CRUDE PROTEIN AND MINERAL STATUS OF FORAGES GROWN ON PELLIC VERTISOL OF GINCHI, CENTRAL HIGHLANDS OF ETHIOPIA

by

LEMMA GIZACHEW S/GEBREAL

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Dedicated to

My wife Tadelech, who endured the challenges of attending to the needs of our children alone for the period I spent on this study

and

My children Kidist, Brook and Hanna whom I was not able to stay with at a very vulnerable stage of their life, may this convey the best future for them.

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CRUDE PROTEIN AND MINERAL STATUS OF FORAGES GROWN ON PELLIC VERTISOL OF GINCHI AREA, CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT

The study was conducted at Ginchi, which is situated in the western Shoa zone of the central Ethiopian highlands. The main aim of the study was to assess the crude protein (CP) and mineral status of feeds produced in the Vertisol area of Ginchi by relating them to pasture management, seasonal and/or soil factors. Aspects of the farming systems that relate to feed resource management, utilization, constraints and opportunities were also investigated. The N and mineral element status of the soil and the feeds were evaluated during the dry and wet seasons of 2001 by analysing samples collected from adjacent 18 year round grazed grassland (YRG) plots, 12 seasonally stock excluded grassland (SSE) plots, 10 tef (*Eragrostis tef*) and 9 grass pea (*Lathyrus sativus*) plots, and noug (*Guizotia abyssinica*) seedcake samples obtained from oil extracting plants.

The results of the farming systems study demonstrated a strong inter-dependence between crop and livestock subsystems. Livestock rely on crops for their diets as much as the latter do on livestock for traction power and manure. Stored feed supplies are preferentially fed to working oxen, milking cows and animals intended for sale. The period extending from the late dry season (March-May) up until the mid wet season

(July) appeared to be the time when feed shortages were most critical. Smallholders try to cope with the problem through efficient use of SSE grassland, crop residues and crop weeds. Occasionally they also provide domestic herbivores with locally produced supplemental feeds, common salt, mineral rich soil or mineral water.

Soil samples were analysed for particle size class, pH, organic matter (OM), cation exchange capacity (CEC), N, P, Ca, Mg, K, Na, Fe, Mn, Cu and Zn. Most of these soil parameters differ markedly ($P<0.05$) between the different land use systems. Parameters such as OM and total N in particular were very high in grassland soil in comparison to soil under cropping systems ($P<0.01$). The results also revealed a substantial across site variation of these soil parameters.

For native pastures, the type of pasture management had a considerable influence on floristic composition, herbage CP and mineral concentration. Compared to the YRG grassland the SSE grassland contained a higher proportion of herbaceous species with superior CP and mineral concentrations. The CP and mineral contents of YRG grassland exhibited marked changes with the advance of the season ($P<0.05$). For the majority of the elements, the across site variation of herbage mineral concentrations were substantial.

Appreciable mineral concentration differences ($P<0.05$) were noted between residues of tef and grass pea. These residues were also characterized by substantial CP and mineral concentration variations across sites. Noug seedcake and grass pea grain were rich in CP. The level of P in noug seedcake was also exceptionally high.

The observed high variations in soil and feed N and mineral element contents, and the lack of strong and consistent correlations between soil and feed suggest that soil analyses are not reliable in determining the N and most mineral elements status of feeds produced in the Vertisol area of Ginchi. The only soil mineral elements with any degree of reliable predictive ability were exchangeable Na and available P.

The findings of this study clearly demonstrated that the CP and mineral element concentrations differed among the different feed classes produced in the Vertisol area of

Ginchi. For most of the examined feeds, concentrations of P, Na, Cu and Zn were below the recommended dietary requirements of cattle.

Keywords: Crop residue, crude protein, farming systems, floristic composition, mineral elements, pasture management, season, supplemental feeds, Vertisols

DECLARATION

I hereby declare that the subject matter contained in this dissertation is my own independent work and that it has not previously been submitted to another University for degree purposes. Sources of laboratory procedures and consulted materials are cited. I furthermore cede copyright of the dissertation in favour of the University of the Free State.

Signature Date 09-02-2003

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CHAPTER 1

INTRODUCTION

Ethiopia is essentially an agrarian country, where the agricultural sector contributes the largest share of the gross domestic product (GDP), foreign earning, employment and raw material to the local industry. Presently livestock contributes about 15 % of the total GDP and 40 % of the agricultural GDP of the country (Abassa, 1995). At the level of the household, livestock fulfil a variety of functions. They provide owners with ready cash, manure, farm power, milk, meat, hide and skins. They are also kept as a means of capital accumulation and to meet ceremonial functions and gain higher social status in the community. The current contribution of the livestock sector to both household and national economy, however, is far less than expected and the livestock performance remains very low, even by African standards. For example, Africa's continental average for cattle meat and milk production was 146 and 490 kg $head^{-1} year^{-1}$, respectively (FAO, 1998). Meat and milk production for Ethiopia for the same period was on the order of 105 and 209 kg $head^{-1} year^{-1}$.

Among the hosts of factors contributing to the low level of livestock productivity, nutritional inadequacy of native pastures and crop residues is most notable (Jutzi *et al.*, 1986). This fact has influenced past and present livestock research to focus on aspects of animal nutrition. A lot more needs to be done in this area, however, as a small improvement in the provision of a balanced diet can bring about a sizeable gain in animal production. Improved livestock production requires the provision of all essential nutrients in adequate quantity. Among nutrients required by livestock, the attention given to the mineral status of feeds has been generally low in Ethiopia. A number of reasons can be given for this disproportionately low research input, some of which are the high analytical costs, lack of appropriate facilities and the generally held misconception that mineral levels in forages could satisfy animal requirements. The latter had no scientific ground, for forage-based diets can rarely supply all required mineral elements at an amount enough to meet livestock requirements. The limited studies in Ethiopia, for instance, have confirmed deficiencies of some mineral elements in crop residues and native pastures (Faye *et al.*, 1983; Kabaija & Little, 1988; Woldu Tekle-Debessai *et al.*, 1989; Khalili, 1991; Lemma Gizachew *et al.*, 2002).

In the present study, crude protein (CP) status of feed was examined in addition to minerals, because it is the adequacy of CP supply that ultimately determines the absolute amount of minerals consumed by livestock relying on fibrous feeds (McDowell, 1996). In any event, information on factors governing the CP content of feed is under-documented in Ethiopia.

For the domestic herbivores of the Ginchi Vertisol area, native pastures and crop residues are the major sources of minerals and other nutrients, although whole crop or grains of grass pea (*Lathyrus sativus*) and noug (*Guizotia abyssinica*) seedcake, common salt, mineral rich soil and water (*hora*) are occasionally used. The mineral content of the soil is an important determinant of feed mineral composition, but this, to a great extent, depends upon the status of factors limiting plant nutrient availability (Reid & Horvath, 1980; McDowell, 1985). For the poorly drained Vertisols of Ginchi, the issue of plant nutrient availability is as important as the total amount of nutrients in the soil. Plant genotype is the other important factor that affects CP content of feed and mineral composition. Plant species vary in the extent to which they extract nutrients from the soil solution. In food crops, the influence of genotype on crop residue CP and mineral composition is evident even among cultivars belonging to a single plant species (White *et al.,* 1981). Likewise, in grasslands factors that affect floristic composition can have a substantial influence on the mineral concentration of available forages. Stage of maturity also affects forage CP and mineral composition considerably. In Ethiopia, studies investigating the effects of the above factors on feed CP and mineral concentrations are virtually non-existent. Such information is vital, particularly for identifying potentially limiting mineral elements and factors controlling their dynamics.

This study aims at addressing the following objectives:

i) to describe the livestock feed production, management and utilization as well as the bio-physical and socio-economic environments of the Vertisol area of Ginchi

ii) to assess the status of soil nutrients and related physico-chemical parameters of highland Vertisols under native grasslands and cropping systems

iii) to investigate the effects of soil, pasture management, genotype and season on CP and mineral composition of highland native pastures

iv) to evaluate the CP and mineral composition of crop residues and supplemental feeds grown on Vertisols of Ginchi area

CHAPTER 2

LITERATURE REVIEW

2.1. SOIL NUTRIENT STATUS AND FACTORS INFLUENCING THEIR AVAILABILITY

Studying the nutrient status of soil is important for two basic reasons. Firstly, soil is the primary reservoir of plant nutrients and it has a major effect on the concentration of N and mineral elements in forages growing upon it. In cases of inherent soil infertility, forages react to low level of available nutrients by limiting their growth or reducing the concentration of the deficient elements in their tissue or by both (Underwood & Suttle, 1999). Secondly, soil directly contributes to the mineral element needs of the grazing animals when ingested as such or as a pasture contaminant. Soil contaminated pasture swards contain much more mineral elements than their clean counterparts. This is particularly true for Fe, Cu and Mn, elements whose levels in the soil exceed that of the pasture by 3-16 fold (Healy, 1973). Under a heavy grazing intensity, animals consume a high amount of soil, which then negatively affects the health and mineral element status of the animals. At a high grazing intensity, annual soil consumption may amount to 700 kg head^{-1} in cattle and 75 kg head^{-1} in sheep (Grace, 1983). Nevertheless, the extent of absorption by the animal is influenced by the antagonistic interaction between the mineral elements and the conditions of the animal's alimentary tracts. A high level of soil ingestion of some soils was observed to cause a 50 % decline in Cu availability (Suttle *et al.*, 1984). This is due to the high level of Fe in the soil, which ties up Cu and transforms it to an insoluble form. Grace *et al.* (1996), on the other hand, did not find any change in liver Cu, Mn, Fe and Zn concentration of sheep fed with two types of soil.

Based on the amount required to fulfil plant physiological functions, nutrients in the soil are classified into macro- and micro-nutrients. Plants take up N, P and K in large amounts and hence are called macro-nutrients. Nutrients like Ca, Mg, Na, Fe, Mn, Cu and Zn, on the other hand, fall under the micro-nutrient category because plants require them in lesser quantities. From the plant nutrition's viewpoint, it is also important to make a distinction between the total reserve and the plant available fraction of an element in the soil. The total nutrient reserve is directly related to the type of parent material and extent of weathering. Soil that develops from basic igneous rocks (granite and basalt), for instance, are rich in most nutrients in comparison to those originating from acid igneous or sedimentary rocks (limestone and sandstone) (Reid & Horvath, 1980; McDowell, 1985). Similarly, soil developed from relatively less weathered Vertisols contains a higher nutrient reserve than the highly leached and weathered Oxisols, Alfisols or Ultisols (Haby *et al.,* 1990). The Pellic Vertisols of the study area, which originates from weathered basalt are claimed to be rich in Ca, Mg and K (Desta Beyene, 1982; Kamara *et al.,* 1989). The amounts of readily soluble trace elements are also reported to be higher in fine textured than in coarse textured soils (McDowell, 1985). A plant available nutrient is of immediate and practical significance as it largely governs the concentration of N and minerals in pasture and/or residues of food crops. Although the ability of plants to extract nutrients from the soil differs appreciably among different genotypes, the concentration of elements in their tissues generally reflects the amount of available element in the soil solution (Reid & Horvath, 1980). The availability of soil nutrients to plants is controlled by drainage, soil pH, CEC, texture, OM contents and interaction between nutrients (Cottenie, 1980; Reid & Horvath, 1980; Katyal & Randhawa, 1983; McDowell, 1985; Tisdale *et al.*, 1993). The amount of plant available nutrients in the soil environment can also be affected by the prevailing land use system (Lewis *et al.*, 1987; Aguilar *et al.*, 1988; Bowman *et al.*, 1990; Tisdale *et al.*, 1993).

The drainage status of a soil is often associated with the landscape position and/or the nature of a soil. Soil properties follow a certain pattern of distribution in line with the variation in soil texture, moisture content and nutrient movement and storage on different positions of the landscape (Malo *et al.*, 1974; Loganathan *et al.*, 1995). Soil nutrients may accumulate in the lower landscape positions, but some of these nutrients could have a limited availability if the drainage condition is poor. Waterlogging creates an environment that favours the reduction of elements such as Cu, Fe and Mn, and increase their solubility and availability to plant roots (Healy, 1973; Reuters, 1975; Reid & Horvath, 1980; Tisdale *et al.,* 1993). Flooding increases the relative amount of Ca in the soil solution and pasture uptake, but poor soil aeration depresses pasture growth (Currier *et al.*, 1983). Other workers (Pastrana *et al.*, 1991a) have also reported a change in exchangeable soil Ca content with season in response to soil moisture status. For N, excessive soil moisture and poor aeration slows its mineralization from OM and favour a high rate of de-nitrification. In effect the concentration of N in plants tend to decrease in poorly drained soils (Reid & Horvath, 1980). Poor soil drainage also slows down the decomposition of organic P to inorganic P (Tisdale *et al.,* 1993) and suppresses the subsequent uptake by plants. Similarly, waterlogging influences plant Mg uptake. In water-saturated soils, low soil oxygen was shown to impair Mg uptake of cool season pasture species, while the removal of excess water through drainage improved soil aeration and utilization of Mg (Elkins *et al.,* 1978). Waterlogging can induce Cu deficiency, particularly in soils rich in OM (Katyal & Randhawa, 1983).

Soil pH alters the rate of OM break down and the subsequent release of nutrients to plants. Low pH increases the availability of acidic cations (Al, Fe and Mn) to a toxic level. At high concentrations, these elements interfere with the absorption of P, Ca, Mg and other basic cations (Reid & Horvath, 1980; Tisdale *et al.*, 1993). The availability of the acidic cations decreases with the rises of soil pH above the near neutral reaction. High exchangeable Ca raises soil pH, which in turn depresses the availability of P, Fe, Mn, Cu and Zn (Tisdale *et al.*, 1993). Phosphorus forms less soluble compounds with Fe^{3+} and Al^{3+} at low pH, more soluble compounds at near neutral pH (6.0 to 6.8), and less soluble compounds with Ca^{2+} and Mg^{2+} at a pH value of 7 or more (Tisdale *et al.*, 1993). The pH of surface soil (0-20 cm) in the present study area is reported to range from weakly acidic to neutral (6.1 to 6.8) with a high base saturation (Morton, 1977; Desta Beyene, 1982). For the same soil a slight rise in soil pH, however, was noted with an increase in soil depth (Kamara *et al.*, 1989).

The amount of soil exchangeable cations that is regarded as low or high is related to the CEC of the soil. In a soil having a CEC value of ±25-meq (100 g soil)$^{-1}$, cations level in excess of 19.96, 1.28 and 2.47-meq (100 g soil)$^{-1}$ demonstrate high exchangeable Ca, K and Mg, respectively (Cottenie, 1980). At the same value of CEC, cations level lesser than 4.99, 0.19 and 0.25-meq (100 g soil)$^{-1}$ signify very low soil concentrations of Ca, K and Mg, respectively. For the Vertisols around Ginchi, values higher than the upper limit have been reported for the above exchangeable bases (Desta Beyene, 1982; Kamara *et al.*, 1989).

The soil clay minerals act as a source for exchangeable cations (Haby *et al.,* 1990). Fine textured soils that originate from rocks rich in minerals containing Ca are particularly high in exchangeable Ca. Amongst the clay minerals, the 2:1 montmorillonitic clays being high in CEC are able to hold more exchangeable cations. The level of montmorillonitic clay in the soil of the study area exceeds 50 % (Morton, 1977; Kamara *et al.*, 1989).

Soil OM serves as a reservoir of plant nutrients, but high OM may not necessarily ensure increased availability of every plant nutrient. For instance, Cu in soil is strongly bound to OM and less readily absorbed by plant roots (Reid & Horvath, 1980; Katyal & Randhawa, 1983; Haynes, 1997). Soils rich in OM are, therefore, low in plant available Cu. The extent of this binding by soil OM is particularly high in montmorillonitic clay minerals (Tisdale *et al.*, 1993). The complexation of Zn by soil OM and clay minerals increases with a rise in soil pH (Tisdale *et al.*, 1993). Nevertheless, compared to Cu and Fe ions, Zn^{2+} ion is very weakly bound by OM (Loneragan, 1975). The OM bound Zn is in dynamic equilibrium with the soil solution and readily available to plant roots (Katyal & Randhawa, 1983; Tisdale *et al.*, 1993).

