Regular coppicing at lower cutting heights is the most common practice. Management practices revolving around cutting heights, frequencies, fertilization, planting densities, etc. are paramount to maintain high productivity, sustainability and quality.

Researchers have reported varying forage yield and quality when different cutting frequencies are imposed on fodder trees and shrubs. Increased forage yields at lower cutting frequencies and higher percent forage fractions at higher frequencies have been reported for leucaena (Guevarra et al., 1978). Working on subabul (Leucaena leucocephala) and hybrid Napier, Maclaurin et al. (1982) found a harvest interval of six weeks to be significantly better in productivity than four or eight week intervals. Both leucaena and calliandra gave a higher leaf yield when the cutting interval was 12 weeks as compared to 6 weeks (Ella et al., 1989). Maximum forage yield of Leucaena leucocephala was obtained with a 40 days interval compared to 60 and 120 days intervals (Pathak et al., 1980). Reduced productivity due to more frequent cutting has been attributed to the increased number of recovery phases (Karim et al., 1991). Whiteman and Lulham (1970) suggested that the severe check in growth caused by frequent cutting results in mobilization of sugars and amino acids from the roots to support development of new leaves, thus severely suppressing root formation, and further limiting the production of subsequent foliage. Too frequent cutting (30-day intervals), especially of short stools, is not recommended, not only because of lower dry matter yields, but particularly because it leads to accelerated depletion of soil nutrients, a decline in vigour with time and the eventual death of the trees (Hill, 1970; Osman, 1980). On the other hand, cutting intervals that are too long may result in higher total N yield, but poor quality forage due to aging (Tangendjaja et al., 1986).

At cutting heights not exceeding 50 cm, no significant differences in yield are expected in Leucaena leucocephala (Karim et al., 1991; Sampet and Pattaro, 1987; Gutteridge, 1988). Above this, however, there is a general tendency for the dry matter yields of Leucaena to increase with cutting height at least up to 1.5 m (Karim et al., 1991; Turkel and Hatipoglu, 1989; Maclaurin et al., 1982; Pathak et al., 1980; Herrera, 1967) except for a few isolated cases (Takahashi and Ripperton, 1949). Similar observations have been made for Calliandra calothyrsus (Otieno et al., AFRENA Maseno draft report, 1992). These observations can be attributed to more sprouting space and increased number of branches per tree at higher cutting heights. Pathak et al., (1980) reported significantly more branches at higher cutting heights than at lower ones. This trend is not clearly maintained above these heights. Catchpoole and Blair (1990) found that leaf production was unaffected by cutting at heights ranging from 1.5 m to 2.5 m above the soil surface. As is true with cutting interval, N yields per tree increases with increasing height, but overall nitrogen percentages are not affected (Karim et al., 1991).

Higher plant densities result in higher total production. By increasing the density of plants from 12,346 to 444,444 plants/ha, significantly greater production of the edible dry matter of leucaena was obtained (Maclaurin et al., 1982). At the highest density of leucaena (15 x 50 cm), slightly higher percent forage fractions were obtained compared to lower densities (Guevarra et al., 1978). Ella et al. (1989) reported increasing leaf and wood dry matter production up to 40,000 trees/ha, but observed and postulated that yields would only increase marginally at higher densities. This is because as number of plants per unit area increases, competition for moisture, nutrients, space, etc., starts to set in and the potential vigour of individual plants begins to become limited. Though they recorded higher total forage yields at higher plant population densities, Pathak et al. (1980) observed a relatively slight increase in number of branches per plant, which was not significant.

Fertilization has a positive effect on productivity and value of forage. Fertilization causes fast growth and quick supply of required fodder. From an experiment carried out to study the productivity of grass-sesbania intercrop as compared to grass-nitrogen interactions, Mathuva et al. (1987) reported that fertilizer application gave the highest dry matter yield, while the intercropped grass gave DM above that of pure unfertilized grass. The fast growth also enables harvesting at an early age when the forage is highly nutritious. Nitrogen fertilization increased production to a greater extent with a shorter cutting interval (Maclaurin et al., 1982).

2.4.3. Alley farming

Recently, the International Livestock Centre for Africa (ILCA) has extended the concept of alley cropping to include animal production (Okali and Sumberg, 1985). In this system, termed alley farming, some portion of the tree foliage is utilized as fodder. Alley farming is seen to be more beneficial to the small scale African farmers, compared to many conventional agricultural methods (Cashman, 1986).

In order to maintain crop productivity and avoid deterioration in soil fertility, proper allocation of the foliage is mandatory. Okali and Sumberg (1985) proposed that 75% of available tree foliage should be applied to the soil as mulch, while 25% should be used as animal feed. An economic analysis of alley farming in Western Nigeria showed that at low crop yield levels, feeding ruminants with part of the foliage from hedgerow intercropping was profitable (Jabbar et al., 1992).

2.5. Limiting factors

The presence of toxic substances (D'Mello, 1982; Minson and Hegarty, 1984; Onwuka, 1992) and other undesirable properties has led to animal health problems when tree and shrub forages are fed as sole feeds. The effects of toxicity are not apparent in free ranging systems because instinct regulates intake of injurious species (Semenye, 1990). Semenye also noted that food selection is limited during drought and in cut-and-carry systems. Care must be taken when browse is being administered to livestock under these conditions. The non-protein amino acid, mimosine, beta-[N-(3-hydroxy-4-oxopyridyl)]-alpha-amino propionic acid, occurs naturally in *Leucaena leucocephala*. Mimosine content in leucaena declines with age (Tangendjaja et al., 1986). It is less than 1% (dry matter) in stems; and ranges from 1% in old leaves to 9.6% in shoot tips (Jones, 1979; Pratchett et al., 1991; Lowry et al., 1983; Guevarra et al., 1978; Joshi and Upadhyaya, 1976)).

Guevarra et al. (1978) observed no significant differences in mimosine content between cultivars, spacings and cutting regimes of *Leucaena leucocephala*. The toxicity of mimosine has been attributed to its metabolic product, 3-hydroxy-4-(1H) pyridone (DHP), a potent goitrogen which is produced during microbial degradation in the rumen (Hegarty et al., 1976). DHP causes goitre, alopecia, loss of appetite, loss of body weight and sometimes death (Jones, 1979; Hegarty et al., 1964; Jones and Megarrity, 1986; Semenye, 1990).

The earlier hypothesis that goats fed on leucaena alone since birth would develop mimosine and DHP-degrading microbes was not supported by research conducted in western Kenya (Semenye, 1990). A bacterium capable of degrading DHP has recently been successfully transfered from Hawaiian goats to Australian ruminants (Jones and Megarrity, 1986), but has not found its way into Kenya. However, according to Jones (1979) and NAS (1977), no health problems are expected if leucaena forms less than 30% of the ruminant feed. The objectionable odour that may sometimes occur in the milk of leucaena-fed cows disappears on boiling and pasteurizing and can be avoided entirely by eliminating leucaena from the animals' diets for 2 hours before milking (NAS, 1977).

No toxic substances have been identified in calliandra (Calliandra calothyrsus). However, the condensed tannin content in calliandra is high (11.07%) compared to that in Leucaena leucocephala (4.32%) (Ahn et al., 1989). Tannins are water-soluble phenolic compounds found in legumes and oilseeds. They have molecular weights between 500 and 3000; they give the usual phenolic reactions, but also have special properties such as the ability to precipitate alkaloids, gelatin and other proteins (Gupta and Halsam, 1979). Their presence in legumes, and the capacity of tannins to precipitate forage proteins and render them unavailable to the rumen microbes, has attracted considerable attention in recent years (Barry and Reid, 1984). Ahn et al. (1989) showed that calliandra and three other species (Acacia angustissima, Acacia aneura and Albizia chilensis) which showed high tannin content with either vanillin-HCl or methanol-HCl methods of analysis exhibited low nitrogen digestibilities. The concentration of tannin, total phenol, flavonol glycoside and neutral detergent fibre in L. leucocephala did not undergo significant changes over 10 weeks of leaf growth (Tangendjaja et al., 1986).

Problems related to high tannin concentrations are still prevalent, but suitable strategies to counter these are being sought and evaluated. Polyethylene glycol (PEG), for example, forms a soluble complex with condensed tannins (Jones and Mangan, 1977) and can be used either to prevent protein reacting with condensed tannins or to displace protein from pre-formed tannin-protein Complexes (Barry and Reid, 1984). This principle was used by Pritchard et al. (1985) to displace tannins from tannin-protein complexes and improve nitrogen digestibility in mulga (Acacia aneura).

3. MATERIALS AND METHODS

3.1. Study area

The study was done at the National Agroforestry Research Centre in Maseno, Western Kenya. Maseno (34 35' East and 0' North) is located 30 km northwest of Kisumu in Nyanza province. It has an altitude of between 1,500 m and 1,600 m above sea level.

The bio-physical and socio-economic factors operating in and around Maseno are comparable to those in many other highland areas of Western Kenya. The long-term mean annual rainfall is about 1,750 mm. Total rainfall received during the study period was 2,995.2 mm. The distribution is bimodal with the long rainy seasons occuring between March and June, and the short rains coming between September and November (see Fig. 1). Average maximum day and average minimum night temperatures between May '91 and November '92 were 26.6 ^{0}C and 17.8 ^{0}C respectively. These were comparable to the respective average annual maximum day and average annual minimum night temperatures of 28.5 ^{0}C and 15.6 ^{0}C in 1990, and 27.3 ^{0}C and 17.2 ^{0}C in 1991.

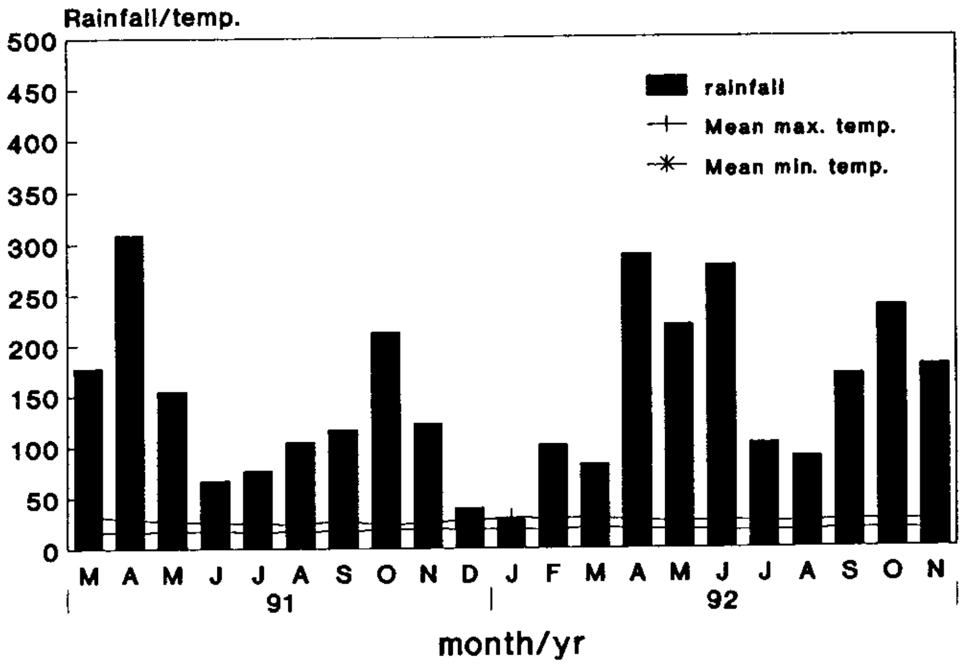

Fig. 1. Average monthly rainfall and temperatures for Maseno research station (May '91-Nov. '92)

Predominant soil types vary with the position in the landscape (uplands, ridges and valley bottoms) (Heineman et al., 1990). The soils around the research site are all based on Nyanzan basalt, granite and phenolitic lavas as the main parent materials. The major soil types are ferralsols, acrisols and lixisols (tropical luvisols) (see appendix 10).

Population densities of over 1,000 persons/km^2 are found, especially in some parts of South and East Bunyore locations. The natural vegetation has been replaced by cultivation and settlement. A dispersed cover of indigenous and exotic tree species found along roads and in and around farms includes Markhamia spp., Sesbania spp., Cassia spp., Agrocarpus spp., Cuppressus spp., Eucalyptus spp., Pinus spp. and Casuarina spp. Farm sizes are reduced (sometimes to less than 0.5 ha per household) to the extent that they can no longer support local families, which are often 6 to 10 people per family. The land use system is foodcrop-based. The main food crops are maize, beans, bananas and vegetables. Others include sweet potatoes, cassava, yams and fruits. Annual food crops are sown twice a year (April and September) to coincide with the rainy seasons. Small-scale production of coffee and tea is done by a few farmers especially around the neighbouring Vihiga and Maragoli divisions. The most important animals are cattle, but goats, sheep, pigs, poultry and bees are also kept.

3.2. Site, experimental design and treatments

The experimental site was formerly under small bushes and couch grass (Digitaria scalarum). The slope is about 5% and is tilted both in north-south and west-east direction. Soils vary from clay loam to sandy clay, with a depth exceeding 1.5 m and a reddish brown colour. Chemical analysis of soil samples taken in 1988 (Otieno et al., 1991) gave the following results:

Average soil pH (in $CaCl_2$; 1:2.5 ratio) 4.42*

Organic carbon (%) 0.93

Total available Nitrogen (%) 0.11

Phosphorus (by Bray no. 2 method) 13.4

Sodium (me/100 g) 0.67

Potassium (me/100 g) 0.71

* increase by 0.5 points to obtain pH in water (1:2.5) values

The experiment was laid out as a randomized complete block design. The four blocks were field bunds constructed along the contour 3-4 m from each other down the slope. Each block had replications of five treatments, each of which was made up of two parallel lines of trees, grass or their shrub-grass combinations (see appendix 2). Plot size was 4 m long and 1 m wide. The two lines were 4 m long and 0.5 m apart. The within-row spacing for trees was 0.25 m, while that of grass was 0.125 m.

The various planting arrangements (treatments) were: 1) pure leucaena (Leucaena leucaena, provenance: Melinda, Belize); 2) pure calliandra (Calliandra calothyrsus, Guatemala); 3) pure Napier grass (Pennisetum purpureum, Vet. farm, Maseno); 4) leucaena + Napier; 5) calliandra + Napier.