As a result of the modifying effect of the interaction between mineral elements and/or the involvement of soil and other environmental factors, soil and plant mineral element associations at times diverge from what is normally expected to prevail from the relative concentration of elements in the soil. The removal or deposition of animal excreta and alluvial materials carried by wind and water erosion and forage contamination by soil contribute to a high variability of elements in soil and forage tissues. As a result, there are a number of studies that documented poor or negative soil and forage associations (Mtimuni, 1982; Khalili, 1991; Jumba *et al.*, 1995b; Lemma Gizachew *et al.*, 2002). In soils excessively high in Fe, Al, or Ca, plants may exhibit P deficiency despite the latter's abundance in the soil solution (Tisdale *et al.*, 1993). This happens because P forms insoluble compounds with Fe, Al or Ca. Elements like N and K, when present in the soil at high concentrations, interfere with plant Ca and P uptake. A decline in pasture Ca and P contents were noted with the increase in the level of soils N (Rosero *et al.*, 1980; Rodgers, 1982). Low Ca and P content of pastures growing on urine patches that are normally high in N and K, reinforces this assertion (Joblin & Keogh, 1979). Phosphorus fertilizers, too, have a depressing effect on pasture Ca concentration (Coates *et al.*, 1990). In both plants and animals, high K in relation to Mg will induce a Mg deficiency. Soil K to Mg ratio in excess of 1 milli-equivalent (meq) is indicative of Mg deficiency

(Cottenie, 1980). Similarly, when present in high amounts, Ca^{2+} and Mg^{2+} compete with K^+ for entry into the plant roots, and plants growing in such soil require a high K supply for optimum performance (Tisdale *et al.*, 1993). When present at high concentrations, Fe, Zn and Cu can cause a Mn deficiency (Katyal & Randhawa, 1983; Tisdale *et al.*, 1993). The Fe to Mn ratio is particularly important to assess the sufficiency or imbalances of these elements. Ratios above 2.5 indicate Mn deficiency, while values below 1.5 show its potential toxicity (Katyal & Randhawa, 1983). Copper uptake by plants root is low in soil solutions high in Zn, Al, Fe or P (Tisdale *et al.*, 1993). Likewise, metallic cations such as Ca, Cu, Mn and Fe, when present at higher amounts, inhibit plant Zn^{2+} uptake (Giordano *et al.*, 1974; Tisdale *et al.*, 1993). Where plant nutrient availability controlling factors and ratios between antagonistic elements are favourable, the plant mineral element concentrations reflect the mineral element status of the soil (Reid & Horvath, 1980). Results documenting positive soil and plant mineral element relationships are thus not uncommon. Russele *et al.* (1989) and Kerridge *et al.* (1990), for instance, have observed strong associations of soil P with that of pasture plant P concentration. Similar positive associations have been found between exchangeable K and pasture K (Russele *et al.*, 1989), and between exchangeable Mg and pasture Mg (McIntosh *et al.*, 1973). Studies of Sherrell & McIntosh (1987) also reported negative correlations between pasture Mn content and soil pH. A lowering in pH raises Mn availability and favours plant uptake. A high plant Mn in soil with a low pH is an expected phenomenon.

Different land uses that influence vegetation cover and the state of soil disturbance, could produce a soil system with a distinct nutrient status and soil environment. This variation can clearly be seen in the same type of soil under cropping and grassland systems. The level of soil OM declines with cultivation (Hedley *et al.*, 1982; Aguilar *et al.*, 1988; Bowman *et al.*, 1990; Tisdale *et al.*, 1993). The decline in soil OM content impoverishes soil fertility and negatively affects soil physical and chemical properties. A concomitant decline in N, P and other essential nutrients with cultivation has been empirically shown in a number of long-term studies (Hedley *et al.*, 1982; Aguilar *et al.*, 1988; Bowman *et al.*, 1990). The opposite course of events takes place under grassland systems, but this is dependent upon the age of the pasture. In the upper layer (0-10 cm) of the soil, properties that are known to affect plant nutrient availability, namely soil pH and OM content were shown to be positively associated with pasture age (Lewis *et al.*, 1987).

2.2. CRUDE PROTEIN AND MINERALS IN FIBROUS FEEDS

Pastures and crop residues often are deficient in one or more of the essential nutrients. Of all nutrients, protein and mineral deficiencies are commonplace in fibrous feeds and are the most serious constraints to increased animal production. To date ample evidences are available worldwide to justify this assertion.

2.2.1. Pasture CP content

In the tropics, for the major part of the year the CP content of grasslands does not meet requirements of grazing animals (McDowell, 1985). The CP content of the Ethiopian highland native pasture, for instance, has been reported to fall below 6 % for more than eight months of the year (Zinash Sileshi *et al.*, 1995). Minson & Milford (1967) stressed that forage containing CP level lower than 7 % cannot meet the minimum N requirements of fibre degrading rumen microbes. Pasture CP content is a function of soil N, stage of maturity (Buxton, 1996) and floristic composition of the pasture especially with respect to legumes (Minson, 1990).

If other nutrients are not limiting, the vegetative growth of forage plants is dependent on the level of N in the soil solution. The level of N in grassland soil can be increased effectively by adopting pasture management practices favouring N-fixing pasture legumes or through the use of N-fertilisers. Fertiliser N raises the concentration of N and dry matter (DM) yields of pastures (Reid & Horvath, 1980; Minson, 1990). It appears that N fertilisers decrease total herbage Ca and Mg levels, while increasing the concentration of K in plants when the latter element is found in adequate supply in the soil (Reid & Horvath, 1980). Rosero *et al.* (1980) also demonstrated a decline in herbage Mg content with N fertilisation. Dramatic responses from grazing animals are often obtained when fertilisation of pastures with deficient soil nutrients is accompanied with adequate application of N fertilisation. Davison *et al.* (1997a, b) have shown a respective milk yield increase of 3 930 to 4 310 and 4 610 kg cow^{-1} for P applied at the rate of 22.5 and 45 kg ha^{-1} together with 300 kg N ha^{-1}. The response to applied P in this study disappeared when the application of fertiliser N is withheld or reduced to 100 kg ha^{-1}. This reinforces the assertion that mineral supplements can only meet the intended goal of raising livestock productivity when the CP content of the diet is within the optimum limit of the requirement (Van Niekerk & Jacobs, 1985; McDowell, 1996).

Compared to mature forages, green and immature forages supply higher amounts of protein to rumen micro-organisms (Buxton, 1996). The specific amino acids and NH_3 released into the rumen for microbial protein synthesis from the pasture and saliva matches the available energy more in immature pastures than it does in fully mature pastures (Hogan, 1982, cited by Minson, 1990). As N is a mobile element, plants break down protein and release N in old leaves to metabolically active younger leaves. At maturity, the protein rich leaves are poorly retained on the stem. Since this leads to the decrease in leaf fraction and a corresponding increase in stem component, the CP content of pastures falls sharply with the progress of maturity (Buxton, 1996). A number of investigators have also reported the fall in CP content of forages with the advance of maturity and season (Roberts, 1987; Dabo *et al.*, 1988; Coates *et al.*, 1990; White *et al.*, 1992; Zinash Sileshi *et al.*, 1995; Kume *et al.*, 2001). When the CP content of forages falls below 7 %, DM intake of animals (Minson & Milford, 1967) and the activity of fibre degrading rumen microbes are hampered (Minson, 1990).

The floristic composition of a pasture has a marked influence on the amount of CP available to grazing animals. Irrespective of ecological origin, grasses contain less CP than legumes (Minson, 1990; Coates *et al.*, 1990). Minson (1990) reported mean CP values of 115 and 170 g kg^{-1} DM for grass and legume species, respectively. Of the total tropical grass samples that the above author used to calculate mean CP value, 50 % of the grasses were found to contain less than the critical CP level.

2.2.2. Crop residue CP content

Coarse and bulky physical characteristics and low concentration of essential nutrients make crop residues less appropriate feeds for a high level of livestock production. A glance at the chemical composition of most crop residues data readily reveals the severity of N deficiencies. Despite the genotype difference, the CP contents of crop residues from the temperate region often do not exceed 4 % (Hvelplund, 1989). From samples collected from the highlands of Ethiopia, Kabaija & Little (1988) reported 1.7, 1.6 and 1.8 % CP values for tef (*Eragrostis tef*), wheat (*Triticum spp.*) and barley (*Hordeum vulgare*) straws, respectively. For the same region and straw types, about three times as high as the above CP values has, however, been documented (Seyoum Bediye & Zinash Sileshi, 1998). This variation may be attributed to soil fertility differences. However, in none of the above cases, did the crop residues contain CP approaching the minimum threshold of 7 %, which is needed to optimise rumen fermentation and maintain a positive N balance. In addition to the low level of CP in crop residues, a large proportion of the protein in these feeds is associated with cell wall structures. As a result, CP in crop residue neither had a high rumen degradability nor appreciable digestibility in the small intestine (Hvelplund, 1989).

The other serious limitation of crop residue based feeds is that the rate and extent of N degradation in the rumen often does not match the products of carbohydrate fermentation. With tef straw, for instance, the amount of ammonia-N released following rumen degradation is 70 % less the level required for optimum fermentation and microbial synthesis (Seyoum Bediye & Zinash Sileshi, 1998). Ammonia needed for this purpose normally comes from the degradation of endogenous and dietary rumen degradable protein (RDP) such as urea. For untreated straw, the recycled endogenous N is reported to represent 37 % of microbial requirement (Durand, 1989). The remaining 63 % of N needs to be supplied by the diet. This signifies how important the CP content of a diet is in attaining maximum feed utilization efficiency.

To transform crop residue from a sub-optimum diet to a more productive diet, raising the CP level through the supplementation of RDP and rumen undegradable protein (UDP) is crucially important. Different avenues are available to improve the protein status of crop residues. This includes selecting crop genotypes with high CP values; treatment with alkali, anhydrous ammonia, or urea; and supplementing them with legume, oil seedcake or other protein sources. As crop residues from cultivars of high DM digestibility are positively associated with CP content (White *et al.*, 1981), developing crops with such desirable feature through breeding, if achieved successfully, would led to the development of a safer and cheaper nutritious diet. Adding urea (RDP source) to tef straw basal diet has been shown to increase the DM intake, but urea treatment appeared inferior to noug (*Guizotia abyssinica*) seedcake or forages legume hay supplementation in terms of sheep daily weight gain (Lemma Gizachew, 1992). Legume supplementation of a straw diet has also a good reputation of improving milk production (Kahurananga, 1982). The superiority of the noug seedcake and the legume hay may be related to their ability to supply RDP, UDP and other limiting nutrients (e.g. minerals) simultaneously. Oilseed cakes are especially superior with regard to supplying both RDP and UDP (Lindsay *et al.,* 1982; Meissner, 1999). Forage legumes also contain either organic substances that protect the degradation of protein in the rumen or supply more UDP particularly when dried or frozen (Tothill *et al.*, 1990). The simultaneous dietary provision of RDP and UDP stimulate cellulolytic activity (Durand, 1989) and increase the amount of protein absorbed in the small intestine. Energy being another limiting nutrient in residues, straw utilization and DM intake could be maximized when small amounts of starchy carbohydrates are fed together with RDP and UDP (Smith *et al.,* 1980).

2.2.3. Pasture mineral content

In both tropical and temperate pastures, mineral deficiencies or mineral element imbalances are responsible for a number of nutritional disorders and sub-optimal performance of grazing animals (Grace, 1983; McDowell, 1985; 1996; Minson, 1990). The mineral composition of pastures and the extent of their utilization by animals are the function of genotype, growth stage, inherent soil fertility/fertilisation, and inter-element interactions.

The mineral element content of pastures varies greatly depending on genotype (Long *et al.*, 1970; Greene *et al.*, 1987; Kabaija & Little, 1988; Hendricksen *et al.*, 1992; Jumba *et al.*, 1995a, b; Grings *et al.*, 1996). Under comparable growing conditions, leguminous forages are generally higher in most of the essential mineral elements than grass species (Reid & Horvath, 1980; Kabaija & Little, 1988; Minson, 1990; Hendricksen *et al.*, 1992; Underwood & Suttle, 1999). Like the legumes, herbs are also high in most mineral elements (McDowell, 1985). Some tropical grasses, however, do excel legumes in their concentration of Mn (Reid & Horvath, 1980), Zn and Mo (Minson, 1990; Hendricksen *et al.*, 1992). Considerable differences in mineral element concentrations also exist between grasses (Long *et al.,* 1970; Kabaija & Little, 1988; Minson, 1990; Hendrickson *et al.*, 1992; Jumba *et al.*, 1995a, b; Grings *et al.*, 1996) and legumes (Kabaija & Little, 1988; Minson, 1990; Hendrickson *et al.*, 1992). Some pasture species contain high level of organic compounds that interfere with the availability of mineral elements. The presence of high concentrations of oxalates in pasture tissue, for instance, can cause Ca deficiency in ruminants even when Ca is present at a high concentration. Marked crystal oxalate concentration differences were reported for tropical pasture species (Blaney *et al.*, 1982; McKenzie & Schultz, 1983).

Pasture species undergo substantial change in their mineral content with the advance of maturity and /or season (Reid & Horvath, 1980; Kiatoko *et al.,* 1982; McDowell *et al.*, 1982; Greene *et al.,* 1987; Roberts, 1987; Pinchak *et al.,* 1989; Espinoza *et al.*, 1991a, b; Pastrana *et al.*, 1991a, b; Hendricksen *et al.,* 1992; White *et al.*, 1992; Grings *et al.,* 1996; Lemma Gizachew *et al.,* 2002). Not all mineral elements in pastures, however, behave the same way with changes in plant physiological development. The decline in the concentration of mobile elements e.g. P, K (Kiatoko *et al.,* 1982; Mtimuni, 1982; Greene *et al.,* 1987; Pinchak *et al.,* 1989; Coates *et al.,* 1990; Espinoza *et al.*, 1991a; Pastrana *et al.*, 1991a; Hendricksen *et al.*, 1992; Grings *et al.*, 1996; Lemma Gizachew *et al.,* 2002) and N (Dabo *et al.*, 1988; Coates *et al.,* 1990; White *et al.*, 1992; Zinash Sileshi *et al.*, 1995; Buxton, 1996) and the little change or increase in less mobile elements such as Ca (Mtimuni, 1982; Greene *et al.*, 1987; Pinchak *et al.,* 1989; Hendricksen *et al.*, 1992; White *et al.*, 1992; Buxton, 1996; Lemma Gizachew *et al.,* 2002) is well documented. The magnitude of such changes, however, could vary among forage species. Forage legumes, for instance, are rich in most minerals and tend to maintain this superiority for much longer periods of the year than grasses in general (Coates *et al.,* 1990). The drop in mineral content of pastures with advance in maturity is the consequences of the decline in leaf to stem and new to old leaves ratios (Minson, 1990; Buxton, 1996). Results of investigations on seasonal trend of mineral elements in pastures, however, differ a great deal. This is because the mineral element status of pastures is modified by a number of environmental and/or management factors that operate in a complex unison.

The herbage mineral composition is often associated with the inherent soil fertility and/or the type and amount of fertiliser applied to the pasture (Minson, 1990). For soils derived from basic rocks, for instance, the availability of trace elements to plants is very high (Grace, 1983; McDowell, 1985). The mineral composition of pastures can effectively be manipulated through the application of mineral fertilisers. Appropriate fertilisers can raise deficient mineral elements and improve DM yield and livestock productivity. Mineral fertilisers, other than correcting the deficient element would have an added advantage of allowing grazing animals to have a more uniform mineral consumption (McDowell, 1996). Unless the mineral fertilisers applied to correct forage mineral deficiency also bring about appreciable DM yield increase, such use often becomes economically prohibitive. Nitrogen and P are the commonest elements that are used in pasture fertilisation, but fertilisers carrying other elements are also utilised in cases of extreme deficiencies in soils or pastures. Phosphorus fertilisers alone or in combination with N have been shown to boost DM yield and pasture P content (Jones, 1990). Raising pasture P to a level sufficient enough to meet livestock requirement, however, demands the application of P fertilisers at high rates (Coates *et al.*, 1990). Similar to P, the low Cu content of herbage could be raised to the limit that satisfy livestock needs through the application of Cu containing fertilisers, but levels in excess of plant requirement have to be applied (Hayne, 1997). Such high doses of mineral fertiliser on pastures have little practical significance in extensive livestock production systems, which are common in large parts of Africa. The effects of N and P fertilisers on mineral composition of pasture are not always positive. According to Rees & Minson (1982), P fertilisers decrease pasture Ca content and voluntary intake, and increase DM retention time in the reticulo-rumen. The longer rumen retention time is attributed to the narrow Ca to P ratio. As it suppresses the legume component, N application on grass/legume pasture also reduces the pasture Ca content (Rodger, 1982). Nitrogen fertilisers increase herbage Na and Zn concentration (Hopkins *et al.,* 1994). However, the availability of Mg to ruminants declines due to the simultaneous rise in pasture K with N fertilisation (Reid & Horvath, 1980).

Practically almost all-mineral elements undergo one or another form of interaction, but in terms of nutritional significance some of the interactions are more important than the others. Of these the Ca-P, K-Mg, K-Na, Cu-Fe, and Cu-Mo/S associations are of great nutritional significance. As most tropical pastures contain high Ca and a low level of P (Kabaija & Little, 1988; Woldu Tekle-Debessai *et al.,* 1989; Minson, 1990), the Ca: P ratio diverges from the suggested 1:1 to 2:1 ratio (Chicco *et al.*, 1973; Mtimuni, 1982; Alfaro *et al.*, 1988; Underwood & Suttle, 1999) and may depress the utilization of the latter. In a review, Reid (1980), however, has shown the possibility of extending the Ca: P ratios from 1:1 up to 4:1 provided the amount of P adequately meets ruminant livestock requirements. McDowell (1985) indicated that the Ca:P ratios below 1:1 and over 7:1 to be detrimental to animals. High Ca in pasture could also impair the absorption of elements such as Mg (Chicco *et al.*, 1973), Zn, Cu, Mn, Fe and I (Alfaro *et al.*, 1988). Similarly, high level of K in lush pasture in relation to Mg is shown to depress the absorption of the latter (Wylie *et al.,* 1985). Such imbalances are the major cause of hypomagnesaemic tetany in beef cows (Reid & Horvath, 1980). The most serious and commonly encountered interaction in pasture based diets is that of Fe and Cu. Iron often occur in high concentration in pastures and becomes responsible for the depletion of Cu in cattle (Humphries *et al.,* 1983; Bremner *et al.*, 1987; Phillippo *et al.*, 1987). Excess Mo and S also interacts in the rumen to form thiomolybdate, which later react with Cu to render it unavailable for normal absorption or enzymatic activities (Lee *et al.,* 1999).