3.3. Plant species

Three plant species, one grass and two shrubs, were used. Napier grass (Pennisetum purpureum) (Judd, 1979) is a perennial native to tropical Africa and has been introduced to many parts of the tropics and sub-tropics. It is propagated by stem cuttings and grows best on deep porous soils of moderate to fairly heavy texture. It occurs naturally in areas with not less than 40 inches of rainfall. Its fibrous root system can reach 4.5 m below ground. It is a major fodder resource in western Kenya and is grown by many farmers on terrace bunds or fodder banks, mainly for cut-and-carry purposes.

Leucaena (Leucaena leucocephala) (NRC, 1984) is a fast growing multipurpose shrubby species native to central America, but has been introduced to the vast majority of tropical and subtropical countries. It withstands large variations in rainfall, sunlight, salinity and terrain, with reduced vigor at high elevations, low soil pH and prolonged drought. Leucaena grows best where annual rainfall is 1,000-3,000 mm and survives dry seasons lasting 8

3.4. Establishment and management

The experiment was established in 1988 (Heineman et al., 1990). The area between bunds was utilized to grow food crops. Trees and/or grasses were planted in staggered lines in order to increase the effectiveness of the planted combination on the bund against soil erosion. Trees received 25 g of diammonium phosphate (DAP) (4.5 g of N and 11.5 g P_2O_5) at planting. The pure tree and grass treatments, together with the tree component in the mixed treatments, were established in April. The grass component in the mixed treatments was established between August and November of the same year.

Trees were managed as hedges and were cut back to 0.5 m in height. Grasses were cut back to ground level. Cutting frequency and timing of cutting between treatments varied initially (between August 1988 and January 1989) depending on the coppice regrowth. From April 1989 on, all treatments were cut on the same date and this was carried out at least twice every growing season at the time of sowing the food crop and around two months later. From May 1991 on (when cutting back had already been done 16 times), hedgerows were strictly harvested at intervals of 2 months, marking the beginning of this study.

3.5. Biomass measurements, sample collection and weather records

At harvesting, only the centre 2 m length of each line was considered. The outer 1 m length on both sides of each line was excluded in order to avoid border effects. The shrubby species were separated and measured as leaf and stem fractions. This ensured that quantitative data were collected specifically on edible parts and also provided the possibility for determining the leaf/stem ratios. At the same time, approximately 500 g of thoroughly mixed samples of fresh leafy material were collected and oven-dried at 60 ^{0}C for 48-72 hrs in order to calculate the proportion of dry matter (DM%).

Dried samples were ground to pass a 1 mm sieve, packed and transported to the University of British Columbia, Canada for nitrogen, mineral and acid detergent fibre (ADF) analysis. Daily rainfall and temperature records were kept using the meteorological equipment available at the Maseno Agroforestry Research Centre tree nursery. The nursery is located about 200 m from the experimental site.

3.6. Analytical procedures

3.6.1. Nitrogen and minerals

Before the inorganic constituents of plant substances can be determined, it is generally necessary to destroy the organic matter. This was achieved in this experiment by using the wet oxidation procedures outlined by Parkinson and Allen (1975).

Exactly 1.000 g samples of oven-dried foliage material were weighed into 100 mL digestion tubes. Five mL conc. sulfuric acid was added and immediately mixed with a vortex mixer. Four mL of lithium sulfate- peroxide mixture (made by dissolving 0.21 g selenium powder and 7 g lithium sulfate crystals in 175 mL 30% H_2O_2) were added in 1 ml aliquots while applying discontinuous heating. After heating on a block for 1.5 h at 360 ^0C, 0.5 mL of H_2O_2 was added, and the tubes were then returned to the block for 0.5 h. The later step was repeated. Another 0.5 mL H_2O_2 and 10 more minutes of digestion were added whenever digests had not attained the expected pale yellow or milky white colour. The resultant digests were cooled to room temperature, made up to 100 mL, transferred to 125-mL plastic bottles and stored in a refrigerator (about 5 ^0C) to await analysis.

Appropriate dilutions were made before chemical analysis. Nitrogen (N) and phosphorus (P) were determined with a Lachat autoanalyser.

Calcium (Ca), magnesium (Mg), potassium (K), zinc (Zn) and copper (Cu) were determined by means of an atomic absorption spectrophotometer. All analyses were read in mg/L and most were calculated and reported in percentages (cg/g). Elements that were relatively low in concentration (Zn and Cu) are reported in mg/kg (ppm).

With the knowledge that crude protein contains about 16% nitrogen (Schneider and Flatt, 1975), the nitrogen contents of the samples were multiplied by 100/16 = 6.25 to estimate the crude protein contents.

3.6.2. Acid detergent fibre (ADF)

The micro-digestion procedure of Waldern (1971) was utilized. Approximately 0.35 g of samples previously oven-dried at 105 ^{0}C were accurately weighed into 50 mL digestion tubes. Thirty-five mL of acid detergent solution [28 mL H_2SO_4/L of deionized water, plus 20 g Hexadecyltrimethylammonium Bromide (CETAB)/L of solution] and 1 mL of Decahydronaphthalene (Decalin) were added to each tube. Each tube was covered with a large marble and the contents heated in a digestion block at temperatures up to 104 ^{0}C for exactly 1 hour. Contents were filtered under suction and washed twice each with hot demineralized water and acetone. The residue was oven-dried at 105 ^{0}C, desiccated and weighed. Corrected ADF was calculated by subtracting acid-insoluble ash from the uncorrected

ADF value as follows:

$$\%ADF_{(uncorrected)} = \frac{(\text{crucible} + \text{dry residue}) - \text{crucible wt.}}{\text{Dry sample wt.}} \times 100$$

The ash that had not disolved in acid (mainly silica) was determined by heating the residue in a muffle furnace at 475 ^{0}C for at least 2 hrs.

$$\%\ \text{acid-insoluble ash} = \frac{(\text{crucible} + \text{ash}) - \text{crucible wt.}}{\text{dry sample wt.}} \times 100$$

Corrected ADF % = ADF % (uncorrected) - % acid-insoluble ash

3.7. Statistical procedures

All data were originally stored in Quattro (Borland International, 1993) and later imported into SAS 6.04 (SAS, 1985). An arcsine transformation was performed to improve normality of those figures expressed in percentages. Bartlett's test (Neter and Wasserman, 1974) was utilized to test homogeneity of variances. Log transformations were performed on data where this assumption was violated. Cu met this assumption without any transformation. DM% and CP% met the assumption after an arcsine transformation, while

Ca%, Mg% and K% did so after both arcsine and log transformations. Fresh leafy biomass, dry matter, P%, Zn and ADF% did not meet the assumptions even after the above transformations, and their results should be treated cautiously.

Where season*treatment interactions were not significant, analysis of variance using the general linear models procedure (GLM), was done for the upper and lower experimental rows combined and separately for all harvest seasons (Model: $Y_{ij} = u + S_i + T_j + E_{ij}$), where Y_{ij}=observation, u=population mean, S_i=effect of season, T_j=treatment effect and E_{ij}= error. Where season*treatment interactions were significant, separate analyses were done for each season (Model: $Y_{ij} = u + T_j + E_j$). When the F test was significant (α=0.05), means were compared by setting up and solving orthogonal contrasts at the α=0.05 significance level.

Separate analyses were done (treating rainfall as a covariate) to eliminate effects associated with the total rainfall received during a growth period. Since temperatures in Maseno do not vary substantially from time to time (Fig. 1), rainfall was assumed to be the main factor determining seasonal effects. Linear correlation analyses were done to determine the strength of relationship between rainfall and the biomass and/or nutrient data. The closeness of the relationship was expressed as the linear correlation coefficient (r).

4. RESULTS

4.1. Leaf/stem ratios

Table 1 shows the proportion of fresh leaf and wood fractions for each of the two shrubby species over 18 months at two-month cutting intervals beginning in May, 1991. For ease of reference, harvesting dates are numbered as shown in Appendix 1. Leucaena leucocephala had an average of 73.8% leaves and 26.2% wood; Calliandra calothyrsus was 70.9% leaves and 29.1% wood. Leaf/stem ratios were consistently higher for leucaena than for calliandra 89% of the time, averaging 2.96 and 2.58 respectively. Ratios obtained at the first cutting were similar to those obtained at the same time the following year, and were even higher at the end of the study period (November, 1992).

Table 1. Average Leaf/stem ratios for _Leucaena leucocephala_ and _Calliandra calothyrsus_ over 18 months.

Harvesting Date	LEUCAENA			CALLIANDRA		
	% Leaves	% Stems	Ratio	% Leaves	% Stems	Ratio
1	67.8	32.2	2.11	64.9	35.1	1.85
2	-	-	-	-	-	-
3	78.9	21.1	3.74	78.2	21.8	3.59
4	78.2	21.8	3.59	76.8	23.2	3.31
5	71.3	28.7	2.48	70.8	29.2	2.42
6	71.1	28.9	2.47	69.4	30.6	2.27
7	69.3	30.7	2.26	66.0	34.0	1.94
8	81.0	19.0	4.26	59.7	40.3	1.48
9	68.5	31.5	2.17	75.6	24.4	3.10
10	77.9	22.1	3.52	76.3	23.7	3.22
Average	73.8	26.2	2.96	70.9	29.1	2.58

4.2. Leafy biomass yields

4.2.1. Fresh biomass yields

The mean fresh and dry leafy biomass yields of the three fodder species and their combinations are presented in Table 2. Analysis of variance tables and the results of mean separations are provided in Appendices 7 and 8, and 9 respectively. Productivity from the pure treatments could be ranked from the highest to the lowest in the following order: *Pennisetum purpureum*, *Leucaena leucocephala* and *Calliandra calothyrsus*.

The mixed treatments gave significantly higher total fresh biomass yields than the pure shrub treatments (p=0.0001). The pure grass treatment had significantly higher fresh biomass yields (p=0.0001) than either of the shrubby species, but was significantly lower (p=0.0106) than the shrub-grass mixtures. Biomass yields from the two shrubs were not significantly different (p=0.6889). Biomass yields from three harvests in the first year were significantly (p=0.0025) higher than those from corresponding harvest times in the second year. Fresh biomass was not significantly correlated with rainfall (Table 4). When treated as a covariate, the latter's effects were found not to be significant (p=0.1268).

In figures 2-21, lines are drawn between data points, not to imply interpolated linear trends, but to facilitate discrimination of data sets when reading the graphs. As illustrated by Fig. 2, the pure grass treatment declined in productivity over time, while the pure shrub treatments maintained relatively uniform productivity. It is suggested that the sharp drop associated with productivity in the mixed treatments may be due to the performance of the grass component in the mixture.

Table 2. Mean fresh and dry leafy biomass yields (kg/100m) of <u>Leucaena leucocephala</u>, <u>Calliandra calothyrsus</u> and <u>Pennisetum purpureum</u> over 18 months.

TREATMENT		FRESH LEAFY BIOMASS			DRY LEAFY BIOMASS		
L1	L2	L1	L2	TOTAL	L1	L2	TOTAL
Leuc.	+ Leuc.	54.53	59.06	113.59	17.06	17.59	34.65
Call.	+ Call.	39.60	36.35	75.95	14.62	13.48	28.11
Napier	+ Napier	125.21	98.75	225.30	25.54	19.47	45.86
Napier	+ Leuc.	222.89	82.62	305.51	45.46	20.94	62.40
Napier	+ Call.	222.81	58.49	281.30	46.58	21.85	68.32

L1 = upper line of treatment   L2 = Lower line of treatment

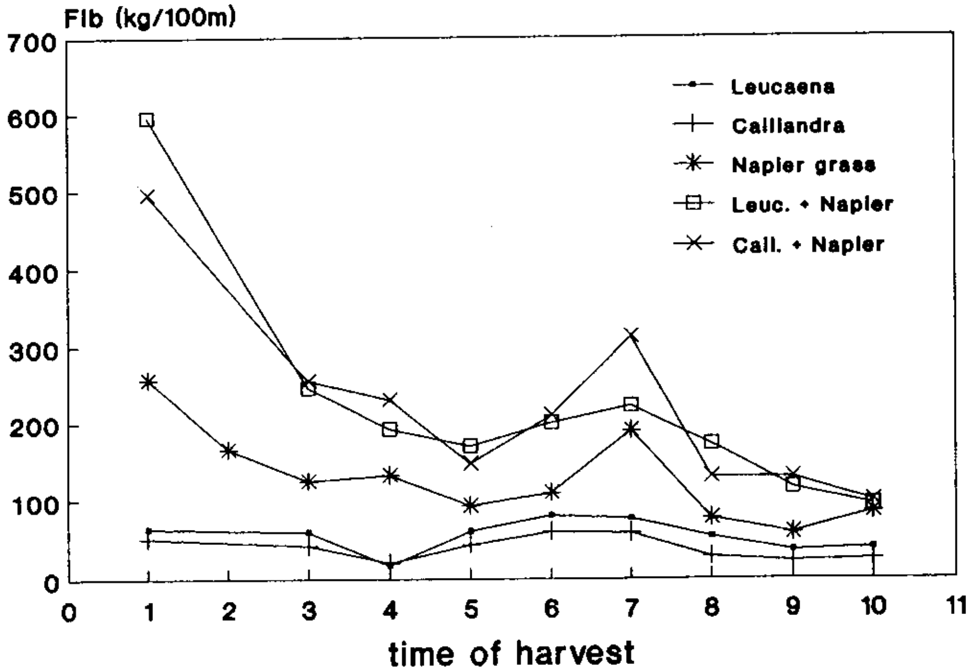

Fig. 2. Fresh leafy biomass yields of *L leucocephala*, *C. calothyrsus* and *P. purpureum* over 18 months of repeated cutting

A separate assessment was done on individual lines. Planting Napier grass in combination with calliandra increased the yield of both components significantly (appendix 9). However, the Napier-leucaena combination benefited the former (p=0.0125), but did not cause any significant difference in the latter (p=0.4170).

4.2.2. Dry matter yields

The mixed treatments were significantly higher in dry biomass production than each of the pure treatments (Table 2). Dry matter productivity from the pure Napier grass was significantly (p=0.0459) higher than that of calliandra but not significantly different (p=0.8921) from that of leucaena treatments. Yields from leucaena and calliandra were not significantly different. Dry matter yields from the first three harvests in the first year were significantly (p=0.0002) higher than the corresponding harvests in the second year. Covariance analysis indicated no significant (p=0.7472) effects associated with rainfall. Productivity in all treatments was higher at the beginning than at the end of the study period, but the drop was substantial for those treatments with a grass component in them (Fig. 3).

Planting Napier grass in combination with leucaena did not cause any significant differences in the dry matter yields of both species (see Appendix 9). Both components in the Napier-Calliandra mixture benefited significantly.

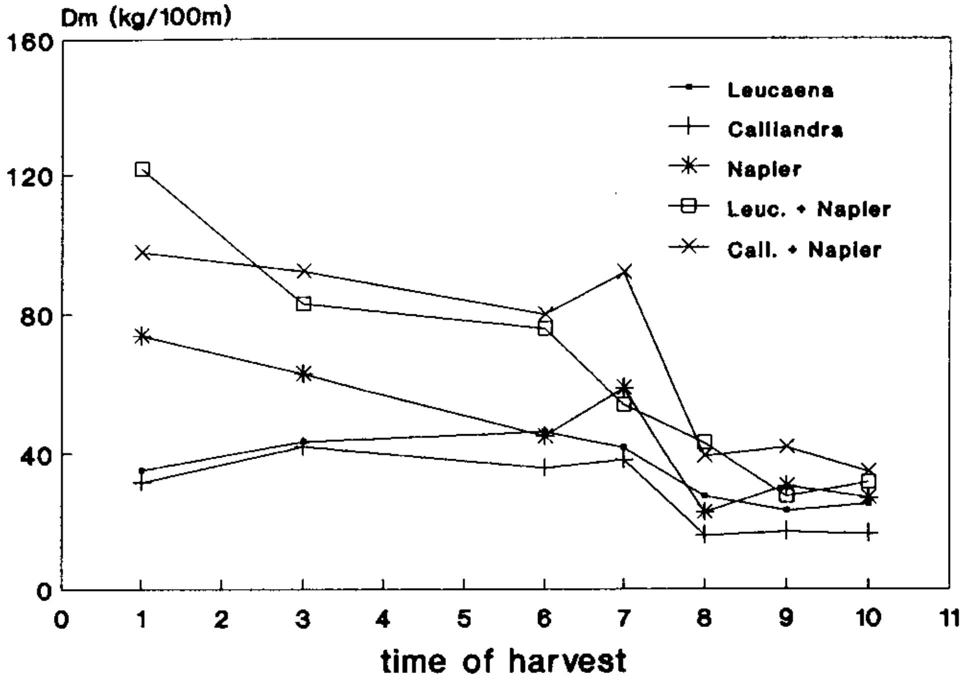

Fig. 3. Dry leafy biomass yields of *L. leucocephala*, *C. calothyrsus* and *P. purpureum* over 18 months of repeated cutting

4.3. Nutrient concentrations

4.3.1. General

The nutrient composition of the three fodder species as determined across the entire study period is summarized in Table 3 (also see Appendices 3, 4 and 5). All nutrients except zinc and copper are expressed in percentages (cg/g). Zn and Cu were relatively low in concentration, and are presented in parts per million (mg/kg). Acid-insoluble ash was negligible in the shrub species, but was high (6.3%) in Napier grass. The acid detergent fibre (ADF) values provided in the table are corrected values obtained after subtracting the acid-insoluble ash content from all samples.

Table 3. Comparative nutrient compositions of L. leucocephala, C. calothyrsus and P. purpureum over 18 months.

Nutrient	Leucaena leucocephala	Calliandra calothyrsus	Pennisetum purpureum
Dry matter, %	32.0	38.5	21.9
Crude protein, %	27.2	21.7	10.6
Potassium, %	1.62	1.08	1.98
Calcium, %	0.757	0.552	0.275
Magnesium, %	0.313	0.218	0.365
Phosphorus, %	0.178[a]	0.182[a]	0.148
Zn (ppm)	19.2	27.6	24.0
Cu (ppm)	8.8[b]	8.6[b]	5.4
ADF, %	29.4	54.1	39.7
Acid-insol. ash, %	-	-	6.3

Means followed by the same superscript on the same row were not significantly different ($\alpha=0.05$)

As shown by Table 3, both the shrubs had a higher proportion of dry matter than the grass. This means that consumption of the same amount of fresh material results in a comparatively higher dry matter intake of the legumes. L. leucocephala was highest in crude protein, Ca and Cu, but it was lowest in Zn and ADF. C. calothyrsus was highest in P, Zn and ADF, but was lowest in K and Mg. P. purpureum was highest in K and Mg, but was lowest in crude protein, Ca, P and Cu.

Since there were significant interactions (α=0.05) between treatment and time of harvest (season), it was necessary to perform separate statistical analyses for each harvest time in order to compare the means at the α=0.05 significance level. The results are summarized in Appendix 9. Correlation analysis showed that most of the nutrients were not significantly related to rainfall under Maseno conditions. As shown by the Spearman rank order coefficients presented in Table 4, only the K content of Napier grass was significantly (r=0.750) correlated with rainfall.

The time to time variation of each of the dry matter and nutrient concentrations are shown for the upper and lower lines of each treatment in Figures 4-21.

Table 4. Spearman rank order coefficients between rainfall and nutrients in L. leucocephala, C. calothyrsus and P. purpureum.

Biomass/ nutrient	Leucaena leucocephala	Calliandra calothyrsus	Pennisetum purpureum
FLB, kg/100m	-0.283	-0.100	0.183
DM, kg/100m	-0.250	-0.393	-0.071
Dry matter, %	-0.024	-0.286	-0.595
Crude protein, %	0.500	0.385	0.360
Calcium, %	-0.067	0.500	-0.600
Magnesium, %	0.234	0.467	-0.400
Potassium, %	0.000	-0.217	0.750*
Phosphorus, %	-0.300	0.343	0.326
Zinc, (ppm)	-0.500	-0.075	-0.100
Copper, (ppm)	-0.059	-0.059	0.259
Acid det. fibre, %	-0.444	0.033	0.517

* Significant correlation between rainfall and nutrient

FLB = Fresh leafy biomass DM = Dry matter

4.3.2. Percent dry matter (DM%)

Calliandra was significantly higher than both leucaena and Napier grass in DM%. Likewise, leucaena was significantly higher than Napier grass in eight out of nine harvests. DM% varied as shown in Figures. 4 and 5.

The DM% of both shrubs and the grass component in the Napier-calliandra mixture were not significantly affected by mixed planting at any one time. In the Napier-leucaena mixture, the DM% of the grass was not significantly different in six out of eight harvests. It was significantly lower in two.

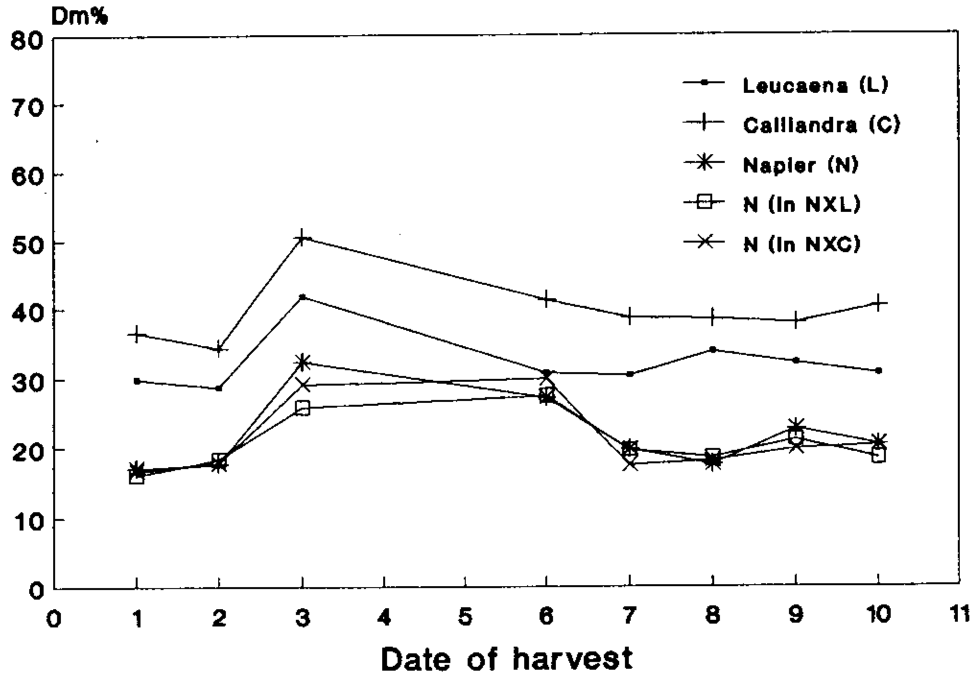

Fig. 4. Variation in the dry matter content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

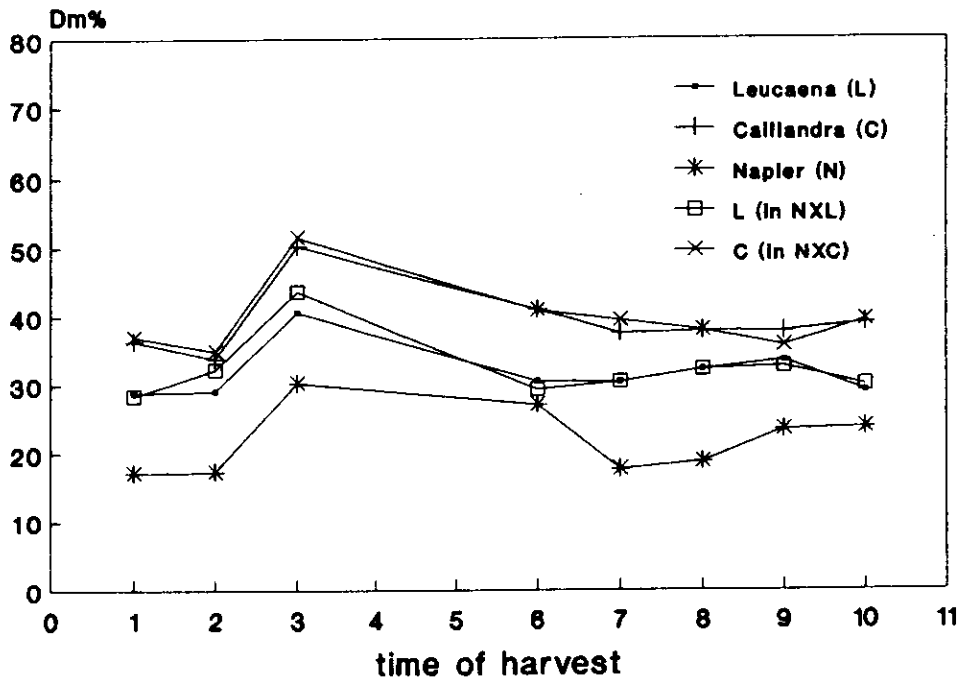

Fig. 5. Variation in the dry matter contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

4.3.3. Crude protein

All species were significantly different from each other in crude protein concentration. At the end of the study period, the crude protein content of each species was similar to that at the beginning (Figures 6 and 7). A relatively uniform level of crude protein was maintained throughout the study period.

No significant difference in the protein concentration of Napier grass was observed when it was planted in combination with leucaena. In combination with Calliandra, there was no significant difference in eight out of nine harvests and a significant decrease in only one. Apart from calliandra, which was significantly higher in only one out of nine harvests, shrub-grass mixtures did not cause any significant difference in the crude protein concentration of the legumes.

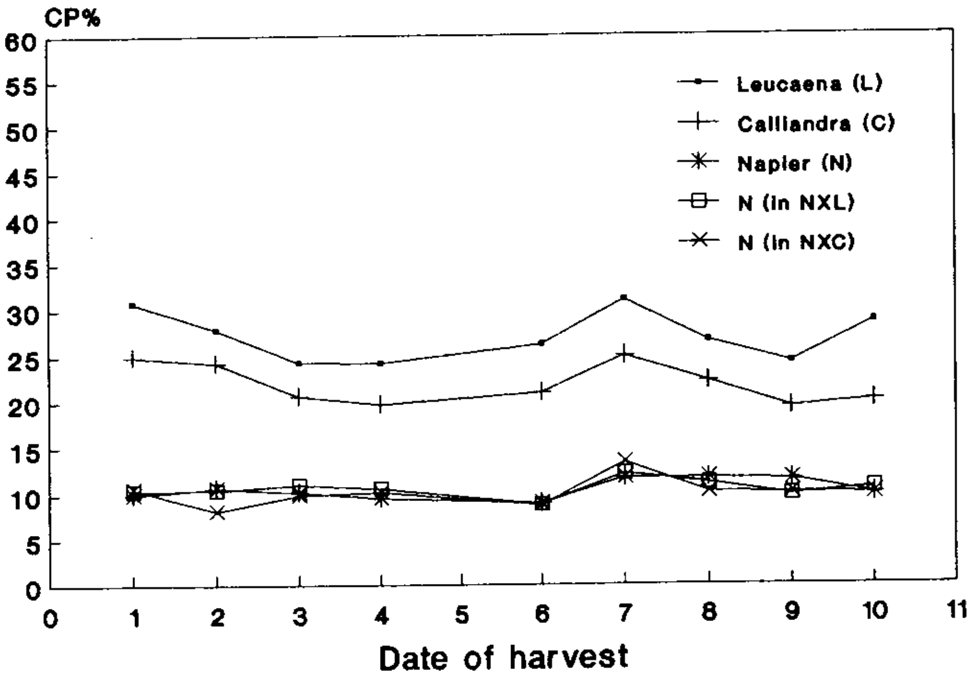

Fig. 6. Variation in the crude protein content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