2.2.4. Crop residue mineral content

Crop residues, like other fibrous diets do not supply all the essential minerals in amounts adequate enough to support high animal production. Low mineral content and poor availability is a common feature of crop residue based diets (Durand, 1989). This author has detailed the role mineral elements play in regulating rumen environment and promoting cell wall digestion and stressed the supplementation of crop residues with elements like P and Mg that are often found in low concentrations in crop residues. In Ethiopia, straw of tef, wheat and barley were shown to be deficient in Na, Zn, and Cu, and marginal to deficient in P (Kabaija & Little, 1988). Because of the variation in nutrient uptake efficiency among crop genotypes and subsequent accumulation of certain elements in plant tissues, the extent of mineral elements deficiencies in crop residue are expected to vary accordingly. Marked differences in the P content of wheat, barley and oat straw has been reported elsewhere (White *et al.*, 1981).

Responses in fibre digestibility of, and livestock performance on crop residues to mineral supplementation have been quite variable. Such inconsistencies are often associated with the protein and energy status of the diets. It is often stressed that any improvement in mineral nutrition can only be realized when the amounts of protein and energy are maintained at optimum levels of livestock requirement (Van Niekerk & Jacobs, 1985; McDowell, 1985; 1996). Doyle and Panday (1990) failed to note significant improvement in DM intake, or digestibility, of poor quality residues fed to sheep, which received a mineral supplement. The residues used in this particular study being of low digestibility (<46 %) and CP (<4 %) may lack the energy and some of specific amino acids required by rumen micro-organisms to synthesis their own protein. Where the energy and protein in a diet is sufficient, correcting the deficient mineral will produce a dramatic result. Even with ammoniated wheat straw containing CP in excess of requirement, cattle attained significantly higher gains with combined energy, protein and mineral supplementation (Beck *et al.*, 1992). With supplementation of urea-molasses-mineral block and crushed barley grain to poor quality wheat straw, Toppo *et al.* (1997) observed improvements in intake and digestibility of all nutrients. Leguminous forages, largely due to their favourable mineral and protein content and OM of higher digestibility, were also claimed to increase digestible OM intake (Goodchild & McMeniman, 1994) and performance of animals (Kahurananga, 1982; Lemma Gizachew, 1992) kept on low quality crop residues.

Owing to their maturity and excessive exposure to rain and sunshine, both the amount and availability of most minerals in crop residues are expected to be low. In grasses, sun curing depresses the availability of some trace elements. Lamand *et al.* (1977), as cited by Durand (1989), reported lower Cu and Zn digestibility in sun cured than in freshly fed forages of the same grass genotype. Improved *in sacco* (Saxena & Ranjhan, 1978a) and *in vivo* (Saxena & Ranjhan, 1978b) fibre digestibilities have clearly been demonstrated in straw supplemented with Co and Cu.

CHAPTER 3

STUDY AREA AND GENERAL METHODOLOGY

3.1. IMPORTANCE OF THE STUDY SITE

There are a number of important reasons for selecting the central Ethiopian Highland in general and the Vertisols of Ginchi area in particular for executing the present soil and feed resource N and mineral element status assessment study. These include:

- In terms of agro-ecological features, the Ginchi area represents much of the central highlands (moist agro-ecology) of Ethiopia. The central highlands are where the major agricultural activities take place and where the highest human and livestock populations are found. Moreover, this agro-ecological zone has an immense potential for intensive livestock and crop production, and is important for meeting the national food self-sufficiency objective.

- Although Vertisols are potentially fertile soils, they have an associated waterlogging problem that presents a demanding challenge with regard to the availability of plant nutrients. Waterlogging is the major culprit for increasing the availability of elements like Fe and Mn to a toxic level (Reuter, 1975; Reid & Horvath, 1980; Tisdale *et al.*, 1993) and reduced availability of Cu particularly in OM rich soil (Katyal & Randhawa, 1983). For domestic herbivores relying on feeds produced under such condition, productivity and product quality can be affected by the supply of elements well above, or below, the tolerable requirement range. The extent to which waterlogging, in Vertisols of Ethiopian Highlands, affect the N and mineral elements composition of livestock feeds has not been studied, and such investigations appear essential.

- The study area is close to the nation's capital (Addis Ababa) and many smaller towns like Ambo, Ginchi, Addis Alem and Holetta and is also accessible through the main Addis-Ambo asphalt road. This makes the area more accessible to agricultural input and markets.

- It is believed that the present study will benefit from inter-institutional Vertisols and crop management research activities that were conducted in the past and which are still underway in the area. By generating additional information the present study will contributes towards the ultimate goal of increased agricultural productivity.

3.2. DESCRIPTION OF THE STUDY SITE

3.2.1. Location

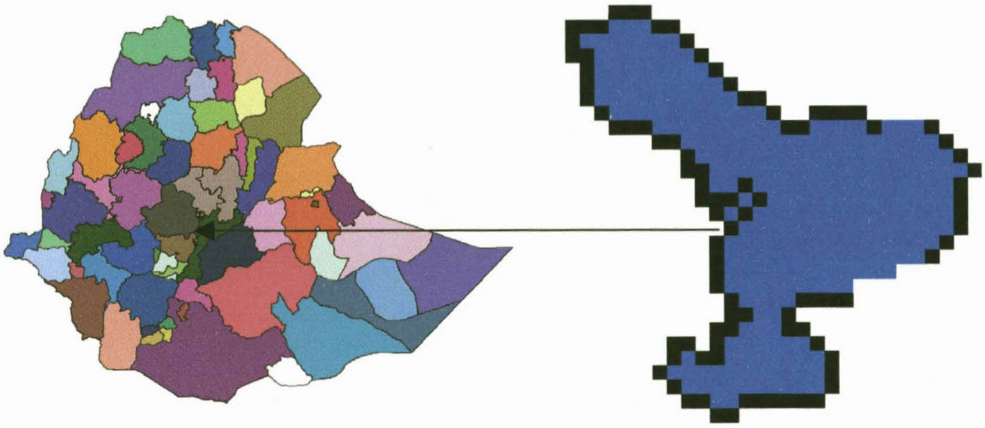

Figure 3.1. Map of Ethiopia and location of Dendi district.

The study was conducted in the Dendi district, located in West Shoa administrative zone of central Ethiopia (Fig. 3.1). Ginchi town, the capital of the district, is situated about 85-km west of Addis Ababa. It lies at approximately 09° 01' N and 38° 20' E. The elevation of the sampling sites ranges from 2 200 to 2 700 m above sea level (a.s.l.). The landscape predominantly constitutes gently undulating plains and wider valley bottoms. In the recently introduced agro-ecological zonation, which is based on the length of the growing period and thermal zones, the study site falls within an area described as tepid to cool moist mid highlands. According to the widely used previous agro-climatic classification system, however, it belongs to the generalized physiographic region of the central Ethiopian highlands (>1 500 m a.s.l.). For the sake of convenience, the latter is used whenever reference was made to the bigger environmental zone to which the study site is a part. The soil and feed (native pasture and crop residues) samples collection sites stretched about 20 km from Ginchi town in two (Addis Alem and Ambo) opposite directions along the main Addis Ababa and Ambo road. Six peasant associations, namely Yubdo-Lagabatu, Dano-Ejersa-Gibe, Awash-Bole, Awash-Boloto, Gatiro-Lafto and Golole-Bolo that bordered the main highway in both sides were used for undertaking the farming systems appraisal, assessment of native pasture floristic composition and collection of soil and feed samples for chemical analysis (Fig.3.2).

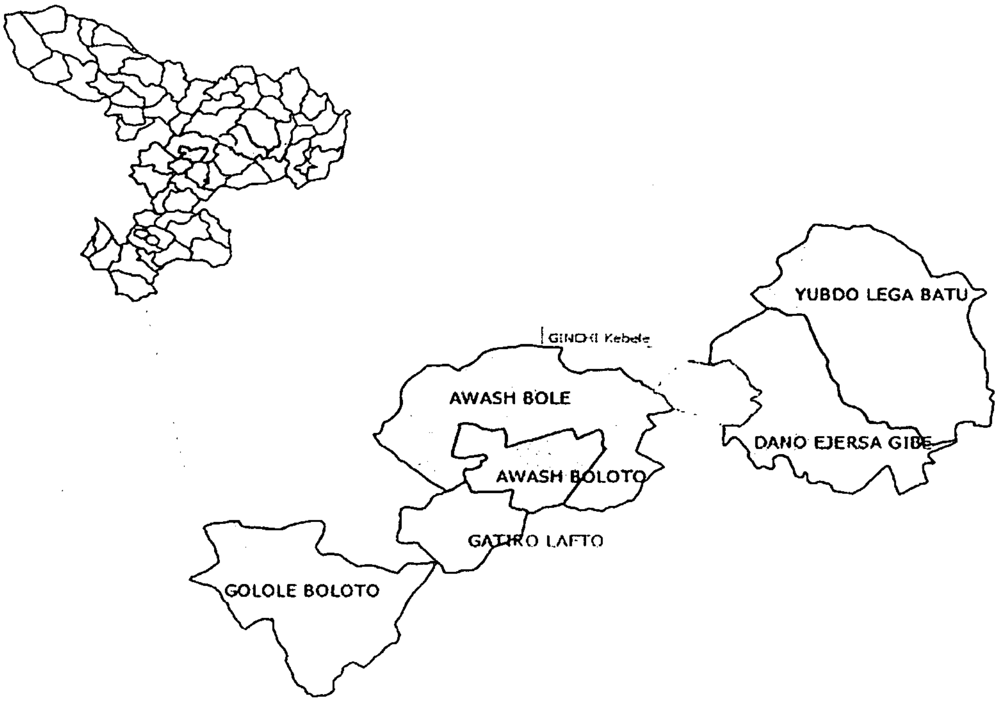

Figure 3.2. Dendi district map and studied peasant associations.

3.2.2. Soil

The major soil in the plains and bottomlands of the Dendi district belong to the Pellic Vertisol soil group (Fig. 3.3). This soil type lies largely within a slope range of 0-2 %. The parent material of the Pellic Vertisol around Ginchi is weathered basalt (Piccolo & Gobena Huluka, 1986) and their clay fraction, which is predominantly montmorillonitic clay, account for > 50 % (Morton, 1977; Kamara *et al.*, 1989). A detailed description of pedons, physical and chemical properties of the Pellic Vertisol of Ginchi has been given by Kamara *et al.* (1989).

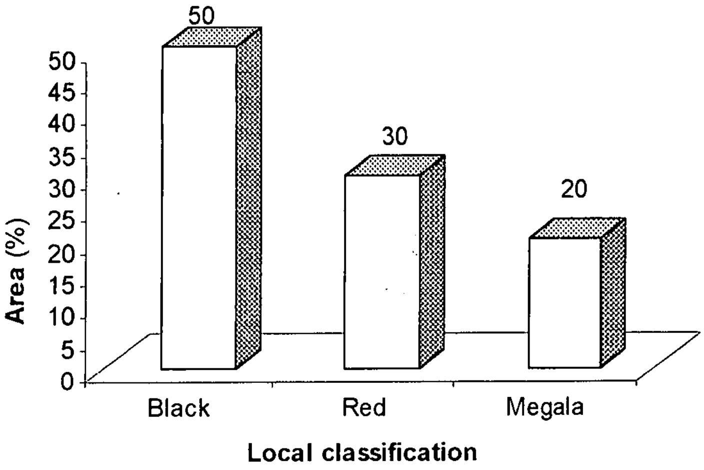

Figure 3.3. Percent area cover of different soil types in Dendi district

As the rainfall in the area is fairly high (Fig. 3.4), Vertisols in bottomland areas are inundated for a major part of the growing season. The seasonally flooded plains and bottomlands are either used for dry season livestock grazing or are cultivated following the termination of main season rain and planted to grass pea (*Lathyrus sativus*), chickpea (*Cicer arietinum*), and other early maturing crops that are capable of completing their life cycle on residual moisture.

3.2.3. Climate

The study area experiences a cool temperate climate. The pattern of rainfall distribution is bimodal and the mean long-term precipitation is 1 080 mm. The main rainfall in the study area is received between May and October, and accounts to over 65 % of the annual precipitation. Around Ginchi, a short rainy season often occurs between March and May, but is not utilized for cropping, as is the case in the other parts of the central Ethiopian highland found at higher altitudes. The short rainy season, however, still plays a crucial role in easing seedbed preparation for the main season planted crops. The short rainy season is particularly important to stimulate grass re-growth, which is badly needed after a long dry spell. Peak precipitation months are July and August with mean rainfall measurement values amounting to 172-mm and 225-mm, respectively.

Extremely low temperatures, that commonly damage crops at higher altitudes of the central highland, are rare at Ginchi. The average maximum daily temperature ranged from 21.4 °C in July to 27.5 °C in February. Average minimum daily temperature varied from 4.4 °C in December to 8.9 °C in March. Measurements of soil temperatures at 5-cm soil depth were 19 °C in December and July, and 22.4 °C in March, respectively.

The rainfall and temperature values recorded during the study period are close to that of the long-term average. And hence only the current rainfall, surface soil (0-5 cm) and air temperatures are given in Fig.3.4.

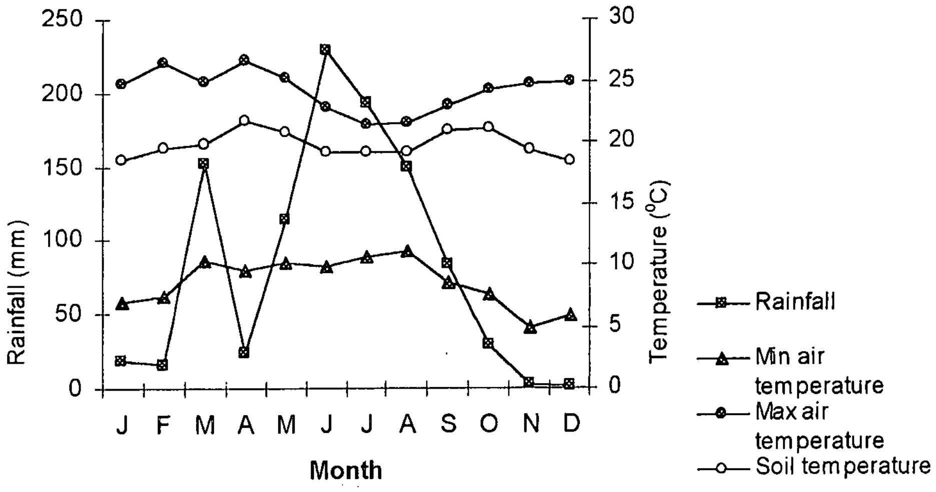

Figure 3.4. Average monthly soil and air temperature, and rainfall of Ginchi Vertisol area for the period January to December 2001.

3.2.4. *Native vegetation*

The vegetation of the study area comprises predominately native pastures. With the exception of the edges of valley bottoms where it is possible to find scattered Acacias, trees are scarce in other physiographic positions of the Vertisols. At the district level, however, forests constitute 10 % of the landmass (Fig. 3.5). Because of overgrazing over the last few decades, the biological diversity of the communally owned grasslands has been degraded and these are generally devoid of the most desirable perennial grass species. The detailed information on dominant and minor forage species is given in Chapter 6.

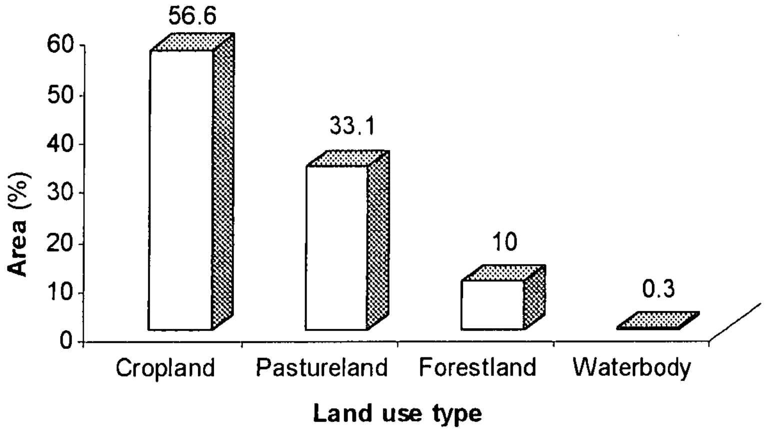

Figure 3.5. Percent area cover of different land use types in Dendi district

3.2.5. *Farming systems*

In the Pellic Vertisol area of Ginchi, a typical mixed farming system, where both crop and livestock production take place on the same farming unit, prevails. Detailed accounts of the livestock and the crop subsystems, the land use types, household (HH) resource endowment and labour management of the study area and that of the Dendi district as a whole are presented in Chapter 4 and Fig 3.5.

3.3. SAMPLING SITE SELECTION PROCEDURE

The predominant production system of the study area being mixed crop-livestock farming, cultivation was found interspersed with permanent and/or temporary (fallow) native pastures. On the bases of use right, intensity and time of utilization, two types of permanent native pastures were identified: the communally owned year-round-grazed (YRG) and the privately owned seasonally stock excluded (SSE) grasslands. The study area has neither uniform soil (Fig 3.3) nor topographic features. In relatively higher physiographic positions many different soils associate with the Vertisols. Both of these factors precluded the regular spacing or random selection of sites that was required for the soil and feed resource (native pasture and crop residue) sampling. As a result, soil, native pasture and crop residue sampling sites were identified by employing two stages of the sampling procedure, namely subjective and random sampling techniques.

During the first stage of sampling, 30 YRG grasslands, and 20 each for SSE grassland, tef and grass pea plots were selected subjectively. At this stage of sampling, similarity of slope, aspect and soil (Vertisol) were considered. Criteria such as soil colour, width and depth of cracking during the dry season were used to identify the Vertisol proper.