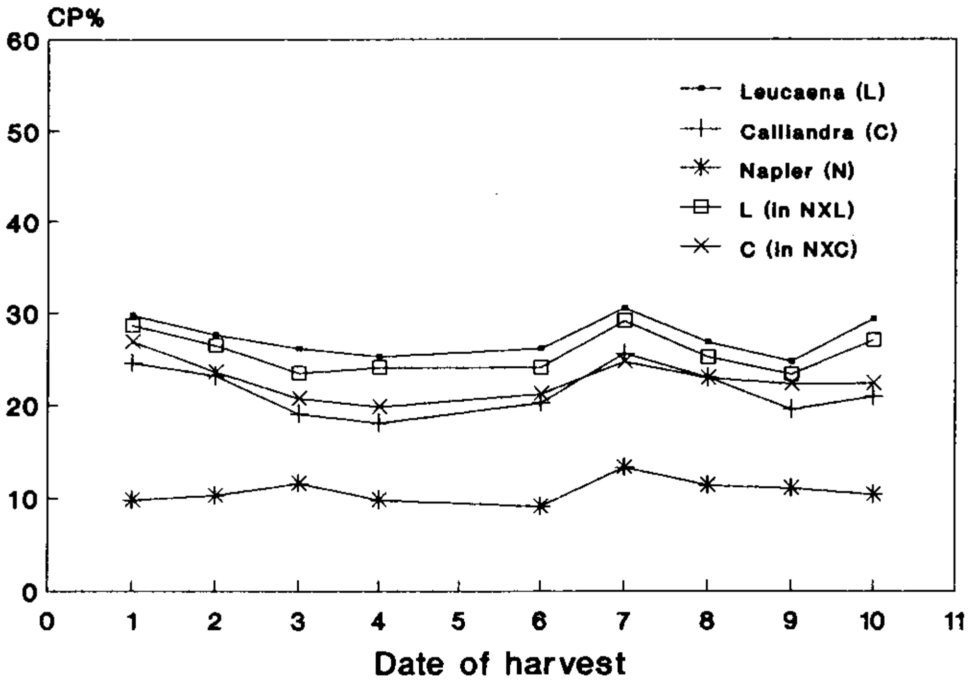

Fig. 7. Variation in the crude protein contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

4.3.4. Calcium

Both shrubs were significantly higher in Ca concentration than the grass. Leucaena was significantly higher than calliandra in seven out of nine harvests. Napier grass maintained a uniform level of Ca throughout the study period, while both legumes showed a gradually increasing trend (Figures 8 and 9).

Ca concentration in Napier grass was not significantly affected when planted in combination with the legumes. When mixed with Napier grass, the concentration of Ca in both leucaena and calliandra were not significantly different in eight out of the nine harvests.

4.3.5. Potassium

Leucaena was significantly higher than calliandra in K concentration. K content of Napier grass was significantly higher than that of leucaena in six out of nine harvests, but was not significantly different in the other three harvests. Figures 10 and 11 show all species to have returned to about the initial level of K by the end of the study period.

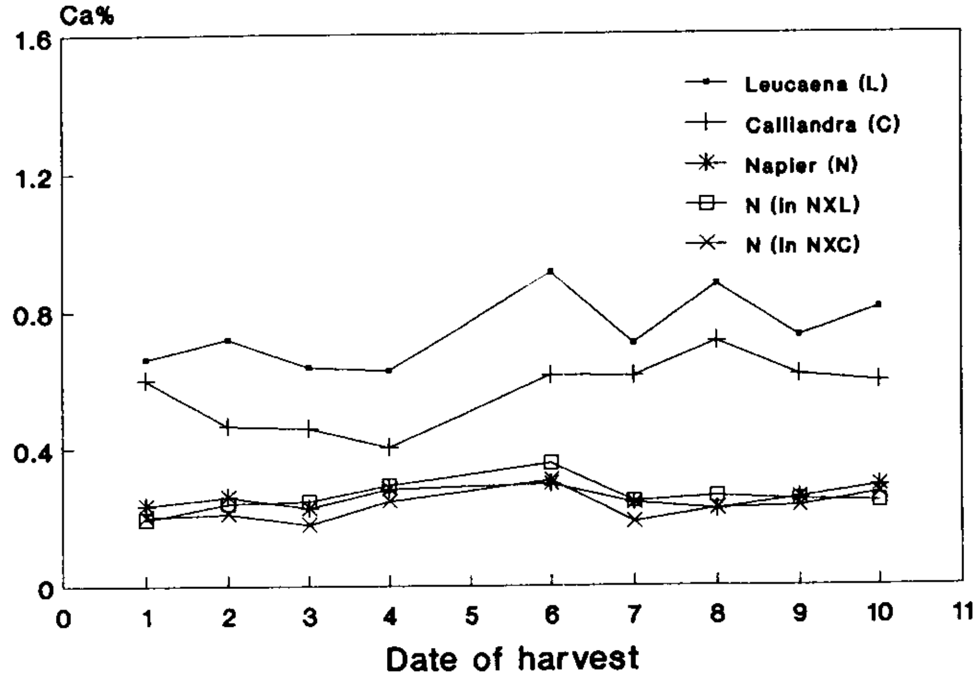

Fig. 8. Variation in the calcium content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

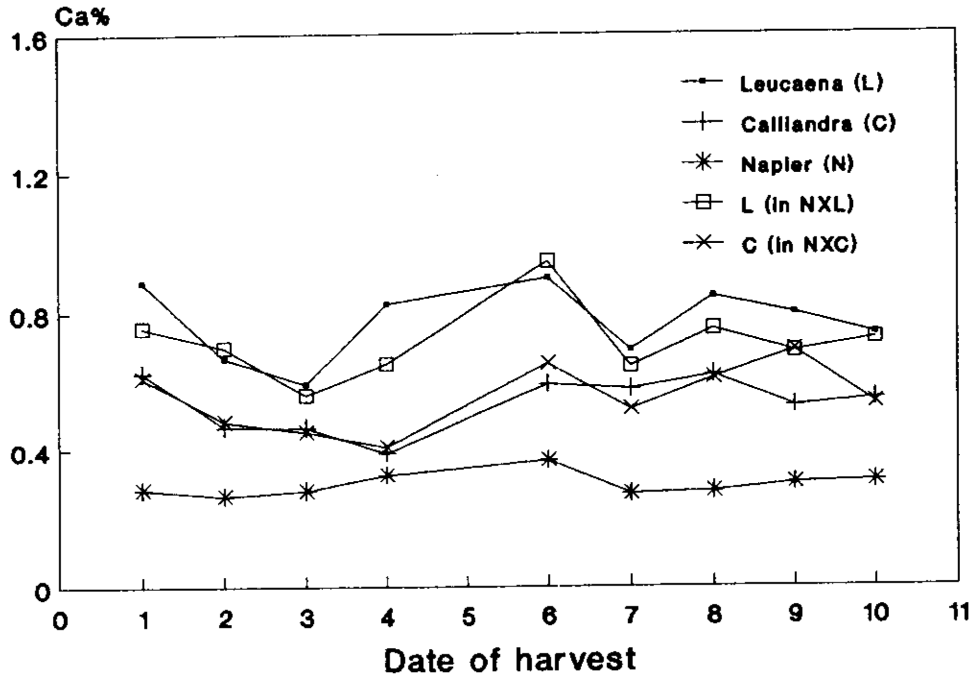

Fig. 9. Variation in the calcium contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

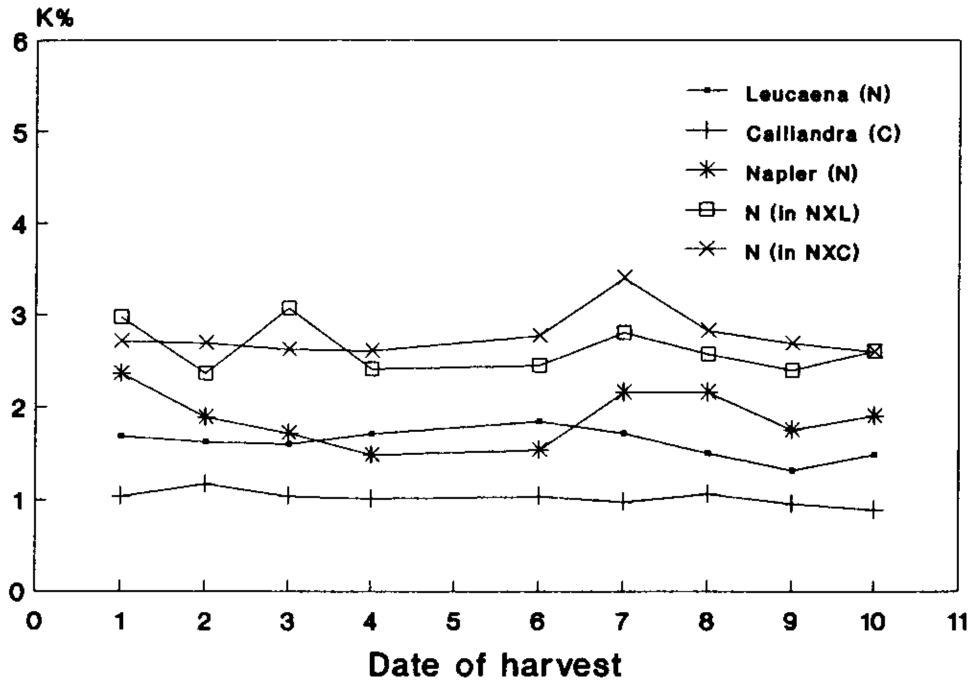

Fig. 10. Variation in the potassium content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

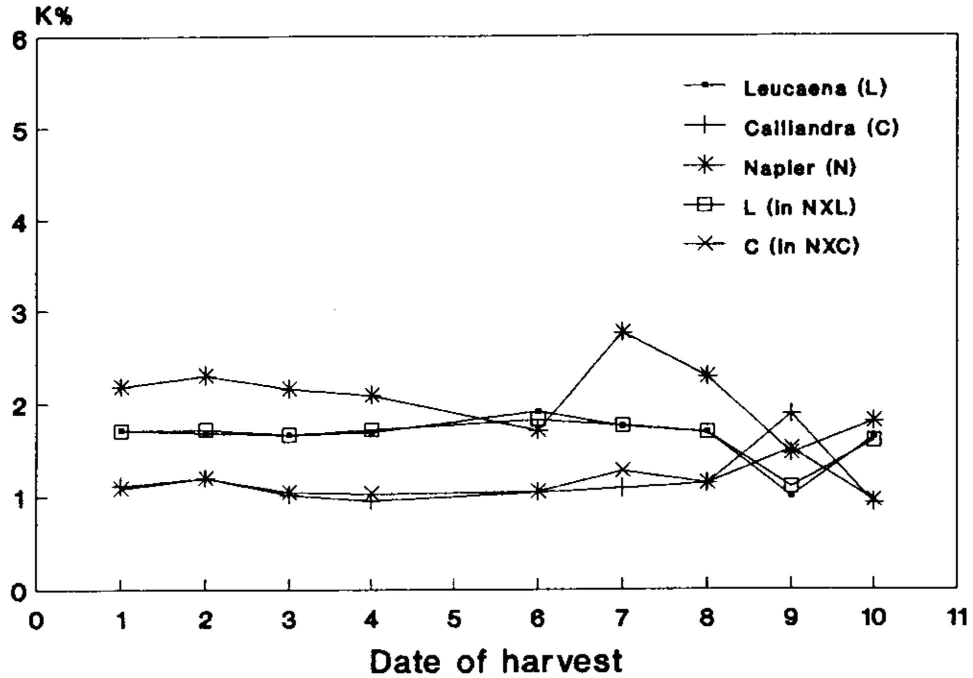

Fig. 11. Variation in the potassium contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

K concentration of Napier grass was higher in the mixed treatments. The difference was significant in five out of nine harvests in the Napier-leucaena mixture and in seven out of nine harvests in the Napier-calliandra mixture. Except for calliandra, which was significantly lowered in only one harvest, none of the legumes differed significantly in the concentration of K when planted with Napier grass.

4.3.6. Magnesium

Mg concentration of Napier grass was significantly higher than that of leucaena in all except two out of nine harvests. Mg content of calliandra was significantly lower than that of Napier grass and leucaena in eight out of nine harvests. Mg levels of all species at the end of the study period were similar to those at the beginning (Figures 12 and 13).

Mg concentration of Napier grass decreased when combined with either legume. The decrease was not significant in seven out of nine harvests with leucaena and three out of nine harvests with calliandra. None of the woody perennials, however, was affected significantly by planting in combination with the grass.

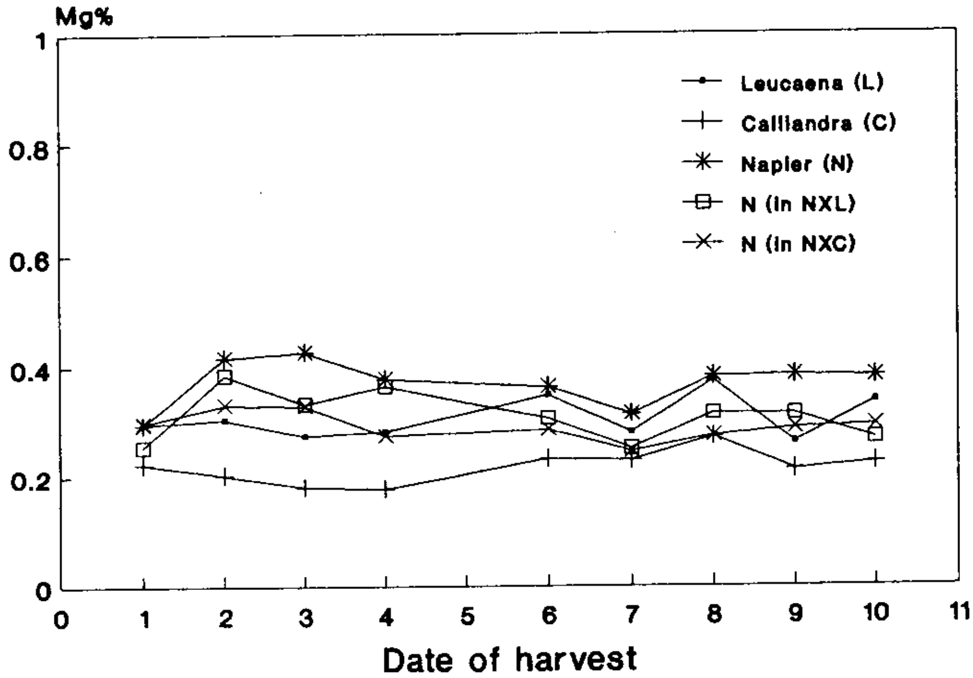

Fig. 12. Variation in the magnesium content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

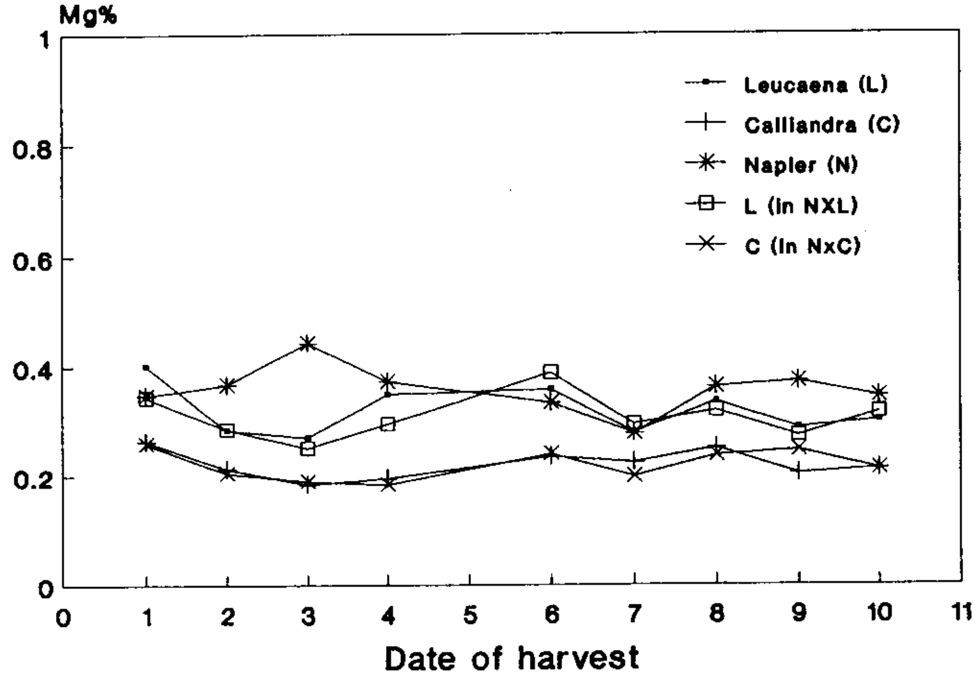

Fig. 13. Variation in the magnesium contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

4.3.7. Phosphorus

Both legumes were higher in P concentration than Napier grass. However, the difference was significant in only four out of nine harvests with leucaena and five out of nine harvests with calliandra. In all cases, the legumes were not significantly different from each other. The P concentration of all species were at similar levels at the end as at the beginning of the study period (Figures 14 and 15).

P concentration in all species was not significantly altered by planting in shrub-grass mixed arrangements.

4.3.8. Zinc

Calliandra was either similar or higher than the other species in Zn concentration in all harvests. The difference was significant in eight out of nine harvests with leucaena, and in four out of nine harvests with Napier grass. Napier grass was significantly higher in Zn concentration than leucaena in four out of nine harvests. Figures 16 and 17 show the variation of the concentration of Zn in all species over 18 months.

Planting Napier grass with either of the legumes did not cause any significant difference in the zinc concentration of all species.

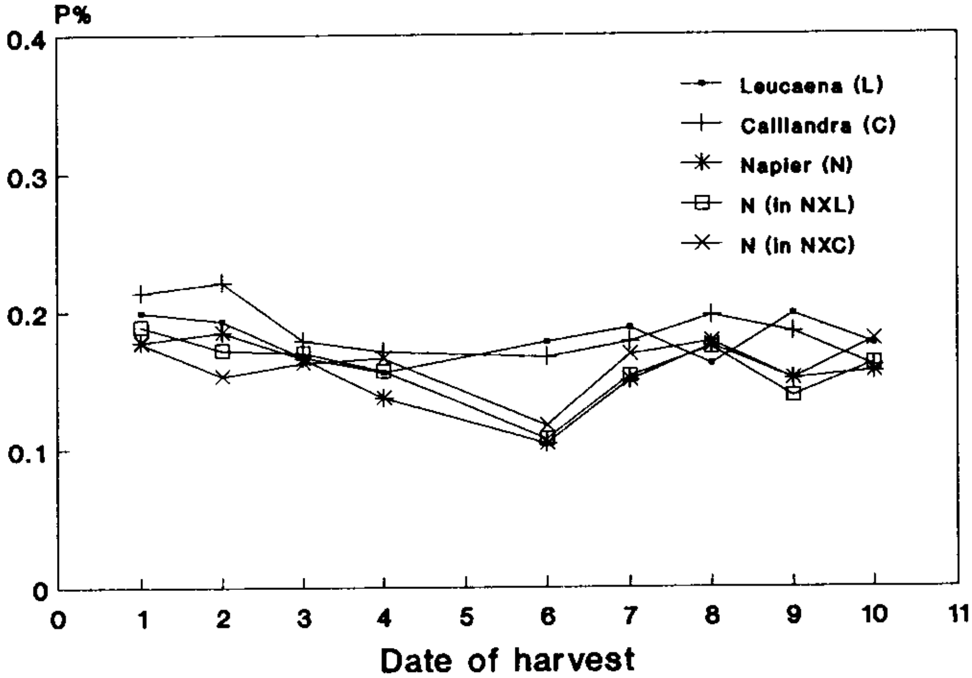

Fig. 14. Variation in the phosphorus content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

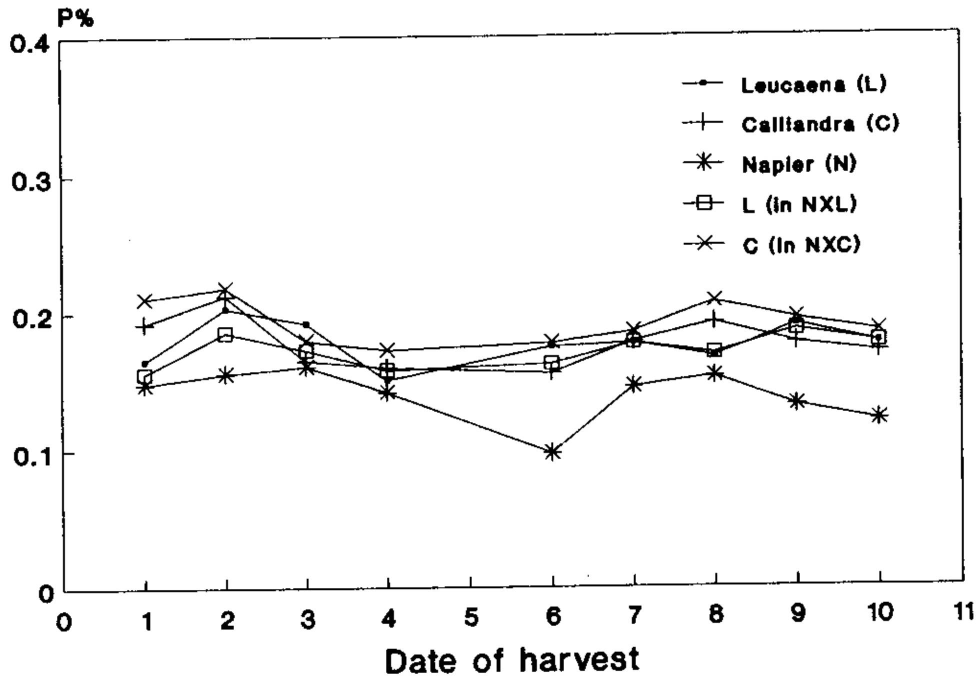

Fig. 15. Variation in the phosphorus contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

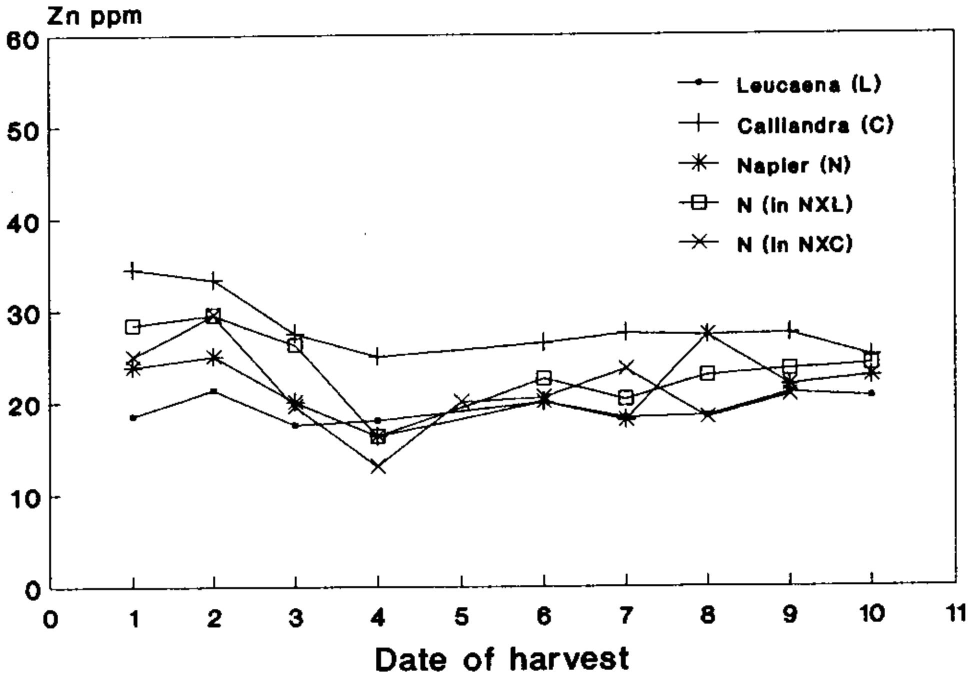

Fig. 16. Variation in the zinc content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

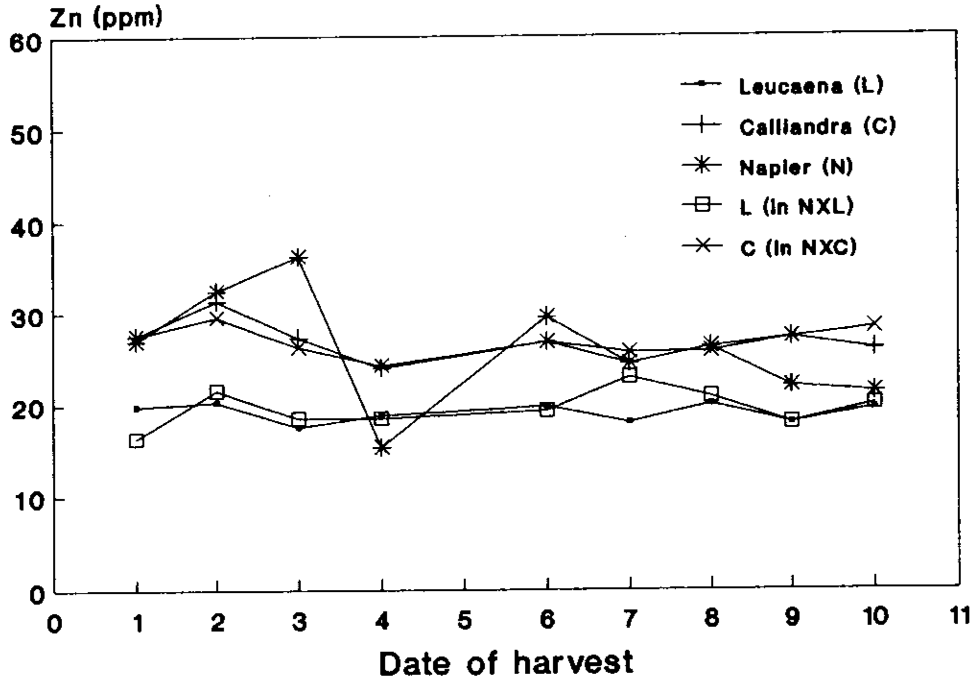

Fig. 17. Variation in the zinc contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

4.3.9. Copper

Cu concentrations were the lowest among the nutrients studied. Both woody perennials were higher in the concentration of copper than the grass. The differences were significant in seven out of nine harvests for leucaena and eight out of nine harvests for calliandra. The concentrations of Cu in the two legumes were not significantly different in seven out of the nine harvests. By the end of the study period, Cu concentrations had returned to levels similar to those at the beginning, but both shrubs showed peaks at the 6^{th} harvesting date (Figures 18 and 19).

The concentrations of Cu in Napier grass and calliandra were not significantly altered by establishment in shrub-grass mixtures. Similarly, the Cu concentration in leucaena was not significantly different in eight out of nine harvests.

4.3.10. Acid detergent fibre (ADF)

Calliandra was significantly higher than leucaena in fibre (ADF) content. ADF content in calliandra and leucaena was, respectively, significantly higher, and significantly lower than that of Napier grass in eight out of nine harvests each. The shrubs tended to gradually increase while the grass tended to remain at similar levels of ADF throughout the study period (Figures 20 and 21).