During the second stage of sampling, 18, 12, 10 and 9 sites were randomly selected from purposively identified sites for YRG grassland, SSE grassland, tef and grass pea crop fields, respectively. It is these sites that were sampled for soil and feed samples, and in the case of the grasslands, further assessed for DM yield and floristic composition. At each site, soil and feed samples were obtained from two fixed 50-m long perpendicularly intersecting transects. Further descriptions of the procedures of the various components of the study area are given in the relevant chapters.

CHAPTER 4

FARMING SYSTEMS OF THE GINCHI VERTISOL AREA

4.1. INTRODUCTION

The highlands of Ethiopia have high human and livestock population densities with well-integrated farming systems (McIntire & Gryseels, 1987). They support up to 120 people and 130 tropical livestock units (TLU) per km^{-2} (Livestock strategy document, unpublished). One TLU is equivalent to one bovine animal of 250 kg live weight (ILCA, 1990; see Table 4.2). The area experiences very strong interdependence and integration between the crop and livestock sub-systems.

Vertisols constitute 35 % of the land area in the central Ethiopian highlands. These soil types are generally under-utilized because of poor internal drainage problems and high-energy demand for cultivation. Under the prevailing crop husbandry, crop yields per unit area are low. Considering the inherently high fertility of these soils, the presently low productivity of crops and pastures can be increased if appropriate surface drainage implements are utilized. Marked grain and crop residue yield improvements and positive returns to labour on Vertisols have been documented in areas where an animal drawn surface water draining implement such as the broad bed maker (BBF) has been introduced (Jutzi *et al.*, 1987). The extent of use of such productivity raising external inputs, however, is low and the operating system can generally be regarded as a low-input agriculture. Like elsewhere in the highlands, farm size per household is small (1-4.5 ha) and fragmented.

This farming systems study was carried out to obtain an overall picture of the bio-physical and socio-economic environments of the Ginchi Vertisol area with special reference to aspects of management and utilization, constraints and opportunities of livestock feed resources. The study area has much to share with other parts of the highlands in terms of the above variables, but the nature and properties of the Vertisols presents unique challenges to the system. The current investigation tries to explore these unique and common features of the farming systems. This study, therefore, was conducted to address the following objectives:

i) to have an understanding on the livestock feed production, management and utilization, and related bio-physical and socio-economic environment of the study area, and

ii) to assess the perceptions of farmers specifically concerning the major constraints and opportunities for livestock feed production

4.2. MATERIALS AND METHODS

4.2.1. Reconnaissance survey and key informant interview

The information used to describe the overall farming systems and detailed livestock and feed production characteristics of the Ginchi Vertisol area was obtained from secondary data, direct field observation and the synthesis of the participatory rural appraisal (PRA) data. The PRA technique as its name implies, is more participatory, flexible and more robust in grasping the full picture of an agricultural system than the rigid approaches used in formal surveys. In addition to empowering the informants, the PRA technique is efficient in the use of money and time. Participatory rural appraisal techniques encompasses a number of techniques, but in the present study use is made of transect walks and key informant interviews.

A reconnaissance survey was conducted in January and August 2001, to obtain a full picture of the physiographic features, soil and vegetation types, crops grown and animals raised in the study area. This involved visits to the target villages and undertaking informal talks with farmers while they were busy with their farming routines. This helped a great deal in fine-tuning the open ended semi-structured questionnaires (Appendix 4.1).

The key informants were farmers and development agents (DA) assigned to extension posts. The discussion with the key informants was held with 15-18 farmers drawn from different resource endowment strata at each site and DAs from the respective localities. The selection of key informants' was carried out with the help of a DA residing in the community. The discussion with key informants was guided by semi-structured questionnaires, which were organized more to stimulate discussion on topics of interest than to dictate participants' perspectives

The key informants interviews were organized at two localities, namely Borodo and Asgori. Soils at both localities are predominantly typical Pellic Vertisol. The key informants from the Borodo area represent the Yubdo-Lagabatu and Dano-Ejersa-Gibe peasant associations (PA) and the adjoining PAs, whereas the groups from Asgori came from Awash-Bole, Awash-Boloto, Gatiro-Lafto and Golole-Bolo PAs (Fig. 3.2). Peasant association refers to a local community with defined boundaries and grass root administrative structure that runs the day-to-day political and socio-economic activities. The two sites share similar bio-physiographic features, but have some differences in terms of land size under private and communal ownership and the number of animals per household (Figs.4.1 and 4.7). The size of plots put to different land uses and the number of animals owned per household is larger at Asgori than it is in Borodo localities.

4.2.2. Assessment of ecto- and gastro-intestinal parasites

Information on major livestock feeds and diseases, and general feeding and disease control schemes were obtained through discussions held with farmers and district agricultural development bureau subject matter specialists and DAs. With regard to livestock health, more emphasis was placed on parasites because it was assumed that high parasite burdens predisposes grazing animals to mineral deficiency and results in poor livestock productivity. The presence and absence of ticks was examined from 50 randomly selected mature local zebu cattle at Borodo and Asgori localities. Faecal grab samples were obtained from each of the animal examined for tick infestation. The types of gastro-intestinal parasites in the faecal samples were determined by the Mc-Master technique (Hansen & Perry, 1990).

4.3. RESULTS AND DISCUSSION

4.3.1. Bio-physical environment

The detailed description of the bio-physical environment of the study area, namely the soil, climate and native vegetation features are given in Chapters 3, 5 and 6. Only the aspects of livestock, feeds and food crops are dealt here.

4.3.2. Livestock production

4.3.2.1. Livestock type and their importance

Cattle, sheep, donkey and poultry are the major classes of livestock raised by farmers in the Vertisol area of Ginchi. Horses are less common. Cattle are exclusively of the indigenous shorthorn zebu breed type (Fig. 4.3). Farmers reportedly say that the number of livestock has declined over the last ten years because of declining productivity of communal grazing areas, crop encroachment into the grasslands and subsequent feed shortage. The number of animals across household and PAs varies, but most farmers are entitled to two or more cattle (particularly draught oxen), a few sheep, a donkey and a handful of poultry. Owing to the relatively larger privately and communally owned grasslands, farmers in the vicinity of Asgori do possess more animals than their counterparts around Borodo. The number of different classes of animals owned by an average household (HH) at Borodo and Asgori is shown in Fig. 4.1.

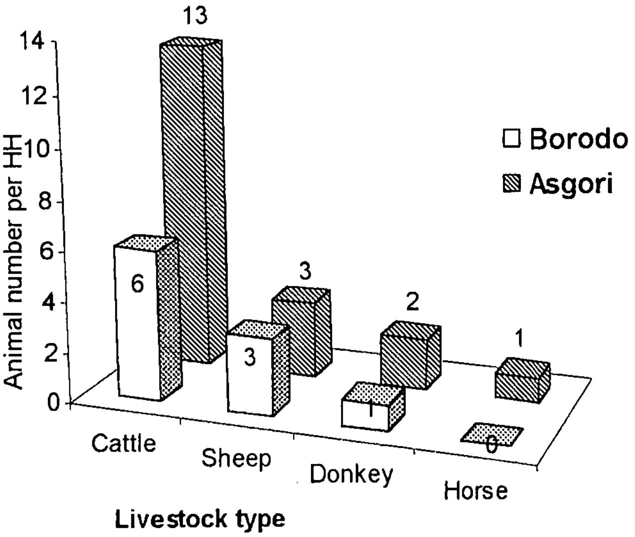

Figure 4.1. Average number of domestic herbivores per household at two localities of Ginchi Vertisol area.

The shorthorn zebu cattle are sources of draught power, a farm input that determines the timeliness of seedbed preparations and area of land cultivated in a season. The use of oxen for tillage operation is quite widespread and has a long history in Ethiopia. Among all animals used for traction in sub-Saharan Africa, 50 % are found in the highlands of Ethiopia (Jutzi *et al.*, 1987). Households with draught power access cultivate on average 25 % more area than those without draught power (McIntire & Gryseels, 1987). The timing of cultivation is particularly crucial for the Vertisols, which are, workable only for brief period of a year. In addition, oxen ownership earns the bearer social prestige and external labour input in exchange for a ploughing service. Because of such obvious benefits a high premium is put on oxen. Dung is another important commodity obtained from cattle. In the dry season dung is made into cakes, which serve as a source of cooking energy. During the rainy season, animal manure is used to fertilize plots intended for growing maize and *enset (Ensete ventricosum)*. Furthermore, cattle provide owners with milk, a badly needed animal protein source. The proceeds from the sale of butter and homemade cheese are important sources of cash for women. Sheep are kept mainly for meeting emergency cash needs. They are also slaughtered during a festive period. Some enlightened farmers in the area supplement their farm income by selling fattened sheep during major holiday seasons. Donkeys are important pack animals. They are used to transport farm produce from the field to the homesteads. Off-farm transportation of goods and grains is also undertaken with the aid of donkeys. Around Asgori where women have to travel a long distance to fetch water, donkeys are valuable assets to a household.

4.3.2.2. Livestock husbandry

Herbivores belonging to different classes of livestock graze together on crop stubble and pasture during the day. During the night-time mature cattle and equines are sheltered in kraals while calves and small ruminants are housed indoors.

To minimize crop damage, free movement of animals is controlled more during the wet season than it is in the dry period. Up until crop harvest, grazing animals are strictly tended and confined on meagre herbage growing on roadsides and communally owned YRG grassland. As relatively better-drained upper slopes are planted to crops and the valley bottoms are inundated with water, feed availability during the mid wet season is thus as critical as the late dry period.

Selective feeding is undertaken in the use of conserved hay, crop residues, and bought-in or home-grown supplemental feeds. Purchased concentrate feeds are exclusively fed to animals in fattening programmes. With regard to the conserved feeds (grass hay and crop residues), the first priority is given to working oxen and then to milking cows and animals under fattening programmes. Donkeys are not given any additional feed, except at the time when they transport harvested crops to the homestead. During this period, they have access to the whole crop (un-threshed crop) being transported.

4.3.2.3. Feed resources and feed management

4.3.2.3.1. Major feeds and local mineral sources

Three categories of feed resources can be identified in the Vertisol area of Ginchi. These include native pastures, crop residues and agro-industrial by-products. The types of native pastures prevailing in the area were described in Chapter 3. Pictures showing the condition of the wet season SSE grassland and YRG grassland are also presented in Fig 4.2 and Fig. 4.3, respectively. Smallholders in the central highland had the tradition of setting aside or resting part of their landholding during the growing season. The SSE grassland could either be under permanent native pasture or have variable years of cropping history. Native pastures grow on soils of varying physical environment and land use histories, which include agriculturally less suitable (e.g. stony area) uplands, seasonally waterlogged bottomlands, spaces between crop fields, roadsides and fallow lands. Recent statistics showing the area covered by native pasture in the highland is not available. Past estimate (Lulseged Gebrehiwot, 1985) put the area of highland grassland to 7.3 million ha. Since then a good proportion of these grasslands have been diverted into crop fields. What remains has also been overgrazed. It is thus unlikely that feeds coming from native pasture supply the previously assumed 50 % nutrient needs of ruminant and equine population.

Figure 4.2. Wet season SSE grassland.

Figure 4.3. Wet season YRG grassland.

The crop residues generated by the crop subsystem make up a significant portion of livestock diet, particularly during the late dry and early wet season. Jutzi *et al.* (1987) reported that crop residues provide 50 % of all the ruminant's diet in the highlands of Ethiopia. The type and amount of crop residues produced in Dendi district and estimated duration of residue use to sustain existing ruminant population are given in Tables 4.1 and 4.2. Even though crop residue produced presently in the district is only adequate to meet the maintenance requirement of existing ruminants for a maximum of 4 months (Table 4.2), in reality its use is thinly extended for over 6 month period. The total available crop residue presented in Table 4.1 was derived from grain yield data. The conversion factors suggested by Nordblom (1988) have been adopted for lentil (1), wheat (0.8), barely (1.2), maize (2) and sorghum/millet (3). For the grain legumes the conversion factor of lentil was employed. From local experience, a kilogram of tef straw is available to feed livestock for each kilogram of grain harvested; hence a factor of one is used for tef. Dendi district encompasses quite diverse agro-climatic zones with distinct soil, climatic and physiographic features. As a result the dominant crops grown by farmers in different sub-agro-ecologies of the district varies a great deal. In the intermediate altitudes (2 000-2 200 m a.s.l.), in which the study area (Ginchi) falls, tef, wheat, grass pea and chickpea predominate. In the elevations of either extremes, the importance shifts to cool (>2 200 m a.s.l.) season crops notably barley and faba beans or warm (<2 000 m a.s.l.) season crops such as maize and sorghum. The extent of production of crops like maize, sorghum, millet, barley and faba bean is thus low in the study area. Though estimates of the contribution of crop residues to maintenance requirements of livestock was made at a district level, the same trend would apply for the study area. If a difference exists, it would be on the type of crop residue used to feed livestock. From cereals, tef, and from that of grain legumes, grass pea constitutes the largest share of crop residues fed to livestock around Ginchi area.

Apart from serving as livestock feed, straw of tef is sold to meet some incidental household expenditure. About 75 kg of tef straw, which is equivalent to a donkey load, costs 25 Ethiopian Birr (1USD = 8.5 Eth. Birr).

Farmers commonly preserve residues of tef (rarely barely) and grass pea following threshing. Grass pea haulm is used to supplement the low CP tef straw. Practically, all farmers exercise stacking of these residues in their backyard. While stacking, the most nutritious and chaffy pulse haulms are placed at the bottom or middle and covered by straws coming from the cereals. This protects the nutritious pulse haulms from being blown away by wind or damaged by unexpected rain. Separate stacks of pulses like grass pea haulms are thus unthinkable for they readily absorb rainwater and spoil. In excessively wet seasons, or early cessation of rainfall, the growth of maize crops often become stunted and fail to bear grain. In such instances it is alternatively cut green and fed to animals.

Table 4.1. Type and amount of crop residue available to livestock in Dendi district.

Crop type	Area cultivated (ha)[a]	Grain yield (t/ha)[b]	Total grain yield (t)	Total residue yield (t)
Tef	20 570	0.91	18 718.7	18 718.7
Wheat	15 723	0.99	15 565.77	12 452.616
Barley	18 692	0.82	15 327.44	18 392.928
Sorghum/millet	2 899	1.58	4 580.42	13 741.26
Maize	3 460	2.32	8 027.2	16 054.4
Chick pea	2 189	0.70	1 532.3	1 532.3
Grass pea	2 010	1.20	2 412	2 412
Noug	1 927	0.30[a]	578.1	-
Lentil	326	0.24	78.24	78.24
Faba bean	1 589	0.78	1 239.42	1 239.42
Field pea	1 413	0.50[a]	706.5	706.5
Total available residue (t)				85 328.37

[a] Dendi district agricultural development office (unpublished data).

[b] Central statistical authority (1999).

Table 4. 2. Estimate on the duration of crop residue feeding in Dendi district.

Class of animals[1]	TLU[2]	Residue as sole maintenance diet[3]
Cattle (less calves)	148 197.7	115.16 days
Sheep and cattle	149 139.2	114.43 days
Sheep, goat and cattle	159 863.5	106.75 days

[1] Cattle, sheep and goat population (Dendi district agricultural development office, unpublished data)

[2] TLU estimates were calculated by multiplying cattle heads with a factor of 0.7, and sheep or goat heads with a factor of 0.10 (ILCA, 1990).

[3] Maintenanec DM intake calculated at 2 % of live weight

Noug seedcake is the major agro-industrial by-product produced in the Ginchi area that is used as livestock feed. Along with crop residues, grass hay and other bought-in feeds (e.g. molasses and wheat bran), is used to fatten animals. A fair number of farmers in the study area currently engage in small scale stall-feeding. Old oxen, old and barren ewes, castrated and un-castrated male sheep are fattened and sold at a good price during festive seasons. During the periods of good harvest and low grain price, like the current year, green-matured whole crop or whole grains of grass pea are used as an alternative fattening diet. When grains of grass pea is used to feed work oxen or animals kept for fattening, it is boiled prior to feeding. Such heat treatment is important for overcoming the negative effects of anti-nutritional chemicals such as phytate, tannins and neurotoxins that are commonly high in grass pea grain (Hanbury *et al.*, 2000).

Mineral sources the significance of which in livestock production and reproduction has been duly recognized in the study area include common salt, mineral water (*hora*) and mineral rich soil. The mineral concentration of these local mineral sources is shown in Table 4.3. In the study area, the use of common salt, *hora* or mineral soil, however, was sporadic and inconsistent. Those farmers (e.g., Asgori locality) within a half-day trekking distance from the *hora* source take their animals to the locality two-three times a year. The periods of these visits are confined to the wetter part of the year (June to December). Farmers say that it is during the rainy season that the *hora* becomes cool and potable. They claim *hora* enhance the desire of female cattle to seek bulls and it also controls internal parasites. On the basis of the data presented in Table 4.3 the *hora* water was virtually free of Cu and Zn and was also fairly low in the remaining elements. It is thus apparent from this that the infrequently consumed *hora* would contribute little towards alleviating the deficiency of some elements in native pasture and crop residues. The soil that is used as a mineral source is shiny and deep black in colour. After scraping off the upper surface (0-15 cm) soils, the underlying mineral soil is dug out and fed to animals mixed with leaves of *Vernonia amygdalina*. The mineral soil, too, is given to animals only during the rainy season (September). This soil may be regarded as good source of Ca, Mg and Na, but was poor in other mineral elements (Table 4.3). The use of common salt is largely limited to animals kept in fattening programmes, milking cows and draught oxen. Oxen are given salt during July and August. Farmers claim that offering *V. amygdalina* leaves and common salt to lactating cows increases milk production.