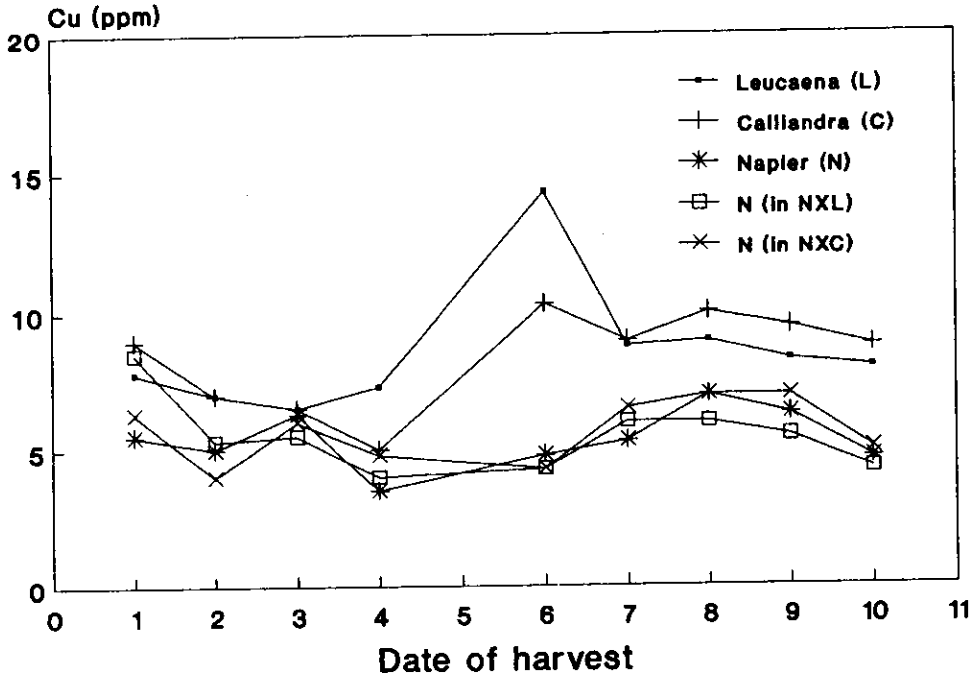

Fig. 18. Variation in the copper content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

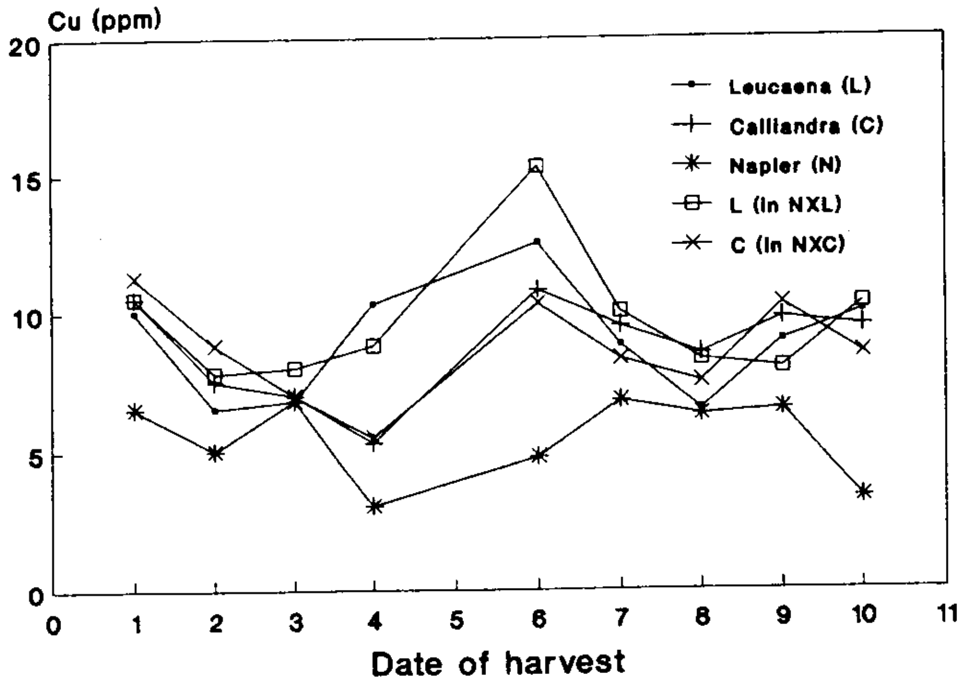

Fig. 19. Variation in the copper contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

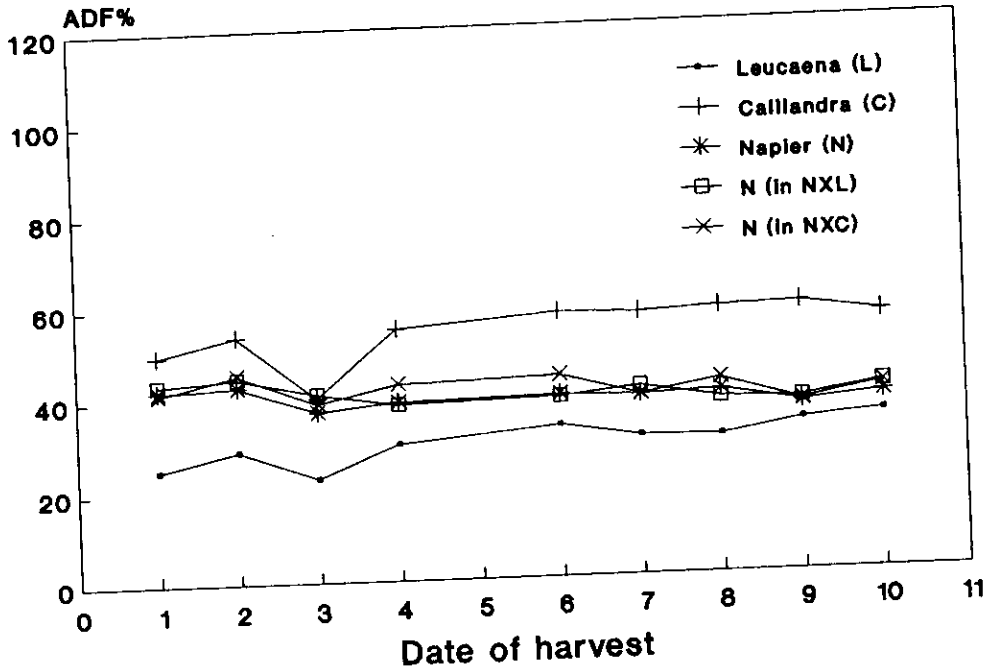

Fig. 20. Variation in the ADF content of *P. purpureum* when grown in pure arrangements and in combination with *L. leucocephala* and *C. calothyrsus* over 18 months

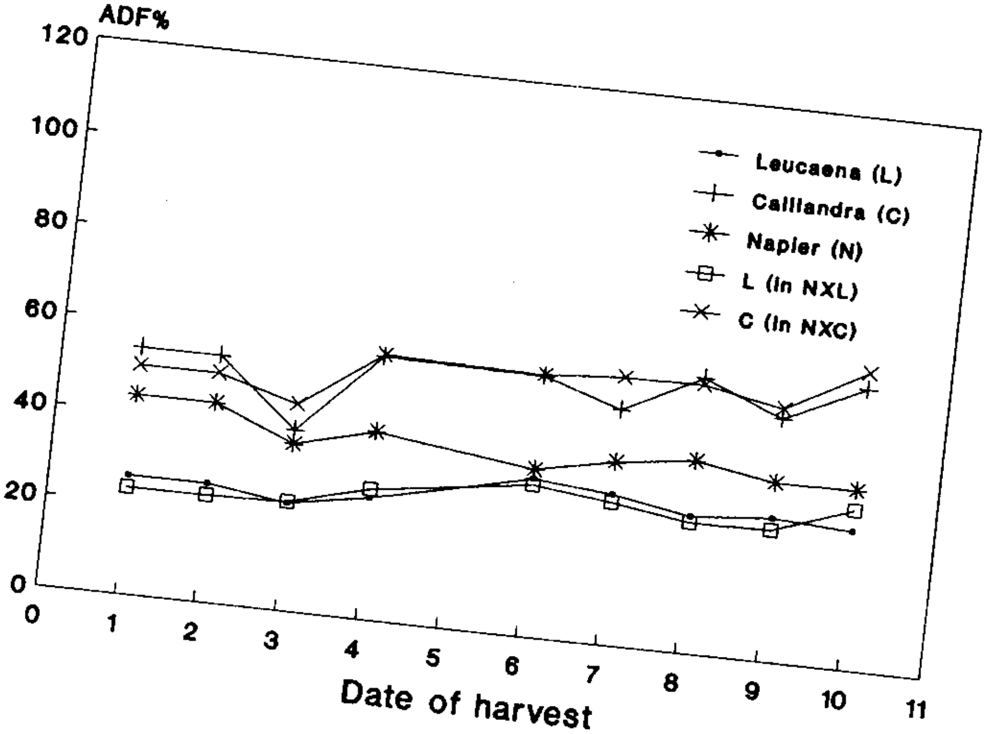

Fig. 21. Variation in the acid detergent fibre contents of *L. leucocephala* and *C. calothyrsus* when grown in pure arrangements and in combination with *P. purpureum* over 18 months

The ADF contents of Napier grass and leucaena were not significantly changed by their shrub-grass combinations. In the Napier-calliandra mixture, the proportion of ADF was not significantly affected eight out of nine harvests both ways.

5. DISCUSSION

5.1. Leaf/stem ratios

Knowledge of leaf/stem ratios provides an opportunity for making quick estimations of edible biomass in woody forage plants. It allows optimum rationing of tree-based feeds while at the same time avoiding time and labour costs that would be incurred when separating leaves and stems for feeding or measurement purposes. The results obtained in this study show that leucaena regrowths have a higher proportion of leaves than calliandra regrowths. Phiri et al. (1992) suggested that the much higher ADF value in calliandra than in leucaena could be due to the lower leaf to stem ratio in the former. The information available in the literature concerning this aspect is limited and appears to show slight differences from place to place.

Pathak et al. (1980) reported an average leaf/stem ratio of 2.01 (1.53-2.71) for leucaena. This ratio decreased significantly with increasing cutting interval and increasing planting density, but was not significantly affected by changes in cutting height. In his literature review, Jones (1979) reported regrowing leucaena shoots, 0.5 to 1 m long, to consist of 75 to 80 percent nutritious leaves. Leaf/stem ratios based on dry matter yields (tonnes/ha/year) of leucaena were 2.07 for cultivar K341 and 1.87 for cultvar K8 (Guevarra et al., 1978). Young calliandra trees planted at different spacings yielded 59-68% leaves when first cut back to 1 m after five months of growth (Baggio and Heuveldop, 1984). When new sprouts were cut back to the same height, five months later, the proportion of leaves ranged from 57-63%. Most of these values are lower than the results of the present study and the differences may be attributed either to the bio-physical environment, the plant varieties, or management strategies.

5.2. Leafy biomass yields

The high biomass productivity shown by Napier grass in this study has long been recognized by Kenya's Ministry of Agriculture and has been widely utilized to benefit small and large scale dairy farmers in the high potential areas (Abate et al., 1985). The apparent setback observed in this experiment was the significant loss in productivity in the second year. Similar results were obtained in Kitale, western Kenya, where in the absence of fertilizer, the dry matter yield of Napier grass, Guinea grass and Rhodes grass decreased substantially in the second year after planting (Sheldrick and Thairu, 1974; cited by Wolfgang Bayer, 1990). This phenomenon may be attributed to the continued depletion of the soil nutrient resources resulting from repeated harvesting without replenishment. Wolfgang Bayer (1990) further stated that while unfertilized Napier swards became unproductive after 3-4 years, those which received doses of appropriate fertilizer showed no decline in yields even after 30 years.

Though the study period was relatively short, the maintenance of biomass productivity by the woody perennials supports reports from many sources that woody legumes have advantages over grasses in this respect. In Indonesia where it was introduced in 1936 with seeds from Guatemala, calliandra plantations for firewood production are harvested annually for 15-20 years and produce 35-65 m^3 per hectare per year (NAS, 1979). Similarly, some leucaena hedges in Hawaii have been trimmed at least twice a year for more than 40 years (NRC, 1984). These observations may be attributed to the high coppicing ability and the extensive taproot systems which tap water and essential nutrients from far below the soil surface, sustaining biomass productivity even during drier periods. Leucaena, for example, is so resilient that pastures near Brisbane in Australia have been browsed almost continuously for about 20 years without requiring replanting (NAS, 1979). Aspects relating to appropriate management of individual shrub and grass species are discussed in section 2.4.

Establishing and managing appropriate trees and shrubs in association with grasses for fodder has potential quantity and quality advantages for extended periods. The relatively high productivity shown by the mixed treatments were a direct result of significant increases in biomass production (of at least one of the components in the mixture) when components were grown as mixtures rather than pure hedgerows. These demonstrated the positive interactions that occurred when Napier grass was planted in combination with the two woody legumes.

From earlier studies in the same experiment (Otieno et al., 1991), Napier grass gained in fresh biomass productivity by 48% when planted in combination with leucaena and by 9% when in combination with calliandra. Both shrub species benefited from the combination with calliandra gaining by 43% and leucaena by 35%. These advantages have long been appreciated elsewhere by farmers (who graze their animals in tree-grass mixed pastures) and researchers alike. In South-East Queensland, Australia, for example, pastures combining leucaena and Rhodes grass (Gloris gayana) have been grazed for more than 20 years and have retained a good balance (NRC, 1984). Similarly, leucaena/Brachiaria brizantha pastures in Malaysia and leucaena/pangola grass pastures in Northern Australia have remained in balance after being grazed for several years (NRC, 1984). Research in India showed significantly higher total green forage and dry matter yield in the treatment where hybrid Napier and subabul (Leucaena leucocephala) were planted in paired rows (Gill et al., 1990).

These mutual benefits may be attributed to: 1) the nitrogen-fixing and nutrient-cycling ability of the legumes, resulting in improved soil nutrient status, 2) the reduction of direct competition for moisture and nutrients by adjacent fodder lines; grasses explore upper layers of the soil profile, while trees and shrubs have long taproot systems which occupy much deeper soil layers, and 3) the combined protective effect against run-off and soil erosion, thereby ensuring maximum utilization of available moisture. Information on soil conservation aspects of different agroforestry practices have been dealt with in detail by Young (1989).

5.3. Nutrient concentrations

5.3.1. Comparative information from literature

The nutrient composition of leucaena, calliandra and Napier grass as found in the literature are provided for comparison purposes in Table 5.

Table 5. The nutrient composition of L. leucocephala, C. calothyrsus and P. purpureum as found in some literature.