Table 4.3. Mineral concentration of local mineral sources.

Variable	Mineral water (mg/L)[1]	Mineral rich soil (mg/kg)
PH (H_2O)	6.00	6.62
Ca	72-76	6 347
P	0.06-0.14	2.23
Mg	46-49	1 814
K	35-48	489
Na	245-252	986
Fe	0.05-0.08	4.42
Mn	0.15-0.25	5.92
Cu	-	2.05
Zn	-	0.68

[1] Source: Ambo mineral water factory (unpublished data).

4.3.2.3.2. Feed calendar and feeding strategies

The feed calendar of the Vertisol area of Ginchi is shown in Fig. 4.4. Unfortunately the available feed from each feed type has not been determined quantitatively. What is shown in the feed calendar is the duration that ruminant animals depend on a particular feed type. There exists some periodicity in the use of SSE grassland locally called *kalo,* and crop stubbles. The use of crop stubble begins around mid November and continues until the start of the following season's land preparation, which often takes place in March. There is no restriction to the utilization of YRG grassland for farmers residing in the same peasant association but access to SSE grassland is confined to a certain part of the year. There is a strict SSE grassland utilization strategy in the area. The access to first grazing of crop stubbles and SSE grassland is restricted to the owners. The owners exclusively graze the SSE grassland from late September up until March. The permission to use these feed resources by other farmers' animals is only granted after the lawful owners of the land have utilized much of the available forage. Such free access to all animals extends from March to early July.

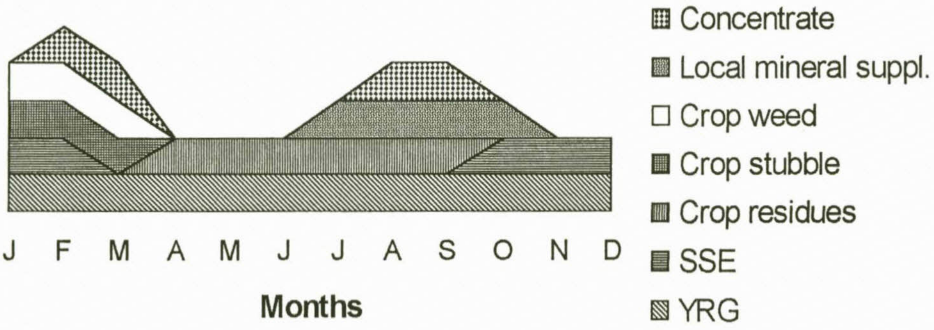

Figure 4.4. Periods during which different feed resources are available to livestock in Ginchi area.

Farmers in the study area follow different strategies to cope with the feed shortage problems, which they encounter, both during the wet and the dry seasons. As native pasture growth is stimulated with improved soil moisture in the rainy season, YRG grassland becomes a predominant supplier of stock feed until crop harvest. Crop weeds and remnants of conserved crop residues are used during this period to augment the limited DM supplies from YRG grassland. Livestock feed during the post crop harvest period comes largely from crop stubble and SSE grassland grazing, and conserved crop residues. Crop residue feeding usually begins in April and extends up to September or until it is depleted. On privately owned SSE grassland, farmers keep animals away for part of the rainy season to stimulate grass growth which is later grazed or used for hay production. Animals are barred from the SSE grassland from early July to October or in some cases from July to January. The size of the SSE grassland is variable and ranges from 1 000 to 2 000 m^{-2} per a household. The size as well as number of farmers having SSE grassland is reportedly declining. The decrease in the size of landholdings is the prime reason for this decline. In most cases the land assigned for SSE grassland is either unsuitable for cultivation or prone to wet season flooding. Farmers, who do not have such types of land, use part of their crop field for this purpose. The practice of resting a worn out crop field or leaving it fallow is becoming less common in the area. However, at times when farmers fall short of cash needed for the purchase of mineral fertilizers, plots that have been under tef for 3-4 years may be rested for a season. Because of its small size, not more than one percent of the SSE grassland owners make hay and hence it is largely grazed *in situ*. Those who manage to make hay have better chance of bridging the seasonal fluctuation of feed supply or sell it at a good price. A donkey load of hay, for example, fetches 25 Ethiopian Birr. There are some farmers in the area that have few or no animals but keep SSE grassland for generating an additional farm income.

4.3.2.4. Livestock diseases and parasites

Different types of diseases exist in the area. Formal veterinary services attach high importance to diseases having a nature of outbreaks. The control and protection of such diseases in most cases are handled by the animal health unit at district level free of any cost through an organized campaign. Most often farmers use herbal medicines to treat sick animals and only take sick animals to distant animal health clinics when such local initiatives fail to restore the health of the animals.

There are no available data to show the extent of production loss due to parasites in the study area. Looking at the level of parasite infestation of cattle, ecto- and gastro-intestinal parasites are definitely of economic importance. There is, however, little involvement of the formal animal health service in the control and treatment of ecto- and gastro-intestinal parasites. Ticks are the most common ecto-parasites in the area. Although efforts have not been made to identify the tick species, cattle in different age categories have been noted, during the study, to be laden with heavy tick infestations. Various groups of gastro-intestinal parasites also affect grazing animals. From faeces samples collected in the wet season, trematodes (liver flukes), nematodes (round worms) and cestodes (tape worms) were noted to be important gastro-intestinal parasites of cattle (Fig. 4.5). The extent of infestation was mild to moderate for trematodes and nematodes, and low for cestodes. The animals from which samples were collected were older than one year of age and were thus able to tolerate parasite infection better than young calves. The short horn zebu cattle, which are adapted to the environment, may have the ability to tolerate the ecto- and gastro-intestinal parasites that are widespread in the area.

As the ecto- and gastro-intestinal parasites either suck blood and/ or compete with the host for digested nutrients, high infestations would cause emaciation, anaemia or sub-optimum growth and production. Moreover, gastro-intestinal parasites could damage the alimentary tract and other organs such as liver and would impair the absorption and utilization of nutrients, including minerals. A low growth rate, depressed voluntary intake, reduced metabolizable energy (ME), Ca and P utilization have been reported elsewhere in sheep whose small intestines were infested with roundworms such as *Trichostrongyle species* (Sykes & Coop, 1976). It is a foregone conclusion that animals on a poor plane of nutrition are particularly vulnerable to parasitic infection. In a study conducted in Australia, sheep fed extra protein were found to be least affected by the adverse effects of *Haemonchus contortus* infection (Datta *et al.,* 1998). For animals of the study area, that subsist on sub-optimum protein and mineral diet, a decreased immune response to parasite infection is expected.

Group herding, free animal movement, absence of seasonal pasture burning and overstocking seems to have contributed to the spread of parasites among herds grazing the YRG grassland. The seasonally waterlogged bottomland grazing grounds are also likely to be an ideal environment for the survival and multiplication of the snails, which are the intermediate hosts of the trematodes.

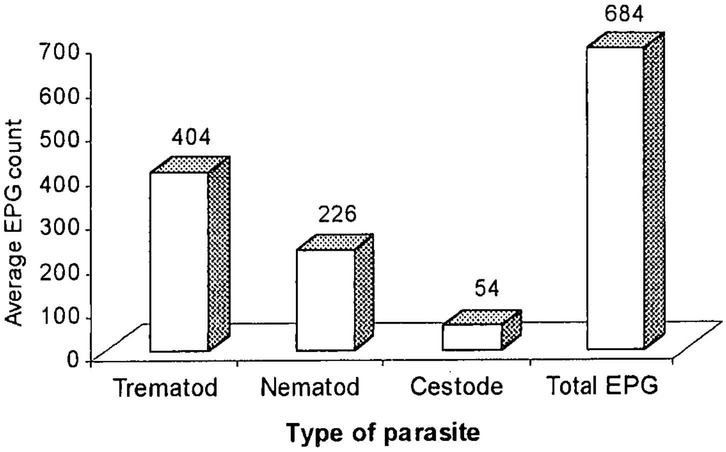

Figure 4.5. Average egg per gram (EPG) faeces count of gastro-intestinal parasites in cattle.

Feed related animal health problems also occur in the study area. Wet season grasslands in valleys and lower slopes contain a significant proportion of *Trifolium* species. Most species of this genus contain potent poisons when grazed prior to full bloom. In the study area, the incidence of bloating due to the ingestion of *Trifolium* based pasture is quite high and affected animals often die within a short time of exposure. The effective way of containing the problem is to keep away grazing animals from *Trifolium* pastures during the vegetative growth stage. Feeding animals with hay or straws before they start grazing is also claimed to reduce the risk of bloating from *Trifolium* ingestion. Prior feeding of animals with high polyphenolic *Sesbania sesban* foliage also prevents the occurrence of bloat (Tothill *et al.*, 1990). The life of bloated animals could be saved if the excess-trapped air is effectively released with a puncture on the rumen by a vet or experienced local health assistants. Considering the general deficiency in protein in the area and the potential of legumes to solving the problem, the evaluation of non-bloating legumes definitely deserves attention.

4.3.2.5. Major constraints to livestock production

The major constraints to livestock production were drawn from discussions with the key informants and direct observation of the condition of animals and the availability of the feed during the dry and wet seasons of 2001. Guided by the objectives of the study more emphasis was given to identify feed related constraints.

In the study area feed shortage is the principal constraint of livestock production. Native pastures and crop residues are deficient in essential nutrients and are limited in supply. Although the severity of the problem takes a certain seasonal pattern, it could be said with confidence that in neither the wet nor dry seasons do ruminant animals obtain sufficient feed to sustain adequate production. As a result cattle growth rates are slow (sexual maturity takes 3-4 years) and calving intervals are long (1.6 to 2 years). Mortality of young calves and low conception rates are also common. Working oxen receiving inadequate crop residues and grass hay particularly show a marked loss of condition. In the dry season, the peak feed shortage period is February to April, whereas its equivalent in the wet season falls in July and August. In the former case, animals experience substantial body weights loss and milk yield drops. At times, the peak critical feed shortage period in the dry and wet seasons coincides, when the short rains fail or are reduced.

Communally owned YRG grasslands, which in the past were rich in species of high feeding values, have deteriorated due to mismanagement. The gradual encroachment of crops into the grasslands and the subsequent diminishing of grazing areas, coupled with lack of effective community controls, has led to over stocking and eventual overgrazing.

Water, too, is a serious constraint in the study area during the dry season. Farmers have to trek animals long distances to water them. Considering the low moisture content of the available feed during this period the implications of water shortage on livestock productivity is obvious.

Animal health services give more emphasis to contagious diseases. Preventive and control measures of parasites have not been given the attention they should deserve. Mixed herding is conducive for the spread of parasites. Where grazing animals of different households share similar grazing ground, implementing effective ecto- and gastro-intestinal parasites control and preventive measures is practically impossible.

4.3.2.6. Local coping strategies

Farmers do appreciate the nutritional constraints and have followed different options to overcome them. The locally adopted strategies, to improve the qualitative and quantitative supply of livestock feed, include:

- Conservation of crop residues.
- Seasonal closure of privately owned SSE grassland (*kalo)* and use for hay production or *in situ* grazing.
- Use of bought-in concentrate primarily for the purpose of fattening animals.
- Seasonal provision of locally available mineral sources such as common salt, mineral rich soil or *hora*.
- Planting of fodder trees like *Sesbania* species as a fence line around the homestead. *S. sesban* is well adapted to seasonally waterlogged Vertisols and its use as feed allowed sheep grow at 50 g day^{-1} (Tothill *et al.*, 1990).
- Use of weeds, whole plant or grain of some crops (e.g. maize and grass pea) as emergency feed.

4.3.3. Crop production

4.3.3.1. Crop types

The climatic situation and the deep black clay soils suit a wide array of crop species. Crops grown on Vertisols include tef, wheat, barley, maize (*Zea mays*), sorghum

(*Sorghum bicolour*), grass pea (*Lathyrus sativus*), faba beans (*Vicia faba*), field pea (*Pisum sativum*), chickpea, lentils (*Lens clinaris*) and noug (*Guizotia abyssinica*). In addition to grain, these food crops produce a wide range of crop residues and agro-industrial by-products that may be utilized to feed the ruminant livestock population. Most of these food crops belong to local landraces but farmers also grow improved varieties of wheat, barley, tef and maize.

4.3.3.2. Crop husbandry and cropping calendar

The cropping husbandry practices, particularly the intensity of seedbed preparation and time of planting differ from crop to crop. Maize and sorghum are planted in April, followed by faba bean and *samareta* (early maturing local barley variety) in May and June. The planting of wheat occurs in July and August. To minimize the negative effects of waterlogging, the wheat crop is either planted on raised seedbeds or provision is made to drain the excess water using furrows. Due to its tolerance to waterlogging, tef is planted in the middle of the rainy season (mid July-early August). Pulses are planted at the end of the rainy season (early September-first week of October) and grow largely on residual moisture. Their seedbed preparation is also less demanding. Among the cereals, the last phase of tef seedbed preparation is the most daunting task. The entire family participates in the puddling and trampling of the seedbed prior to planting. Being the major crop in terms of area cultivated, it absorbs the highest share of the family labour. For the rest of the crops, the excess surface water is drained from the field with the aid of furrows. Most farm operations over the same period, thus increasing the pressure on family labour. Weeding for early-planted crops begins around June (if consecutive two or more weeks of dry spell minimizes the puddling of the soil) and extends until mid November. Harvesting and threshing activities start in October and may continue until February.

4.3.3.3. Crop inputs

Mineral fertilizers and improved seeds of some crop species are the most commonly used purchased inputs. The use of pesticides is confined to periods of serious insect pest outbreaks such as armyworm. Most of the interviewed farmers complained that weeding absorbed the largest share of household labour but none confirm using herbicides. Farmers appreciate the role of purchased inputs on the productivity of most crops, but attributed the low use to high cost and cash shortage. Despite soaring prices, farmers in the area apply modest amounts of mineral fertilizers to crops such as tef, wheat and maize. The application rate of mineral fertilizers varies depending on the crop type and the resources of the farmers. Modal farmer both at Borodo and Asgori apply urea (46 % N) and di-ammonium phosphate (DAP) (18 % N and 46 % P) at the rate of 50 and 100 kg ha^{-1} for tef, respectively. For wheat, average income farmers at Borodo apply half of the above figure. At Asgori, the amount of urea and DAP used for wheat is similar to that of tef. Farmers at Asgori apply more fertilizer to wheat field not because soil in this site is less fertile than that at Borodo, but this is rather the reflection of better farm income. Other important crops in the area such as grass pea, chickpea and noug do not receive fertilizer. In addition to mineral fertilizer, plots designated for *enset* and maize are fertilized with animal manure.

4.3.4. Significance of crop-livestock interaction

There is a close inter-dependence between the crop and the livestock subsystems in the study area. Crops are not grown solely for grain production but more importantly for the highly valued residues, which are used as livestock feed. Livestock in turn provide the draught power and manure to the crop subsystem. In this smallholder production system, the vagaries of adverse climatic effects on crops and cash shortages in years of low grain price are overcome by the sale of animals. As a consequence of these complementarities, any external or internal intervention made on one of the subsystem has a positive or negative nock-on effect on the other. Good examples of these are the integration of forages with food crops. Integrating forages with annual food crops strengthens the link between the crop and the livestock subsystems. Apart from increasing the qualitative and quantitative supply of livestock feed, forage crops, particularly legumes, can promote sustainable crop production by restoring OM and improving the nutrient content of the soil. A wealth of information witnessing to the simultaneous positive benefits of forages crops to crop and livestock production is available in the scientific literature (Jutzi *et al.*, 1987; Thomas & Lascano, 1995; Holford & Crocker, 1997; Devendra & Thomas, 2002). Planting leguminous forages on lands, that would otherwise lie fallow, or growing them in association with food crops apart from providing quality feed would improve soil fertility, which in turn increases the yields of the succeeding crops. Furthermore, forage food crop associations reduce the dependence of the mixed farming systems on external inputs and arrest land degradation by providing sufficient soil cover. From previous local research initiatives, undersowing of forage legumes in wheat appears to be such a successful intervention (Abate Tedla *et al.,* 1993).

The use of key external productivity raising inputs such as surface drainage implements, fertilisers, supplemental feeds, etc. in the mixed crop-livestock system of the Ethiopian highlands are constrained by cash shortage. In areas where the crop-livestock interaction is quite strong like Ginchi, the introduction of an appropriate animal drawn surface drainage implement can have a far greater effect on food and feed production than the tractor powered implements. Effective animal drawn implements are now available. Although not in wide use, an implement like a BBF, which can be used to prepare the last phase of seedbed, could help in draining the excess surface water that often interferes with plant growth. From the on-farm studies the employment of such technology has empirically been shown to markedly improve crop and feed production (Jutzi *et al.*, 1987). The introduction of BBF in the seasonally waterlogged Vertisols areas, for instance, has increased grain and straw yield by 144-297 % and 153-252 %, respectively. This technology has further increased labour productivity by 33-50 % and released children and women from arduous task of constructing broad beds and furrows by hand.

4.3.5. Landholding and labour management

4.3.5.1. Household size and division of labour

The average size of a household is seven persons and varies from four to nine. As the major labour input of a household comes from the family, the size and age structure of the household is very important. Exchange of labour among neighbouring farmers at the time of peak labour demand periods is also common and such labour exchange practice in the area is called *debo*. The household family size and the division of labour across the gender and age structure are similar at Borodo and Asgori localities.