Nutrient	Leucaena leucocephala	Calliandra calothyrsus	Pennisetum purpureum
Dry matter, %	28.0[a], 28.3[b],	33.0[a], 39.0[g]	16.6[b], 20.0[d],
Crude protein, %	25.24[a], 26.9[b], 25.9[j]	24.47[a], 22.0[f], 21.63[g]	11.9[b], 10.1[c], 8.7[d],
Potassium, %	1.7-2.6[i]	0.69[k]	1.31[d]
Calcium, %	2.36[j], 0.5-1.18[i]	1.03[k]	0.60[d]
Magnesium, %	0.17-0.41[i]	0.37[k]	0.26[d]
Phosphorus, %	0.16[e], 0.23[j] 0.15-0.38[i]	0.15[e], 0.11[k]	0.41[d]
Zinc (ppm)	28.0-44.0[i]	-	19.0-28.0[h]
Copper (ppm)	7.0-11.0[i]	-	4.0-8.0[h]
Acid detergent fibre, %	22.64[a], 22.6[b],	46.27[a], 70.1[k]	44.1[b], 38.3[c]

[a]Phiri et al. (1992), [b]Van Eys et al. (1986), [c]Sands et al. (unpublished, 1982), [d]NRC (1988), [e]Ahn et al. (1989), [f]NRC (1983), [g]Baggio and Heuveldop (1984), [h]Njwe and Kom (1988), [i]Jones (1979), [j]NAS (1977), [k]Blair et al. (1988)

5.3.2. Percent dry matter

The product of DM% and fresh biomass/100 m length of hedgerow gives dry biomass/100 m. The DM% values obtained are similar to most of those provided in the literature (Table 5). A change in DM% causes a corresponding change in absolute dry matter values. The amount of dry matter in any fresh feed material determines the amount of nutrients in that material since all nutrients are contained within the dry matter. A kg of silage, for example, is worth less than a kg of good hay largely because it contains less dry matter (Schneider and Flatt, 1975).

DM% is expected to increase in the dry season and with age because of increased lignification in both cases. However, little information, is known about the effect of management on the proportion of dry matter. It can be inferred from this experiment that establishing the three species as shrub-grass mixtures does not impose significant changes on the proportion of dry matter.

5.3.3. Crude protein

The crude protein values determined in this study were similar to those obtained from research elsewhere (see Table 5). All species had protein contents well above the 7% level known to limit the intake of tropical forage (Milford and Minson, 1966). However, only the two legumes were above the 19% level recommended for lactating dairy cattle by the National Research Council (Appendix 6). This supports the general consensus that many multipurpose tree and shrub legumes have high potentials as protein supplements to conventional livestock feeds (e.g. Devendra, 1990; Bamualim et al., 1984, Flores et al., 1979). The high quality protein associated with leucaena is attributed to the balanced nature of its amino acid composition (NAS, 1977). Calliandra's role as a protein supplement may be limited by the presence of high levels of condensed tannins which have the capacity to bind feed protein, reducing its solubility in the ruminant digestive system (Ahn et al., 1989). The results are of particular interest to the small scale dairy owners of western Kenya where protein is a major limiting factor in many livestock production systems and where household income is generally too low to allow purchase of high protein concentrates.

Apart from type of species, the protein content of forage plants is expected to vary with the environment and type of management. According to Le Houerou (1980), protein content in grasses is expected to drop significantly during prolonged dry periods, while that in trees and shrubs behaves likewise but to a lesser magnitude. The protein content of leucaena fodder (mainly leaves along with some soft twigs) was found to range from 20-24% during different seasons (Joshi and Upadhyaya, 1976). In Siaya and Kakamega districts, the decline in crude protein and general quality of different feedstuffs during the dry season was reflected in the weight changes of livestock (Sands et al., unpublished data, 1982). Adverse effects on the weight changes of sheep and goats were minimal, and it was suggested that their selective feeding habits, compared to cattle, allowed them to select the better quality forage under these conditions. However, these observations were not apparent in this experiment, where protein content of all species showed a positive but insignificant relationship with rainfall.

The results showed that the three species used could be established as shrub-grass mixtures on hedgerows without causing adverse effects on the protein content of any of them. This is advantageous in that farmers can incorporate mixed forage as hedgerows in their small farms, which not only serve as cut-and-carry fodder, but also help in minimizing soil erosion. However, optimum harvesting frequencies must be established since foliar protein content declines with age (Jones, 1979; Snyders, 1991), causing a decline in animal productivity (Snyders, 1991). Crude protein is not affected by cutting height (Pathak et al., 1980). Higher planting densities resulted in slightly lower protein percentage in Leucaena leucocephala (Pathak et al., 1980).

5.3.4. Minerals

When dietary crude protein and energy are present in sufficient quantities, mineral deficiencies may depress forage utilization and intake, and animal performance can be increased by mineral supplementation (Prabowo et al., 1983). It has been stated that the concentrations of mineral elements in forages are dependent upon the interaction of a number of factors, including soil, plant species, stage of maturity, yield, forage management and climate (McDowell, et al., 1983). Under Australian conditions, on a variety of soils, Ca concentration in leucaena rarely exceeds 1% in the dry matter, whereas in the material grown in India and Malawi, values of more than 2% Ca are reported in leucaena leaf (Jones, 1979). Jones (1979) found the concentrations of P, S, Ca, Mg and Na to decrease with aging leucaena leaves, while those of K, Cu and Zn did not show clear trends.

According to the recommendations made by the National Research Council (1988) for diets fed to dairy cattle, all species in the present experiment were sufficiently high in K. Njwe and Kom (1988) found adequate levels of K on four dominant grass species of natural pastures of the west region of Cameroon. Except in the case of calliandra, Mg levels were similarly adequate. K is not known to be a limiting nutrient in many parts of the tropics (Minson, 1990), while Mg, together with K, Fe and Mn may be deficient under specific conditions in some tropical regions (McDowell et al., 1983). Though the legumes used in this experiment were generally higher in minerals than the grass, they did not confirm their full potentials as likely supplements to ordinary feeds. Contents of Ca, P, Cu and Zn were generally low compared to those recommended for consequence to the results obtained.

There is limited information in the literature regarding the effect of management on mineral content of forages. Pathak et al. (1980) found highest foliar Ca and P concentrations at 120 (compared to 40 and 60) day cutting intervals and 20 (compared to 10 and 30) cm cutting heights of Leucaena. When 1.5, 3 and 4 plants/m^2 planting densities were compared, Ca content was highest at the medium population density, while P was highest at 4 plants/m^2. The results of the present experiment showed that leucaena and calliandra can be grown in association with Napier grass without causing any negative effects on the species composition of minerals, except Mg. The Mg content of Napier grass was generally lower in the mixture, while the composition of K was generally higher. Given appropriate management, total mineral quantities in the mixed arrangements will be much higher because of the significant increases in total biomass production. As plants mature, mineral elements such as P, K, Mg, Na, Cl, Cu, Co, Fe, Se, Zn and Mo are expected to decline due to a natural dilution process and translocation of nutrients to the root system (McDowell et al., 1983).

5.3.5. Acid detergent fibre (ADF)

Fibre can be defined nutritionally as the insoluble organic matter which is indigestible by proteolytic and diastatic enzymes and which cannot be utilized except by microbial fermentation in the digestive tracts of animals (Van Soest, 1967). Ruminants require adequate coarse fibre for normal rumen function and maintenance of normal milk fat in dairy cattle (Van Soest, 1990). Fibre quality is determined by particle size, buffering capacity, cation exchange capacity, and fermentation rate. The acid-insoluble ash, which was negligible in the legumes, and highest in Napier grass (6.3%) is mainly made of silica, and was subtracted from all sample values to get the ADF values recorded in the present study. The results agree with the statement made by Goering and Van Soest (1970) that silica content in many grasses is a principal factor in reducing digestibility.

Research workers in recent years have argued in favour of the neutral detergent procedure as a better method of analysing total fibre compared to the traditional ADF and crude fibre methods (Goering and Van Soest, 1970; Van Soest et al., 1991). NDF (neutral detergent fibre) can be correlated with fill, intake, digestibility, and energy content, all of which are important for animal performance. ADF, however, being a rapid method for lignocellulose estimation in feedstuffs (Van Soest, 1963), can better be related to digestibility than intake because the lignified matrix in it is the most unavailable feed fraction (Van Soest, 1990). The work done by Lohan et al. (1980) in Himachal Pradesh showed a significant negative correlation between in vitro dry matter digestibility and NDF, ADF and cellulose. Van Soest (1963) found the known dry matter digestibilities of eighteen forages, including ten different species of grasses and legumes to decrease with increasing ADF. Wilson et al. (1966) showed a negative relationship in sheep between fodder intake and crude fibre, NDF, and ADF contents. Bamualin et al. (1980) also found that the nylon-bag dry matter digestibility of browse legumes was negatively correlated with NDF, ADF, and lignin, and positively correlated with nitrogen and ash contents. Consequently, the high ADF fraction determined for Calliandra, as compared to the other species, is expected to have a detrimental effect on its intake, digestibility, and general feeding value. A low dry matter digestibility of 35.43% for calliandra was obtained by Baggio and Heuveldop (1984). Foliage of Leucaena, which had the lowest ADF value in this study, is known to exhibit high dry matter digestibilities, e.g 70% (NRC, 1984) and 62.2% (Van Eys et al., 1986). The dry matter digestibility of Napier grass is intermediate at 51% (Van Eys et al., 1986).

The ADF contents of all species examined in this experiment were well above the minimum (21%) recommended by the NRC (1988) for dairy cattle. The values are slightly higher than most of those available in the literature (see Table 5). The differences may be associated with environmental conditions, stage of growth, plant variety, and methods of analysis. In influencing feed fibre composition, these factors also affect the general character of feeds. The decline in in vitro organic matter digestibility and in vitro cell wall digestibility after the start of the rains was attributed to increases in ADF and lignin that occured in feed resources during the dry season (Sands *et al*., unpublished data, 1982). According to these authors, ADF levels are expected to increase with age. In the present experiment, there was no significant relationship between rainfall and ADF.

The results indicated that all the plant species used in this experiment can be established in shrub-grass mixtures without affecting their fibre content, and by inference, their digestibilities and feed utilization relative to ADF. It is not clear why ADF contents of both shrubs showed a gradual increase over the study period, while the grass maintained a relatively constant level.

6. SUMMARY AND CONCLUSIONS

Many small scale farmers in western Kenya keep a minimum number of animals in keeping with the land tenure situation associated with high human population densities in the region. Napier grass is a high biomass producing fodder crop and forms the main portion of many livestock diets. Its low levels of crude protein and most minerals, which are expected to drop significantly during extended dry periods, and its reported biomass fluctuation with season and drop overtime make it an unreliable fodder crop at some points in time. Woody perennials maintain biomass productivity for a longer time, some are high in crude protein and some minerals, and may provide supplements to conventional feeds.

Initial biomass production was higher for the Napier grass than for the two shrubs. The overtime drop in productivity of the grass may be attributed to frequent cutting which weaken plant regeneration capacity, and depletion of soil nutrients; and emphasizes the need for fertilizer application or replanting at short intervals. Resources to purchase inorganic fertilizers are limited and farmers may prefer the later approach. The ability of the shrubs to maintain productivity for longer periods may partly be due to their possession of long taproot systems which, unlike in grasses, explore deep soil layers for moisture and nutrients. Where the production of large fodder quantities is not the main objective, the low productivity of woody perennials is not of major concern because small quantities of shrub can provide the required nutrients.

The results were consistent with most of those available in the literature in that the two shrubs were higher in the concentration of most nutrients than Napier grass. All species were at similar levels of most nutrients at the end of the study period as at the beginning. Leucaena's possession of high levels of most nutrients, low levels of ADF and high dry matter digestibilities makes it superior to calliandra in fodder quality, except for the presence of mimosine in its tissues. The negative effects of Mimosine can be reduced by administering feeds at the right proportions. No toxic effects related to mimosine, for example will be expected in ruminants, pigs and chicken if diets contain less than 30%, 10% and 5% of leucaena leaf respectively. Feeds supplemented with Calliandra have improved livestock performance. But calliandra's high fibre and condensed tannin contents, and consequent low dry matter and protein digestibilities, make its relative value as animal fodder questionable.

Introduction of appropriate woody perennials into the small-scale farming systems of western Kenya can alleviate problems related to fodder quality and quantity. In recognition of this fact, and considering the relative land tenure and logistic advantages of combining woody perennials and grasses in small scale farms, management of fodder as tree or shrub-grass combinations in small holder livestock systems are being studied. According to the results of this experiment, leucaena and calliandra can be established as shrub-grass combinations without causing adverse effects on biomass productivity and most nutrient contents if proper management strategies are applied. The shrubs fix atmospheric nitrogen and improve the soil nutrient status, provide a microclimate for enhanced growth of both components, and provide a more effective barrier to soil erosion (Young, 1989).

Of all biomass and nutrients considered in this study, only K in Napier grass was significantly correlated with rainfall. Other correlations were not significant and varied in extent from species to species and from one parameter to another. Expected correlations between rainfall and biomass (especially of Napier grass) may have been overshadowed, in part, by the significant drop in the productivity of the later over the study period. It is suggested that the presence of some rainfall in each month of the year, and the absence of long dry seasons, keep soil moisture levels reasonably high so that adverse quality and quantity effects that have been caused by prolonged drought in dry areas elsewhere are not clearly observed at Maseno. It is also noted that nutrients, especially minerals, are highly influenced by soil physical and chemical conditions, and different recommendations might apply to different edaphic and climatic conditions.

These results are of particular interest to the small scale farmers of western Kenya where farms are too small to supply sufficient livestock fodder, per capita income is too low to allow purchase of high protein concentrates, and where the need to establish and manage high nutrient fodder trees and shrubs in farming systems is rising. Though the survey conducted by CARE in 1991 (Scherr and Alitsi, unpublished data, 1991) showed animal fodder to be the primary use of less than 1% of 29 main species (comprising about 90% of trees on farms) in Siaya and South Nyanza districts, fodder trees and shrubs have continued to gain popularity in the recent past. Continued research programmes to increase pest and disease resistance and to reduce toxicity and anti-nutritional characteristics of the species studied in the present experiment would be of tremendous additional benefit.

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APPENDIX 1. Total rainfall received at harvesting and field data collection dates.