Although all members of the household execute most activities jointly, there exists a distinct division of labour by age and gender. The division of labour by gender is shown in Fig 4.6. Activities such as livestock feeding, puddling of tef plots, weeding and transporting harvested crops are undertaken jointly by all members of the family. In addition to the household chores (caring for young children, fetching water and food preparation) women are involved in the milking of cows and dung cake making. Children are responsible for tending livestock. The men handle operations like ploughing, harvesting, threshing and fencing.

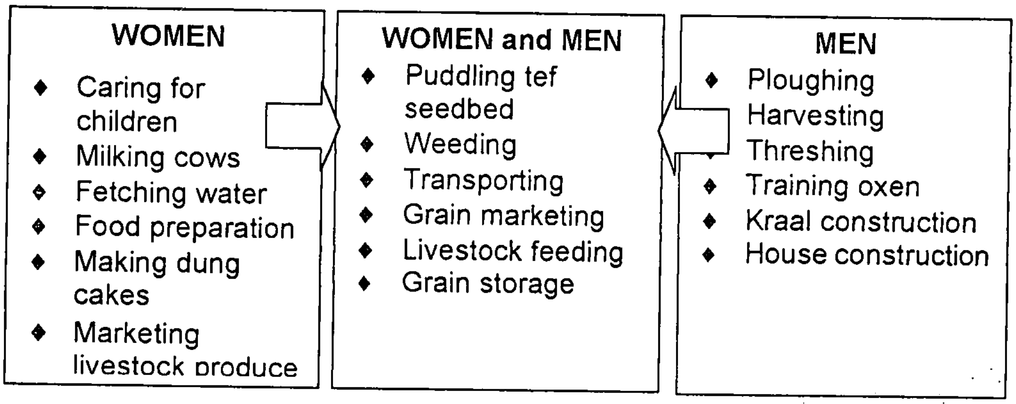

Figure 4.6. Household division of labour by gender category in Ginchi Vertisol area.

4.3.5.2. Farm size and land use pattern

The Vertisols area of Ginchi is among the most densely populated part of the central highlands. Individual landholding ranged from a little above 1.0 ha to 4.5 ha. The majority of farmers generally own around 2.5 ha, but there is a marked difference in landholding across the different PAs. The comparative land endowment of the two localities, Borodo and Asgori, for example verifies this fact (Fig. 4.7). Around Borodo, about 50 % of the farmers own a land measuring about two ha. Conversely, at Asgori a modal farmer's landholding could be as high as 3.5 ha. These have been observed to have a direct effect on the area of land under different crops, SSE and YRG grasslands. Of the total private landholding in both localities only about 5 % is set aside for grazing or hay production.

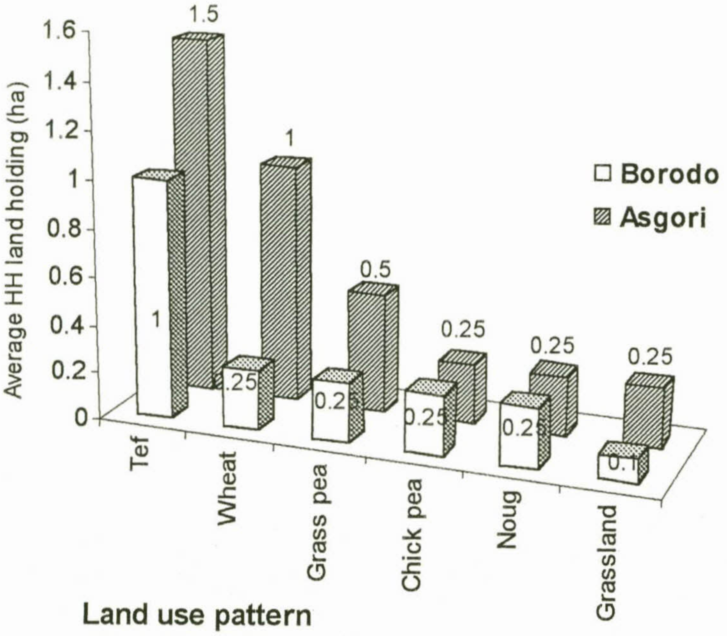

Figure 4.7. Land use pattern at two localities of Ginchi Vertisol area.

Over the past ten years, there is a clear indication of an increase in human population and a corresponding decline in individual landholding. Croplands are engulfing the communal grazing areas at an alarming rate. As a result the traditional fallow system, which is called *worxeba or chifliqi* locally has now almost been abandoned. Farmers who are forced to fallow their farmland because of an extreme decline in fertility and who are unable to apply mineral fertilizer, can only rest the plot for one season. In the meantime these farmers sharecrop with other farmers who are unable to use their cropland because of lack of oxen and/or labour shortage. Widowed women and elderly men are reported to engage in such arrangements.

The expansion of cropping at the expense of communal grazing land has serious implications for livestock nutrition. It increases the dependence on crop residues, a feed resource that often has a sub-optimum nutrient concentration and low digestibility. To solve this nutritional problem and raise livestock productivity, feeds of higher nutritive value must be used as a supplement to crop residues, must be bought in or produced on the farm itself. The latter is the most realistic option, but the problem is how to overcome the issue of land and labour competition. Growing improved forage crops using production technologies that compete less for the above resources with food crops probably have a great future. Undersowing of forages in cereals and backyard fodder tree plantations, which do not displace the main food crop, could have a better chance of penetrating into the system. Presently the need to grow cultivated forages is increasing among smallholder farmers. Some have already started planting fodder trees around their homesteads. With careful identification of forage production technologies and forage crop varieties such sporadic initiatives can be expanded to a community level.

4.4. CONCLUSIONS

In the Vertisol area of Ginchi, as elsewhere in the tropics, there are marked complementarities between crops and livestock in terms of resource use. However, the system has been constrained by the lack of productivity, increased inputs and appropriate technologies. Native pasture and crop residues hardly satisfy even the maintenance requirement of the existing animal population. Any tangible improvement in livestock productivity requires an increase in quality and quantity of the feed supply. Measures such as improving the management of native pastures, optimum use of locally available protein and mineral supplements and integrating forages into the cropping system have great scope for alleviating the feed inadequacy problem. Failure to improve the qualitative and quantitative supply of feeds will result in the perpetuation of poor livestock productivity.

As communal grazing grounds are overstocked and hence overgrazed, the feed shortage problem is particularly acute for those farmers who do not have *kalo* or do not conserve crop residues. Periodic resting and optimum stocking can restore the condition of these grasslands, but the implementation of such interventions may be impractical under the communal land tenure system.

The wider adoption of efficient animal drawn farm implements could further enhance the contribution of livestock to the system and reduces the drudgery of labour. Improving the fertility of croplands and grasslands through increased use of legumes has a potential to bring a sustainable increase in overall farm productivity. The above interventions can also increase land productivity and arrests environmental degradation.

CHAPTER 5

SOIL NUTRIENT STATUS AND RELATED PHYSICO-CHEMICAL PARAMETERS

5.1. INTRODUCTION

Vertisols, or deep black clay soils, are distributed in almost all agro-ecological zones of Ethiopia. In the highlands, these soils cover an area of about eight million ha (Jutzi *et al.*, 1987). Because of waterlogging and cultivation problems only 25 % of the Vertisols in the highlands are cultivated and the remaining 75 % are kept under native pasture (Berhanu Debele, 1985). These soils exist in association with other soils and occupy most catenary positions of the landscape in some parts of the central highlands (Fisseha Itanna, 1992). The moist chroma value of 1.5 or less within the top 50 cm soil matrix puts the black clay soils in the study area in a Vertisol soil group known as Pellic Vertisols (Kamara *et al.*, 1989).

Even though many plant and/or animal mineral element deficiencies have been traced back to low levels of same elements in the soil, many studies have failed to observe the strong relationships between soil and plant mineral element composition (Mtimuni, 1982; McDowell, 1985; Khalili, 1991; Jumba *et al.*, 1995b; Lemma Gizachew *et al.*, 2002). This is because a number of soil and non-soil factors control the availability of soil nutrients to plants. In the poorly drained Vertisols of the Ethiopian highlands, poor aeration could no doubt affect the availability of plant nutrients. Low soil N and P have also been documented to limit crop and pasture production in the Vertisols of Ethiopian highlands (Astatike Haile, 1979; Desta Beyene, 1982; Berhanu Debele, 1985; Jutzi *et al.*, 1987). Information on the levels of other essential soil nutrients, notably micro-nutrients, and status of soil parameters influencing nutrient availability for Vertisols of the Ethiopian highlands are, however, very limited. The soil factors that affect the availability of soil nutrients to plants include OM, CEC, texture and pH (Cottenie, 1980; Reid & Horvath, 1980; Katyal & Randhawa, 1983; Tisdale *et al.*, 1993). These soil factors can be further modified by the prevailing land use system. Studies conducted elsewhere show that the soil environment under grassland generally is favourable for increased availability in comparison to continuously cultivated soil (Lewis *et al.*, 1987; Aguilar *et al.*, 1988; Bowman *et al.*, 1990; Tisdale *et al.*, 1993). In Ethiopia, a similar comparative study has not attracted the level of attention it should deserve. The present study was intended to bridge this knowledge gap.

Objectives

The objectives of this study were to:

i) assess the soil nutrient status and related physico-chemical parameters of Pellic Vertisols under cropping and permanent grassland conditions, and to

ii) investigate the association of soil nutrients with soil physico-chemical parameters.

5.2. MATERIALS AND METHODS

5.2.1. Collection and preparation of soil samples

Composite surface (0-15 cm) soil samples were collected from adjacently lying cultivated fields and grassland areas during the early part of the dry season (January-February, 2001). For the cultivated land soil samples came from areas under grass pea and tef cultivation, while soil samples representing the grasslands were obtained from YRG and SSE grassland fields. The grass pea, tef, YRG and SSE grassland fields at each site were situated within close proximity to each other. In most cases all the land use types share a similar altitude, slope, aspect and soil, though the tef fields tended to occupy landscape positions relatively less prone to seasonal inundation. The procedures followed in selecting the sampling sites are described in Chapter 3.

Soil sampling, either in grass pea, tef, YRG or SSE grassland fields, was undertaken independently. The number of sub-samples that were taken in a site, as well as the collection, processing and analytical techniques, however, were the same for each of the above land use types. Fields under grassland and grass pea crops had no previous history of mineral fertilization, but the tef fields received an annual average of 41 Kg N

ha^{-1} and 20 kg P ha^{-1}. The number of sample sites for grass pea, tef, YRG and SSE grasslands were 9, 10, 18 and 12, respectively.

From each land use type, 20 surface soil sub-samples were randomly taken per site using a stainless steel soil auger (75 mm diameter) along two fixed perpendicularly intersecting 50-m long transects. The opposing ends of the two transects were marked to aid in subsequent native pasture or whole tef and grass pea crop sampling. The sub-samples were collected in clean plastic bags, and thoroughly mixed to obtain one composite sample from each site. As a precaution against the resistance of clayey soil clods to later grinding, hand crushing was carried out prior to complete air-drying. The composite samples were air-dried under shade, crushed in an agate mortar and passed through 2-mm sieve. Until the time of laboratory analysis soil samples were stored in plastic bags.

5.2.2. Analytical procedures

The particle size class analysis, extraction and determination of soil nutrient level and other soil chemical parameters for each composite sample were performed in duplicate. The hydrometer method (Bouyoucos, 1951) was used to determine the sand, silt and clay fractions. Particle size values ranging from 2.0-0.05, <0.05-0.002 and <0.002 mm were adopted as a particle size class ranges of sand, silt and clay, respectively. The soil pH in a 1:1 soil:water suspension was measured potentiometrically using a pH meter with a combined glass-electrode (Thomas, 1996). Total N was determined by the regular Kjeldahl method using a block digester (Bremner & Breitenbeck, 1983), where air dried sample was digested with sulphuric acid (H_2SO_4) and distilled with NaOH using boric acid as an indicator. The distillate was then titrated with a 0.01N HCl and a titration value was calculated to obtain total N percent. The method of Olsen *et al.* (1954) with soil:solution ratio of 1:20 and a shaking time of 30 minutes were employed for available P determination. The extraction solution, 0.5N $NaHCO_3$, was adjusted to pH 8.5 with NaOH. The filtrate was then read using a spectrophotometer (Spectronic 20, Bausch and Lomb). The CEC of the soil was determined by an ammonium acetate method (Cottenie, 1980). Molar neutral ammonium acetate (pH 7) was used to extract the exchangeable cations (Ca, Mg, K and Na) (Cottenie, 1980). A 0.005 M DTPA (diethylene triamine penta-acetic acid), buffered at a pH of 7.3 with 0.1M TEA (triethanolamine) in the presence of 0.01 M $CaCl_2$, was employed to extract plant available Fe, Mn, Cu and Zn (Lindsay & Norvell, 1978). The extracts of DTPA and neutral ammonium acetate solutions were then analysed by atomic absorption spectrophotometry (AAS) with a Perkin-Elmer AAS 2380 (Perkin-Elmer, 1982). The sum of bases (Ca, Mg, K and Na) was divided by the CEC to obtain the base saturation (Tisdale *et al.,* 1993). The soil organic carbon level was determined by a wet oxidation method (Walkley & Black, 1934), of which the value that was then multiplied by a factor of 1.724 to obtain an estimate of soil OM.

5.2.3. Statistical analysis

The Statistical Analysis System (SAS, 1985) was used to analyse soil data. Soil nutrients and related physico-chemical parameters data from the two grasslands and the two crop fields were analysed by one-way ANOVA employing the GLM of SAS (1985). The following model was used:

$Yi = \mu + Li + \varepsilon$

Where μ is the overall mean, Li the effect of land use and ε the residuals.

Pearson correlation coefficients between soil nutrients and physico-chemical parameters were estimated using correlation analysis. Forward stepwise multiple regression analysis was also employed. The level of significance of an effect was tested at $P<0.05$, $P<0.01$ and $P<0.001$.

5.3. RESULTS

Results of the analysis of the soil from the different land use types and the inter-relationships of soil nutrients with that of related soil parameters are presented in Tables 5.1, 5.2, 5.3 and 5.4.

Table 5.1. Least squares means, with indications of the SE of the mean, of soil nutrients and related parameters of Vertisols under different land use systems.

Variable	Grass pea [1,2]	Tef	YRG grassland	SSE grassland	Significance level[3]	Critical level[4, 5]
pH-H_2O (1:1)	6.16±0.08a	6.08±0.08a	5.91±0.06b	5.72±0.07b	**	
OM (%)	2.56±0.47b	3.54±0.45b	7.32±0.33a	6.36±0.41a	**	
Total N (%)	0.13±0.02b	0.19±0.02b	0.30±0.01a	0.27±0.02a	**	
P (ppm)	1.98±0.36ab	2.62±0.34a	1.41±0.25b	1.90±0.31ab	*	10
Particle size class						
Sand (%)	20.2±1.24ab	23.00±1.18a	18.11±0.88b	16.47±1.08b	**	
Silt (%)	21.05±1.54	20.88±1.47	19.59±1.09	17.62±1.34	ns	
Clay (%)	58.72±1.20b	56.12±1.89b	62.31±1.41ab	65.91±1.73a	**	
CEC (meq/100g soil)	41.19±1.37	39.62±1.30	40.15±0.97	38.83±1.19	ns	
Ca (meq/100g soil)	25.92±1.85	21.57±1.76	24.53±1.31	21.71±1.61	ns	<0.35
Mg (meq/100g soil)	7.29±0.48	7.13±0.46	6.61±0.31	6.16±0.42	ns	<0.07
K (meq/100g soil)	2.18±0.20	2.60±0.19	1.96±0.14	2.13±0.17	ns	<0.15
Na (meq/100g soil)	0.21±0.04	0.17±0.04	0.26±0.03	0.17±0.04	ns	
Fe (ppm)	7.66b±2.21b	14.27±2.1ab	18.04±1.56a	16.53±1.92a	**	2.5-4.5
Mn (ppm)	31.79±3.73	35.78±3.53	32.10±2.63	28.29±3.23	ns	2.0
Cu (ppm)	1.28±0.16ab	1.25±0.15ab	1.01±0.11b	1.61±0.14a	*	0.2
Zn (ppm)	0.68±0.09bc	0.99±0.08a	0.89±0.06ab	0.48±0.07c	**	<0.60

[1] Means were based on the following number of composite soil samples: grass pea (9), tef (10); YRG (18), and SSE (12).

[2] Standard error of means (SE).

[3] Significance level: ns (non-significant) = P>0.05, * = P<0.05 and ** = P<0.01.

[4] Cottenie, 1980, McDowell, 1985 and [4]Mtimuni, 1982 (macro-mineral element critical level for pasture & crops).

[5] Katyal & Randhawa, 1983 (micro- mineral element critical level for crops).

Table 5.2. Correlation matrix showing only significant relationships of total N, available P and exchangeable cations with soil parameters under different land use systems.

Soil Parameters[1, 2]	N	P	Ca	Mg	K	Na
Grass pea						
Sand	------	------	------	------	------	------
Silt	0.67*	-0.84**	-0.73*	------	-0.71*	------
Clay	-0.79**	0.87***	0.89***	------	------	------
pH	-0.81**	------	0.75**	------	------	------
OM	0.98***	-0.74*	-0.95***	------	------	------
CEC	-0.89***	------	0.95***	------	------	------
Tef						
Sand	------	-0.67*	------	------	------	------
Silt	------	------	------	------	------	------
Clay	------	0.74*	------	------	------	------
pH	------	------	0.82**	------	------	------
OM	0.98***	------	-0.74**	------	------	------
CEC	------	0.64*	0.67*	------	------	------
YRG grassland						
Sand	0.49*	------	------	------	------	------
Silt	------	------	------	------	------	------
Clay	-0.64**	------	------	------	------	0.47*
pH	------	------	------	------	------	------
OM	0.95***	------	-0.59*	------	------	------
CEC	------	------	------	------	------	------
SSE grassland						
Sand	------	------	------	------	------	-0.58*
Silt	0.65*	------	------	------	------	------
Clay	-0.61*	------	------	------	------	------
pH	------	------	0.74**	0.62*	------	------
OM	0.62*	------	------	------	------	------
CEC	------	------	0.74**	------	------	------

[1] Number of observations: n= 9 for grass pea, n= 10 for tef, n = 18 for YRG and n= 12 for SSE.