Harvesting date no.	Harvesting date (Month)	Total rainfall (mm)
1	May, 1991	495.8
2	July, 1991	209.2
3	September, 1991	212.8
4	November, 1991	382.5
5	January, 1992	71.0
6	March, 1992	130.2
7	May, 1992	413.6
8	July, 1992	514.9
9	September, 1992	205.8
10	November, 1992	359.4

APPENDIX 3. Dry matter and nutrient composition of Leucaena leucocephala at different harvesting dates.

Date	DM%	CP%	Ca%	Mg%	K%	P%	Zn ppm	Cu ppm	Adf%
1	29.30	30.2	0.769	0.346	1.69	0.181	19.1	8.9	25.3
2	28.82	27.8	0.692	0.293	1.65	0.198	20.8	6.8	28.9
3	41.16	25.2	0.613	0.272	1.63	0.179	17.5	6.6	23.0
4	-	24.7	0.722	0.315	1.70	0.153	18.4	8.8	28.0
5	-	-	-	-	-	-	-	-	-
6	30.60	26.2	0.933	0.360	1.90	0.175	20.2	13.5	34.1
7	30.33	30.8	0.698	0.281	1.74	0.183	18.1	8.8	31.4
8	32.93	26.7	0.859	0.355	1.59	0.164	19.3	7.8	29.8
9	32.78	24.5	0.760	0.272	1.15	0.194	19.5	8.6	32.1
10	29.75	29.0	0.770	0.319	1.56	0.177	20.0	9.0	32.1
Mean	31.96	27.2	0.757	0.313	1.62	0.178	19.2	8.8	29.4

APPENDIX 4. Dry matter and nutrient composition of Calliandra calothyrsus at different harvesting dates.

Date	DM%	CP%	Ca%	Mg%	K%	P%	Zn ppm	Cu ppm	Adf%
1	36.38	24.7	0.611	0.242	1.08	0.203	31.0	9.8	51.9
2	34.04	23.7	0.466	0.208	1.18	0.216	32.3	7.3	54.4
3	50.42	19.5	0.458	0.179	1.03	0.170	27.0	6.7	39.8
4	-	18.9	0.395	0.187	0.98	0.165	24.5	5.1	56.1
5	-	-	-	-	-	-	-	-	-
6	41.04	20.6	0.601	0.233	1.04	0.161	26.6	10.5	57.3
7	30.05	25.3	0.633	0.231	1.02	0.179	27.0	9.8	54.3
8	38.14	22.6	0.663	0.261	1.11	0.194	26.8	9.3	59.0
9	37.85	19.5	0.568	0.207	1.38	0.181	27.4	9.6	55.6
10	39.66	20.5	0.569	0.218	0.91	0.165	25.5	9.1	58.6
Mean	38.45	21.7	0.552	0.218	1.08	0.182	27.6	8.6	54.1

APPENDIX 6. Recommended nutrient content of diets for dairy cattle (NRC, 1989).

Nutrient	Early lactation	Dry pregnant cows	Mature Bulls
Crude protein, %	19	12	10
ADF, %	21	27	19
Calcium, %	0.77	0.39	0.30
Phosphorus, %	0.48	0.24	0.19
Magnesium, %	0.25	0.16	0.16
Potassium, %	1.00	0.65	0.65
Copper, (ppm)	10	10	10
Zinc, (ppm)	40	40	40

APPENDIX 7. Analysis of variance table for Fresh leafy biomass production of L. leucocephala, C. calothyrsus, P. purpureum and their shrub-grass combinations

Season	DF	Type I SS	Mean square	F value	Pr>F
Season	8	4.95090277	0.61886285	7.62	0.0001
Treatment	4	8.73481499	2.18370375	26.90	0.0001
SSN*TRT	32	1.90611187	0.05956600	0.73	0.8451

APPENDIX 8. Analysis of variance table for dry leafy biomass production of L. leucocephala, C. calothyrsus, P. purpureum and their shrub-grass combinations

Source	DF	Type I SS	Mean square	F value	Pr>F
Season	6	4.52151871	0.75358645	10.72	0.0001
Treatment	4	2.87628386	0.71907096	10.23	0.0001
SSN*TRT	24	0.70239076	0.02926628	0.42	0.9918

APPENDIX 9. Results of the separation of means (p values) between pure and mixed treatments when the F values were significant

Nutrient	Season	^{L}Napier	^{C}Napier	Leucaena	Calliandra
FLB (kg/100m)	1-10	$^{>}$0.0125	$^{>}$0.0083	0.4170	$^{>}$0.0026
DM (kg/100m)	1-10	0.0649	$^{>}$0.0175	0.7807	$^{>}$0.0018
DM%	1	0.4365	0.7670	0.7192	0.6702
	2	0.6319	0.9141	0.1485	0.5951
	3	$^{<}$0.0023	0.0968	0.1179	0.5381
	4	-	-	-	-
	5	-	-	-	-
	6	0.8692	0.1946	0.5659	0.9821
	7	0.9753	0.1235	0.9993	0.3032
	8	0.3501	0.6242	0.9656	0.9027
	9	0.2804	0.0705	0.7207	0.4051
	10	$^{<}$0.0431	0.9074	0.5981	0.8617
CP%	1	0.7674	0.6367	0.4725	0.1341
	2	0.7868	$^{<}$0.0093	0.2190	0.6551
	3	0.4396	0.6897	0.0711	0.2098
	4	0.3552	0.5593	0.4891	0.2494

	5	-	-	-	-
	6	0.9174	0.8642	0.0501	0.2908
	7	0.7738	0.2699	0.4752	0.6151
	8	0.6918	0.2707	0.2589	0.9343
	9	0.0720	0.1034	0.2184	>0.0163
	10	0.6257	0.9627	0.0933	0.2618
Ca%	1	0.3519	0.4551	0.3112	0.9889
	2	0.5521	0.1102	0.6773	0.7660
	3	0.6091	0.1363	0.7944	0.8403
	4	0.7628	0.3089	<0.0687	0.6357
	5	-	-	-	-
	6	0.0884	0.7438	0.5853	0.3219
	7	0.9095	0.0743	0.5015	0.3944
	8	0.2762	0.9940	0.1530	0.8933
	9	0.8427	0.3953	0.1860	<0.0243
	10	0.2230	0.5767	0.8195	0.8119
K%	1	0.2933	0.4738	0.8541	0.8481
	2	0.0787	>0.0100	0.7115	0.9535
	3	>0.0001	>0.0004	0.9698	0.7227
	4	>0.0423	>0.0122	0.8795	0.3971
	5	-	-	-	-
	6	>0.0006	>0.0001	0.6328	0.9492

	7	0.1312	>0.0205	0.9588	0.1441
	8	0.2343	0.0742	0.9759	0.9593
	9	>0.0288	>0.0032	0.2818	<0.0213
	10	>0.0333	>0.0399	0.7568	0.6500
Mg%	1	0.3569	0.9652	0.1585	0.8492
	2	0.4917	0.0704	0.9987	0.7235
	3	<0.0394	<0.0336	0.6531	0.8592
	4	0.7489	<0.0101	0.0667	0.5835
	5	-	-	-	-
	6	0.0652	<0.0128	0.4626	0.8736
	7	0.1352	0.0991	0.7446	0.3219
	8	0.1238	<0.0163	0.6209	0.5814
	9	0.1148	<0.0315	0.6596	0.1384
	10	<0.0036	<0.0284	0.5832	0.9891
P%	1	0.8217	0.9670	0.5721	0.3364
	2	0.5193	0.1311	0.1488	0.6638
	3	0.7790	0.8818	0.2812	0.4061
	4	0.2142	0.0788	0.3818	0.1068
	5	-	-	-	-
	6	0.8785	0.3692	0.3293	0.0849
	7	0.9058	0.2884	0.9992	0.6650
	8	0.8858	0.9121	0.8911	0.3070

	9	0.2488	0.9524	0.6611	0.0882
	10	0.7124	0.2581	0.9655	0.2093
Zn (ppm)	1	0.1603	0.6926	0.0628	0.9807
	2	0.3583	0.2469	0.5021	0.4943
	3	0.0966	0.9336	0.5938	0.6890
	4	0.9750	0.1186	0.8674	0.7483
	5	-	-	-	-
	6	0.2913	0.8645	0.8489	0.9880
	7	0.2943	0.2634	0.2297	0.7781
	8	0.1073	0.2193	0.7316	0.8528
	9	0.6492	0.4098	0.9566	0.8499
	10	0.4947	0.2525	0.6909	0.1375
Cu (ppm)	1	0.0958	0.6632	0.7140	0.5835
	2	0.7780	0.2688	0.1783	0.1783
	3	0.5025	0.8220	0.4056	-
	4	0.5104	0.1126	0.2203	0.8340
	5	-	-	-	-
	6	0.5603	0.5603	>0.0123	0.6123
	7	0.4708	0.2376	0.2606	0.2922
	8	0.5723	-	0.2216	0.4774
	9	0.5427	0.5427	0.5018	0.7152
	10	0.6956	0.7693	0.8162	0.3590

ADF%	1	0.6822	0.8584	o.2415	0.3722
	2	0.5769	0.4263	0.0632	0.5311
	3	0.2098	0.5354	0.8801	0.0842
	4	0.8109	0.0515	0.2530	0.9031
	5	-	-	-	-
	6	0.7953	>0.0293	0.6379	0.9819
	7	0.6458	0.9929	0.2971	>0.0373
	8	0.5732	0.4594	0.4656	0.7196
	9	0.5822	0.8122	0.4673	0.7436
	10	0.5462	0.6016	0.0934	0.4770

[L] Napier grass in combination with leucaena

[C] Napier grass in combination with calliandra

[<] Significantly lower than in monoculture

[>] Significantly higher than in monoculture

APPENDIX 10. A short description (FAO, 1990; London, 1984) of the soil types common to western Kenya

SOIL NAME	BRIEF DESCRIPTION
Ferralsols:	Strongly weathered soils of the humid tropics with oxic horizons. CEC < 16 me/100 g clay.
Acrisols:	Acid low base status lessives; more strongly leached than luvisols, but insufficiently weathered for ferralsols. Base saturation of B horizon <50% (cf luvisols)
Luvisols:	Lessives - soils having argillic B horizons, with high base status. Base saturation of B horizon >50% (cf acrisols)
Lixisols:	Soils having an argillic B horizon which has a CEC < 24 cmol (+) kg^{-1} clay .Base saturation of B horizon $\geq$50%

APPENDIX 11. Spearman rank order coefficients between different leafy biomass and nutrients in *L. leucocephala*

	FLB	DM	DM%	CP%	Ca%	Mg%	K%	P%	Zn	Cu	ADF
FLB	-	0.857	-.357	0.619	0.167	0.347	0.607	0.262	0.071	0.455	0.192
DM		-	0.143	0.107	0.000	0.306	0.829	-.286	-.214	0.143	-.126
DM%			-	-.667	0.024	-.216	-.107	-.476	-.500	-.333	-.012
CP%				-	0.050	0.268	-.024	0.250	-.000	0.293	-.017
Ca%					-	0.837	0.071	-.500	0.450	0.695	0.619
Mg%						-	0.095	-.577	0.410	0.613	0.282
K%							-	0.048	-.071	0.347	0.190
P%								-	0.200	-.318	0.000
Zn									-	0.276	0.594
Cu										-	0.563
ADF											-

* Significant positive correlations existed between FLB and DM (r=0.857), K% and DM (r=0.829), Mg% and Ca% (r=0.837), and Cu and Ca% (r=0.695)

APPENDIX 12. Spearman rank order coefficients between different leafy biomass and nutrients in *C. calothyrsus*

	FLB	DM	DM%	CP%	Ca%	Mg%	K%	P%	Zn	Cu	ADF%
FLB	-	0.786	0.000	0.647	0.429	0.214	-.143	-.132	0.263	0.611	-.357
DM		-	0.143	0.000	-.357	-.464	-.357	-.321	0.270	0.144	-.821
DM%			-	-.766	-.333	-.190	-.262	-.667	-.611	-.240	-.167
CP%				-	0.736	0.703	0.192	0.529	0.517	0.597	-.201
Ca%					-	0.917	0.150	0.234	0.100	0.745	0.267
Mg%						-	0.183	0.243	0.059	0.703	0.383
K%							-	0.695	0.728	0.243	-.083
P%								-	0.840	-.000	-.318
Zn									-	0.206	-.619
Cu										-	0.042
ADF%											-

* Significant positive correlations between FLB and DM (r=0.785), Ca% and CP% (r=0.736), Mg% and CP% (r=0.703), Mg% and Ca% (r=0.917), Cu and Ca% (r=0.745), Mg% and Cu (r=0.703), K% and P% (r=0.695), Zn and K% (r=0.728), and Zn and P% (r=0.840).

* Significant negative correlations existed between ADF% and DM (r=-0.821), CP% and DM% (r=-0.766), and DM% and P% (R=-0.667).

APPENDIX 13. Spearman rank order coefficients between different leafy biomass and nutrients in *P. purpureum*

	FLB	DM	DM%	CP%	Ca%	Mg%	K%	P%	Zn	Cu	ADF%
FLB	-	0.964	-.107	-.120	0.071	-.405	0.429	0.096	-.214	-.275	0.262
DM		-	0.036	-.198	-.036	-.286	0.393	0.198	0.179	-.072	-.000
DM%			-	-.072	0.238	0.333	-.667	-.443	-.024	0.036	-.952
CP%				-	-.795	0.050	0.485	0.555	0.159	0.752	-.033
Ca%					-	-.1000	-.717	-.795	-.533	-.845	-.150
Mg%						-	-.417	0.435	0.500	0.209	-.217
K%							-	0.586	0.200	0.326	0.567
P%								-	0.720	0.622	0.435
Zn									-	0.603	0.067
Cu										-	-.159
ADF%											-

* Significant positive correlations existed between FLB and DM (r=0.964), CP% and Cu (r=0.752), and P% and Zn (r=0.720).

* Significant negative correlations existed between K% and DM% (r=-0.667), DM% and ADF% (r=-0.952), CP% and Ca% (r=-0.795), K% and Ca% (r=-0.717), P% and Ca% (r=-0.795), and Ca% and Cu (r=-0.845)