[2] Significance level: * = P<0.05, ** = P<0.01 and *** = P<0.001.

Table 5.3. Correlation matrix showing only significant relationships between extractable micro-nutrients and soil parameters under different land use systems.

Soil parameters[1, 2]	Fe	Mn	Cu	Zn
		Grass pea		
Sand	------	------	------	------
Silt	------	------	------	------
Clay	-0.67*	------	------	------
pH	------	------	------	------
OM	------	------	------	------
CEC	------	------	------	------
		Tef		
Sand	------	------	------	------
Silt	------	-0.66*	-0.69*	------
Clay	------	------	0.65*	------
pH	------	------	------	0.85*
OM	0.94***	------	------	------
CEC	------	------	------	------
		YRG grassland		
Sand	------	------	------	------
Silt	0.54*	------	------	------
Clay	-0.58**	------	------	------
pH	------	------	0.53*	------
OM	------	------	-0.51*	------
CEC	------	------	------	------
		SSE grassland		
Sand	------	------	------	------
Silt	0.63*	------	------	------
Clay	-0.67**	------	------	------
pH	------	0.60*	------	------
OM	------	------	------	------
CEC	------	------	------	0.64*

[1] Number of observations: n= 9 for grass pea, n= 10 for tef, n = 18 for YRG and n= 12 for SSE.

[2] Significance level: * = P<0.05, ** = P<0.01 and *** = P<0.001.

Table 5.4. Equation for estimating level of extractable nutrients from related soil parameters.

Component	Land use[1]	Equation	r	r^2	P1[4]	P2
N (%)	Grass pea	$0.04\ (\pm 0.00)\ \mathrm{OM} + 0.02\ (\pm 0.01)$[3]	0.98	0.97	***	
	Tef	$0.05\ (\pm 0.00)\ \mathrm{OM} - 0.01\ (\pm 0.01)$	0.98	0.97	***	
	YRG	$0.04\ (\pm 0.00)\ \mathrm{OM} + 0.02\ (\pm 0.02)$	0.95	0.90	***	
	SSE	$0.01\ (\pm 0.01)\ \mathrm{silt} + 0.02\ (\pm 0.08)$	0.65	0.42	*	
P (ppm)	Grass pea	$0.14\ (\pm 0.03)\ \mathrm{clay} - 5.95\ (\pm 1.70)$	0.87	0.76	**	
	Tef	$0.11\ (\pm 0.05)\ \mathrm{CEC} + 0.09\ (\pm 0.03)\ \mathrm{clay} - 7.11 (\pm 2.00)$	0.88	0.77	*	*
Ca (meq/100g soil)	Grass pea	$1.63\ (\pm 0.20)\ \mathrm{CEC} + 41.42\ (\pm 8.22)$	0.96	0.91	***	
	Tef	$15.78\ (\pm 4.48)\ \mathrm{pH} - 1.69\ (\pm 0.65)\ \mathrm{OM} - 68.40\ (\pm 28.42)$	0.92	0.84	**	*
	YRG	$-1.69\ (\pm 0.54)\ \mathrm{OM} + 0.46\ (\pm 0.21)\ \mathrm{CEC} - 18.56\ (\pm 9.73)$	0.71	0.50	**	*
	SSE	$0.94\ (\pm 0.27)\ \mathrm{CEC} - 14.80\ (\pm 10.43)$	0.74	0.55	**	
Mg (meq/100g soil)	SSE	$2.26\ (\pm 0.66)\ \mathrm{pH} + 0.09\ (\pm 0.04)\ \mathrm{silt} - 8.42\ (\pm 3.96)$	0.79	0.63	**	*
K (meq/100g soil)	Grass pea	$-0.08\ (\pm 0.03)\ \mathrm{silt} + 3.79\ (\pm 0.63)$	0.71	0.50	*	
	Tef	$0.10\ (\pm 0.05)\ \mathrm{CEC} - 1.61\ (\pm 1.80)$	0.62	0.38	*	
Na (meq/100g soil)	YRG	$0.01\ (\pm 0.01)\ \mathrm{clay} - 0.53\ (\pm 0.37)$	0.47	0.22	*	
	SSE	$-0.02\ (\pm 0.01)\ \mathrm{sand} + 0.50\ (\pm 0.17)$	0.57	0.33	*	
Fe (ppm)	Grass pea	$-0.20\ (\pm 0.08)\ \mathrm{clay} + 19.29\ (\pm 4.92)$	0.67	0.45	*	
	Tef	$5.61\ (\pm 0.72)\ \mathrm{OM} - 5.60\ (\pm 2.72)$	0.94	0.88	***	
	YRG	$-0.72\ (\pm 0.26)\ \mathrm{clay} + 63.18\ (\pm 16.06)$	0.57	0.33	**	
	SSE	$-0.80\ (\pm 0.28)\ \mathrm{clay} + 69.32\ (\pm 18.74)$	0.66	0.44	*	
Mn (ppm)	Grass pea	$-1.72\ (\pm 0.61)\ \mathrm{CEC} + 102.74\ (\pm 25.23)$	0.73	0.53	*	
	Tef	$-1.60\ (\pm 0.64)\ \mathrm{silt} + 69.09\ (\pm 13.73)$	0.66	0.43	*	
Cu (ppm)	Tef	$-0.06\ (\pm 0.0.02)\ \mathrm{silt} + 2.50\ (\pm 0.48)$	0.69	0.47	*	
	YRG	$1.32\ (\pm 0.52)\ \mathrm{pH} - 6.77\ (\pm 3.07)$	0.53	0.28	*	
Zn (ppm)	Tef	$0.93\ (\pm 0.20)\ \mathrm{pH} - 4.68\ (\pm 1.25)$	0.85	0.72	***	
	SSE	$0.06\ (\pm 0.02)\ \mathrm{CEC} - 1.67\ (\pm 0.83)$	0.63	0.40	*	

[1] Number of observations: n= 9 for grass pea, n= 10 for tef, n = 18 for YRG and n= 12 for SSE; [3] Values in parentheses indicate standard error; [4] Significance level: * = P<0.05, ** = P<0.01 and *** = P<0.001.

5.3.1. Particle size distribution

As expected, clay was the dominant particle class of the Pellic Vertisols of the study area. Its level ranged from a minimum of 46.72 % to a maximum of 76.56 %. The level of clay among the different land use types differed ($P<0.01$), with the cultivated soil having lower clay percentages. Conversely, sand level was higher ($P<0.01$) in cultivated soil than soil under grasslands. The silt fraction across the different land use systems was similar ($P>0.05$). The SSE grassland soil, which occupies relatively lower landscape positions, had higher ($P<0.01$) mean clay percentage. Soil under tef had the lowest clay and the highest sand contents. From experience farmers seem to have taken note of this slight particle size class difference. They grow tef during the wet season on parts of their holding where the magnitude of the waterlogging problem was less severe.

5.3.2. Soil reaction

Soil pH between some of the land use types was significantly ($P<0.01$) different. Soil under tef and grass pea crops had a higher ($P<0.01$) pH than the soil under YRG and SSE grasslands. The pH ranged from 5.74 to 6.82 in grass pea, 5.88 to 6.50 in tef, 5.70 to 6.29 in YRG grassland, and 5.33 to 6.18 in SSE grassland, respectively. For 80 % of the grassland soil samples the pH was below 6.0, while only 25 % of the soil samples from cultivated soil had a pH below 6.0. The surface soil of the study sites can thus be described as moderate to slightly acidic in reaction.

5.3.3. Organic matter and C/N ratio

In the study area the use of mineral fertilizers, even in cultivated crops, is limited. Nutrients released by soil OM and the mineral particles were, therefore, the prime sources of nutrients absorbed by crops or pastures. Marked difference ($P<0.01$) in soil OM level was observed between cultivated and grassland land use systems. Soil under grasslands appeared to contain about twice as much OM as those soil kept under crops ($P<0.\ 01$). Despite the much lower OM content, the soil colour of cultivated soil remained as dark as those soil under grasslands. In both land use types, the C/N ratios were found in a fairly narrow range. The mean C/N ratios for soil under grass pea, tef, YRG and SSE grasslands were on the order of 11.22, 10.96, 13.82 and 13.73, respectively.

5.3.4. Cation exchange capacity and exchangeable bases

There were no appreciable differences in CEC among the soil samples under the different land use types ($P>0.05$). The CEC values of study sites ranged from a low of 33.18 to a high of 48.32-meq (100 g soil)$^{-1}$. Calcium dominated the exchangeable complex, followed by Mg and K. The exchangeable Na contributed little to the CEC value. Like the CEC values, exchangeable Ca, Mg, K and Na levels among the different land use types were similar ($P>0.05$). These cations, however, exhibited large spatial variations. Exchangeable Ca, Mg and K varied from 14.97 to 46.27, 4.77 to 10.53 and 1.26 to 3.90 meq (100 g soil)$^{-1}$, respectively. The exchangeable Na level ranged from a low of 0.03 to a high of 0.71-meq (100 g soil)$^{-1}$, but 84 % of soil samples analysed had Na ranging between 0.10 and 0.40-meq (100 g soil)$^{-1}$.

Exchangeable Ca was positively correlated ($P<0.05$) with pH and CEC in grass pea, tef and SSE grassland; and with clay content in grass pea (Table 5.2). It had a negative correlation with silt content in grass pea ($P<0.05$), and with OM in grass pea ($P<0.001$), tef ($P<0.01$) and YRG grassland ($P<0.05$). Although their order of importance was less consistent (Table 5.4), the above soil parameters accounted for most of the exchangeable Ca variation. Exchangeable Mg was positively correlated only with soil pH of the SSE grassland ($P<0.05$). A negative correlation of exchangeable K was only found with the silt content of grass pea soil ($P<0.05$). The correlation between exchangeable Na and clay content in YRG grassland was positive ($P<0.05$), while it had a negative correlation with sand in SSE grassland ($P<0.05$).

In soil of all land use types, moderate to high base saturation percentages were recorded. The base saturation percentage of grass pea, tef, YRG grassland and SSE grassland soil ranged from 63 to 98, 64 to 93, 61 to 100, and 64 to 102 %, respectively. Similarly, soil under grass pea, tef, YRG and SSE grasslands had the following respective individual cation percentage saturations: 61-84, 64-80, 64-77, and 66-77 for Ca; 12-30, 14-27, 15-29 and 17-26 for Mg; and 4-9, 6-11, 5-9 and 5-10 for K. The exchangeable Na saturation in soil of all land use types ranged between 0 and 1 %.

5.3.5. Total N

The total N level of the soil between some of the land use types was significantly different ($P<0.01$). Soil under YRG and SSE grasslands had high amounts of total N, while soil under tef and grass pea contained lower amounts of total N ($P<0.01$). The total N ranged from 0.08 to 0.40 %, with 10 % of cropland and 77 % of native grassland samples having above 0.20 % total N. Total N was consistently correlated with soil OM under grass pea ($P<0.001$), tef ($P<0.001$), YRG grassland ($P<0.001$) and SSE grassland ($P<0.05$), and with silt under grass pea ($P<0.05$) and SSE grassland ($P<0.05$). The overriding positive influence of OM on total N was also confirmed from the high r^2-values of the regression analysis (Table 5.4). Total N was negatively correlated with pH ($P<0.01$) and CEC ($P<0.001$) in soil under grass pea, and with clay content in soil under grass pea ($P<0.01$), YRG grassland ($P<0.01$) and SSE grassland ($P<0.05$).

5.3.6. Available P

The difference in the level of available P between soil under some of the land use types was significant ($P<0.05$). Soil under tef had a significantly higher ($P<0.05$) level of available P than that under YRG grassland. Available P in all land use types was low. It was positively correlated with clay content in soil under grass pea ($P<0.001$) and tef ($P<0.01$) and with CEC in soil under tef ($P<0.05$). It was also negatively correlated with OM ($P<0.05$) and silt ($P<0.01$) in soil under grass pea, and with the sand content ($P<0.05$) in soil under tef.

5.3.7. Micro-nutrients

The extractable Fe content between soil under some land use types was significantly ($P<0.01$) different. Soil under grass pea had the lowest ($P<0.01$) Fe content, but the content of Fe in soil under the remaining land use types was similar. Positive correlations were found between extractable Fe and soil OM ($P<0.001$) in soil under tef, and extractable Fe and silt in soil under YRG grassland ($P<0.05$) and SSE grassland ($P<0.05$). Extractable Fe was negatively correlated with the clay content in soil under grass pea ($P<0.05$), YRG grassland ($P<0.01$) and SSE grassland ($P<0.05$), respectively.

Soil under different land use types had similar levels of extractable Mn ($P>0.05$). All soil samples contained high amounts of extractable Mn. More than 60, 80, 83 and 83 % of grass pea, tef, YRG grassland and SSE grassland had over 20 ppm Mn concentration, respectively. Extractable Mn was positively correlated with pH ($P<0.05$) in soil under SSE grassland, while negatively associated with the silt content ($P<0.05$) in soil under tef.

There was a difference in the concentration of extractable Cu in soil under some of the land use types ($P<0.05$). The extractable Cu level in soil under SSE grassland was higher than the Cu levels in soil under tef, grass pea field or YRG grassland. The associations of extractable Cu with pH in soil under YRG grassland ($P<0.05$) and with the clay content in tef field were positive. It was negatively associated with the silt content in soil under tef ($P<0.05$), and with OM in soil under YRG grassland ($P<0.05$).

A significant ($P<0.01$) difference in the extractable Zn level was found between soil of some land uses. The extractable Zn level was higher in soil under tef, but lower in the SSE grassland ($P<0.01$). More than 75 % of samples from the SSE grassland had less than 0.60 ppm Zn, whereas almost all soil samples from the tef, grass pea fields and YRG grassland had more than 0.60 ppm Zn. Extractable Zn was positively associated with pH in soil under tef ($P<0.01$) and with CEC in soil under SSE grassland ($P<0.05$) (Tables 5.3 and 5.4).

5.4. DISCUSSION

5.4.1. Particle size distribution

The soil particle size influences the capacity of the soil to hold water and inorganic nutrients, the ease of drainage and aeration. These factors are crucial for optimum plant growth. For instance, soils that contain a high amount of clay could hold more water and nutrient, but are poor in terms of drainage and aeration. The latter case holds true for the soil under all land uses examined in the present study. The currently observed high mean clay contents (>56%) closely agrees with the findings of Morton (1977) and Kamara *et al.* (1989), who also reported similar clay levels (>50 %) for soil of the study area. The high clay content also conforms to the typical Vertisols physical parameters such as consistency, colour and depth and width of cracking. Observations on the consistency revealed that soil under both crops and grasslands became exceptionally dry during dry spells and sticky following a few days of showers. The soil colour between the different land use types was indistinguishable, which were all dark. Distinct deep cracks were apparent under all land uses, but width and depth of cracks differed between the cultivated and grassland soil. A mean dry season soil cracking depth of 25-52 cm and a width ranging from 3 to 9 cm were found in grassland fields. For the cultivated fields, upper values of the above measurements were observed immediately after crop harvest. Better above ground plant cover and extensive root systems, which slows down loss of water when drying may be responsible for the lower crack size measurements in grassland soil.

The lower clay and higher sand levels in cultivated than grassland soil are indicative of the relative differences in drainage. Although lands under crops and permanent grasslands lie within close proximity, there was a clear tendency across all studied sites for plots used for crop production to occupy relatively higher landscape positions. To counter or lessen the negative impacts of poor aeration or serious waterlogging problem on crops planted during the wet season, whenever possible, farmers avoid the use of foothills for crop production. Where they are forced to use such low landscape positions due to land shortage, the planting time is delayed and crops are allowed to grow on residual moisture. Under such circumstances, much of the growing season is wasted without being exploited for growing crops. The progressive down slope increase of clay and a corresponding decrease in the sand fraction, have been documented for Vertisols of Ethiopia (Fisseha Itanna, 1992).

5.4.2. Soil reaction

Conditions encouraging the net increase, or maintenance, of basic cations (Ca, Mg, K and Na) on the soil cation exchange complex raises the soil pH, while conditions favouring the increase of acidic cations (H, Al and Fe) lower the soil pH (Tisdale *et al.*, 1993). In the present study, soil pH for most soil samples was maintained in a favourable range because of the fairly high base saturation, or the dominance of the soil exchangeable complex by Ca. Soil OM can release hydrogen ions, which contribute to the increase in the acidity of the soil (Tisdale *et al.,* 1993). Even though the extent to which soil OM affects soil pH depends on the type and amount of clay, its influence generally increases with the increase in OM content of the soil. It is then logical to expect a lower pH for the grassland soil that had a higher OM content. Limited availability of some plant nutrients and the corresponding increase in the toxicity of others, which is associated with soil acidity did not appear to be of major concern within the pH range observed in either the cultivated or grassland soil. More harmful effects of a low soil pH occur when the pH drops below 5.5 (Sanchez, 1976). Such low pH levels were experienced in the present study in only two soil samples of the SSE grassland. A high OM level in SSE grassland may be responsible for this relatively low in soil pH.

The best pH range for the availability of most nutrients lies between 5.5 and 6.5 (Tisdale *et al.,* 1993). Currently more than 80 % of the samples had a pH above 5.7, which may be the consequence of moderately high $CaCO_3$ (Piccolo & Gobena Huluka, 1986) and exchangeable Ca. For the same soil, previous studies have reported pH values exceeding 6.0 (Morton, 1977; Desta Beyene, 1982).

5.4.3. Organic matter and C/N ratio

The net addition and loss of OM, that takes place over years, markedly influence the amount of OM in the soil. The influence of this biomass movement into and out of the soil system on soil OM level was evident from the data shown in Table 5.1. The level of OM in cultivated soil was much lower than levels in soil under grasslands. Little above ground biomass, if any, is returned to the soil under present crop cultivation practices. The residues of both tef and grass pea are transported and stacked around the farmers' homesteads for feeding of livestock during the late dry and early wet seasons. It is thus mainly the dead roots that are added to the soil system. For the shallow rooted tef, this too, is of little practical significance. Pasture grasses, on the contrary, have higher root to shoot ratios. A root biomass constituting 53-76 % of the total biomass has been recorded for some tropical grass species (Kanno *et al.,* 1999). Furthermore, tillage operation in crop cultures accelerates OM decomposition and this would further contribute to the decline of the soil OM content. An appreciable and continued decline of soil OM with cultivation is well documented (Sanchez, 1976; Aguilar *et al.,* 1988; Bowman *et al.,* 1990; Tisdale *et al.,* 1993). In the grassland system, regular return of dead roots and litter of grasses and droppings from grazing animals ensure the maintenance of soil OM. Organic matter levels similar to that of the present cultivated soil were reported for the Vertisols of the study area by other workers (Desta Beyene, 1982; Kamara *et al.*, 1989). By the standard of many tropical soils (Sanchez, 1976), the cultivated soil contains moderate amounts of OM, while the OM levels in the grassland soil are high.

In a low input agricultural system, similar to that operating in the study area, the role that OM plays in maintaining soil fertility can be crucial. Apart from improving the physical properties of the soil (e.g. aeration, root penetration, water holding capacity), an adequate soil OM level ensures a steady and a more balanced supply of plant nutrients. Soil OM is an important source for nutrients like N, P, S and most of micro-nutrients (Tisdale *et al.,* 1993). It has been claimed that OM supplies most of the N and half of the P absorbed by unfertilised crops (Sanchez, 1976). Following decomposition, OM bound nutrients are released and become available to plants. By the virtue of their high level of OM, soil from grasslands could have the potential to supply more plant nutrients.

A number of factors affect soil OM decomposition. Some of these are pH, soil moisture and C/N ratio. The observed pH of the grassland soil is relatively lower, but did not appear to seriously affect the normal functioning of soil micro-organisms that are involved in OM decomposition and recycling of nutrients. Moderate soil water availability favours decomposition of soil OM and increase the nutrient available to plants. In the soils studied in this investigation the break down of OM might be impaired by the waterlogging situation, which depresses the activity of micro-organisms. The C/N ratio also controls the rate of OM decomposition. At a C/N ratio exceeding 30, for instance, the level of available N decreases due to immobilization of inorganic N by soil micro-organisms (Tisdale *et al.,* 1993). As the C/N ratios in the present study were much lower than this level, the immobilization of inorganic N may not be of major concern. The present ratios are close to levels considered ideal for optimum N mineralization from OM (Tisdale *et al.,* 1993).

5.4.4. Cation exchange capacity and exchangeable bases

From the data presented in Table 5.1, it is evident that soil under both cultivated crops and grasslands had high CEC values. This is the result of the high clay levels of the studied soil and also the influence of higher OM amount in grassland soil. For the same soil, a similar CEC level of 42.3 meq (100 g soil)$^{-1}$ was reported by Desta Beyene (1982). From a crop nutrition viewpoint, the levels of exchangeable cations, notably those of Ca, Mg and K, were adequate to support optimum production of arable crops (Table 5.1). This is consistent with the findings of earlier studies (Desta Beyene, 1982; Kamara *et al.*, 1989). The same could be deduced from the exchangeable cations, expressed in terms of base saturation percentages. Generally a high base saturation percentage implies increased availability of exchangeable cations (Tisdale *et al.,* 1993). For the study sites base saturation ranged between 61 and 102 %, with more than 60 % of the soil samples having a base saturation higher than 80 %. According to the base saturation class suggested by Cottenie (1980), the soil in the study area had a moderate to high base saturation percentages. In all land uses, exchangeable Na levels were low. Although Na is thought to stimulate plant growth, optimum levels required by crops are not well established. Therefore, whether or not this low level of exchangeable Na meets plant requirements remains questionable.

For Pellic Vertisols of the study area, apparently known to be high in $CaCO_3$ (Piccolo & Gobena Huluka, 1986), the domination of the exchange complex by Ca is as expected. This was also illustrated in the relationships that exchangeable Ca had with most soil parameters (Tables 5.2 and 5.4). No such consistent relationships were noted for exchangeable Mg, K or Na. The level of exchangeable K is important with regard to plant utilization of Mg. Ratios of K/Mg, expressed in milli-equivalent bases, if exceeds unity, seriously impairs plant Mg uptake, and results in plants low in Mg (Cottenie, 1980). In the present case, the K/Mg ratio was so low that the possibility for K inhibiting plant Mg uptake is remote.

5.4.5. Total N

In an experiment previously carried out on Pellic Vertisols of the study area, total N averaged 0.15 % (Desta Beyene, 1982). This value is close to the total N level observed in cultivated soil, but 50 % less than that recorded in soil under grasslands. Based on the established norms (cf. Fisseha Itanna, 1992), the observed mean total N in cultivated soil were moderate, while those values in grasslands were clearly indicative of high total N status for mineral soil. As shown in Table 5.1, the levels of total N in grassland soil were twice as high as the amount in cultivated soil. The lower N level in cultivated soil than in soil under permanent pasture have also been reported elsewhere (Aguilar *et al.,* 1988; Bowman *et al.,* 1990). The high total N in YRG grassland and SSE grassland plots corresponds with the OM content of the soil. The influence of OM on total N was further demonstrated by the consistent direct relationships observed between total N and OM in all land use types (Tables 5.2 and 5.4). Since N is the principal component of soil OM, soil high in OM would supply more N than soil low in OM (Sanchez, 1976; Tisdale *et al.*, 1993). The relatively higher total N values in grassland soil may largely be contributed by N-fixing symbiotic *Rhizobium* species and manure returned by grazing animals. The high level of exchangeable Ca in the studied soil suits the waterlogging tolerant *Trifolium* and native symbiotic *Rhizobium*, which have a higher demand for this element.

The N content of cultivated soil can cheaply and effectively be improved by integrating native *Trifolium* species with cereal crops such as wheat (Abate Tedla *et al.,* 1993). Since such an intervention increases the supply of quality feed without decreasing the grain yield, it can be exploited to bring about a sustainable increase in agricultural production, particularly in the resource poor smallholder farming system. The transformation of total N into plant available inorganic form in the poorly drained Vertisols, however, may be slow because of poor aeration. As excessive wetting of soil inhibits the diffusion of oxygen to sites of microbiological activity, it rather favours the de-nitrification reaction and subsequent loss of N into the atmosphere.

5.4.6. Available P

Soils in many parts of the world are deficient in P. For the Vertisols of the study area, different workers (Piccolo & Gobena Huluka, 1986; Kamara *et al.*, 1989) have reported low available P levels. This was also confirmed in the present study. Due to modest annual application of DAP fertilizer, soil under tef had relatively higher levels of available P. However, extractable P under all studied land uses remained much below the critical level suggested for optimum plant growth (Cottenie, 1980). The level of P available to plants is affected by numerous factors. Of these, soil P level, the type of land use and the soil's P fixing potential are most important. Soil OM is an important source of P. The OM rich grassland soil thus has the potential to supply more plant available P upon decomposition. The turn over of organic P to inorganic P in the present case may be slow due to poor drainage and poor aeration, which inhibit the functioning of soil micro-organisms. The negative relationship of available P with OM in soil under grass pea (Table 5.2) may demonstrate the operation of this phenomenon. Land use practices that affect the OM content of soil generally change the total P balance. Although the total soil P content was not assessed in the present study, its continued decline with cultivation is well established. In their evaluation of the long-term effects of cultivation on soil P, Hedley *et al.* (1982) have found 29 % less total P in cultivated than in adjacently lying soil that are kept under permanent pasture. Soil high in clay has a higher P fixing capability (Tisdale *et al.*, 1993). Such indications have not been confirmed in the present study. On the contrary, available P was positively and significantly associated with the clay content. The mild acidity may in part be responsible for the above positive associations.

The present low level of available P can no doubt affect the efficiency of N_2 fixing symbiotic bacteria and the performance of native clovers of the grassland system as much as it affects crop production. Increasing the level of available P in the soil through application of P is, therefore, important to increase the productivity of both crop and pasture production. The uses of modest levels of P application (10-40 kg P ha^{-1}) in the form of DAP or TSP (triple-super phosphate) fertilisers have been shown to raise DM and seed yield of native clovers growing on Ethiopian highlands Vertisols dramatically (Akundabweni; 1984; Kahurananga & Asres Tsehay, 1984; 1991; Jutzi *et al.,* 1987). Low cost domestically available phosphate rock has also been found to be effective in markedly raising the DM production of native clovers growing on highland Vertisols (Jutzi *et al.,* 1987). These P response studies confirm the limitation of low soil P on native clovers growth that was reported by Astatike Haile (1979).

5.4.6. Micro-nutrients

With the exception of extractable Zn in SSE grassland, all investigated micro-nutrients were found at amounts higher than the critical levels suggested for most crops (Table

5.1). For soil of the SSE grassland, extractable Zn could be described as inadequate for good crop growth. For most crops, 0.60 ppm extractable Zn indicates a deficiency (Katyal & Randhawa, 1983).

Generally the level of extractable micro-nutrients reflects the total amount of these elements in the soil, which in turn depends on the type of parent material. Soils derived from basalt are rich both in macro- and micro-nutrients (Grace, 1983). The studied soils, which originate from weathered basalt are not as rich as those of young basic basalt, but are superior to old acid soils in most nutrients. Other factors also affect the level of extractable micro-nutrients. The most notable of these include clay contents, pH, OM level and CEC values. On the basis of the correlation matrix presented in Table 5.3, silt and clay particle levels appear to affect some of the investigated micro-nutrients. The more or less consistent negative relationship of Fe with clay ($P<0.05$) (Tables 5.3 and 5.4), in particular shows how the increase in clay content negatively affects the availability of Fe. Possibly this was partly due to the negative relationship of clay and soil OM. Negative correlations were found between clay and OM content across all examined land uses. There were no consistent correlations between soil particle class and extractable Mn, Cu and Zn. This implies that the soil particle class had little influence on the supply of plant available Mn, Cu and Zn within the percent particle class range observed in the present study. It was only in soil under tef that Cu was positively correlated with clay content and negatively correlated with the silt content ($P<0.05$). In the remaining land use types its relationships with clay content were negative and non-significant ($P>0.05$). Similarly, the relationship of extractable Mn with silt was negative and significant ($P<0.05$) only for tef soil.

The availability of micro-nutrients is highly dependant on pH. Generally the solubility of most micro-nutrients, and most notably those of Fe and Mn, are expected to decrease as pH moves from moderately acidic to slightly acidic reactions (Tisdale *et al.,* 1993). This, however, was not confirmed in the present study. On the contrary, soil pH was positively and significantly related with extractable Zn in soil under tef ($P<0.05$), with Cu in soil of YRG grassland ($P<0.05$), and with Mn in soil of SSE grassland ($P<0.05$) (Tables 5.3 and 5.4). The absence of negative relationships between pH and extractable micro-nutrients may in part be related to the observed mild acidity and narrow pH range. Across all the land uses, soil pH of 80 % of the soil samples ranged from 5.7 to 6.2.

Soil OM acts as a reservoir for most of micro-nutrients and upon decomposition release certain chelating agents that increase their availability. This holds particularly true for Fe and Zn. The availability of Mn and Cu, on the other hand, was reported to decrease in soil high in OM (Katyal & Randhawa, 1983; Tisdale *et al.,* 1993). The reduced availability of these elements is claimed to be associated with the formation of an unavailable organic complex. The level of extractable Mn in the present study, however, was high (Table 5.1). High Mn in relation to Fe is used to monitor the deficiency or toxicity of the former. A Fe/Mn ratio of less than 1.5 suggests the likelihood of Mn toxicity (Katyal & Randhawa, 1983). In the present study, the Fe/Mn ratios in all analysed soil samples were far below this critical value. On the basis of the correlation matrix and regression equation shown in Tables 5.3 and 5.4, it was only the extractable Fe in soil under tef that was significantly ($P<0.05$) influenced by the OM content of the soil. The high extractable Fe values, which appear to correspond with high accumulation of OM in grassland soil (Table 5.1), did not result in a significant relationship. The level of extractable Fe in soil both under cultivation and grasslands, however, was well above the amount considered critical for optimum plant growth. The assertion that high OM strongly retains Cu was evident only in soil coming from YRG grassland (Tables 5.1 and 5.3). The claimed positive influence of OM on Zn was also not apparent, which may be due to poor drainage and the resultant slow rate of OM break down.

Since CEC is a function of the type and amount of clay and level of OM, its influence on micro-nutrients was rather indirect. The non-significant ($P>0.05$) relationships between CEC and micro-nutrients in almost all land use types may be partly due to the prevalence of exchangeable Ca, which competes with these metal cations for the same exchangeable sites. The competition of Ca^{2+} and subsequent reduction in metal ion adsorption has been reported elsewhere (Kurdi & Doner, 1983).

5. 5. CONCLUSIONS

Irrespective of the type of land use, the studied Pellic Vertisols had a high clay content and a more or less favourable pH and CEC status. Soil OM, which appeared to have a direct influence on total N, accumulated at higher levels under the grassland land use systems. In all types of land uses, the surface soil was sufficiently rich in exchangeable

Ca, Mg and K. However, unless some feasible external sources are obtained, the low level of available P could seriously limit both crop and pasture production. The levels of extractable Fe, Mn and Cu in soil under both cultivated crops and grasslands were adequate to sustain optimum plant growth. Low level of extractable Zn, more specifically in SSE grasslands, requires further study.

Where practicable, reverting croplands into grasslands for a reasonable period (5 or more years) appears to facilitate the restoration of the soil OM content. This may alternatively be achieved by integrating N-fixing native *Trifolium* species into the cropping system. The unexpectedly low levels of extractable P and Zn in apparently OM rich grassland soil may be due to the slow rate of OM decomposition. Devising a practicable way of disposing of excess soil water during the wet season would undoubtedly improve the rate of OM decomposition and enhance the release of OM bound soil nutrients. The presently observed soil nutrient status, which was optimum for most of the examined nutrients, confirms the inherent high fertility of Vertisols. With some improvement in the drainage situation and correction of the deficiency of P and also Zn, crop and pasture productivity could be increased well above the present level.

CHAPTER 6

CRUDE PROTEIN AND MINERAL CONCENTRATION IN NATIVE PASTURES

6.1. INTRODUCTION

Despite the continued expansion of croplands into the grasslands and the resultant decline in the size of grazing areas, native pastures remain the major contributors of livestock feed in the densely populated highlands of Ethiopia. According to earlier estimates, native pastures in the highlands (areas >1 500 m above sea level) occupy 7.3 million ha (Lulseged Gebrehiwot, 1985) and of this about five million ha are situated on Vertisols (Berhanu Debele, 1985; Jutzi *et al.*, 1987). Grasslands on these seasonally waterlogged Vertisols sustain high livestock numbers and provide the much-needed feed year round. Some of the native pasture species growing on these soils produce a high DM yield of superior nutritional quality (Kahurananga, 1982; Mosi & Butterworth, 1983; Akundabweni; 1984; Kahurananga & Asres Tsehay, 1984; 1991; Kahurananga *et al.*, 1985). However, because of continuous overgrazing on communally owned grasslands most of the desirable species like *Themeda triandra*, *Hyparrhenia* species, *Trifolium* species, etc, have largely been replaced by the unpalatable *Pennisetum schimpri.*

Native pasture in the Ethiopian highland follows a distinct seasonal growth pattern that is characterized with varying DM production and nutritional quality. In response to the variation in the seasonal forage availability, the condition and productivity of grazing animals generally undergo cyclic changes. The period that extends from the beginning to the end of the main rainy season (June to September) is characterized by forage of higher CP and energy values (Zinash Sileshi *et al.*, 1995). The grazing animals' performance during the wet season, though better than in the dry season is often claimed to be less than satisfactory. During this part of the year the organic nutrient concentration, specifically those of CP and energy, of the properly managed native pasture are at their best. In a condition where the quantity of available forage meets the fodder requirements of the grazing animals it would be the quality and more specifically the imbalances of minerals and other nutrients that might limit the wet season livestock performance. During the dry season, low DM supply and sub-optimum energy and protein levels of native pastures no doubt limit livestock production, but the nutritional inadequacy might be exacerbated by deficiencies of some mineral elements in the native pastures.

Deficiencies of one or more mineral elements in forages are well documented in eastern Africa (Faye *et al.,* 1983; Kabaija & Little, 1988; Woldu Tekle-Debessai *et al.*, 1989; Khalili, 1991; Jumba *et al.*, 1995a,b; Lemma Gizachew *et al.,* 2002). Nutritional imbalances between mineral elements are also critical, since excesses of one mineral may impair the proper utilization of others. In order to maintain functional and structural integrity and sustain unimpaired health, growth, production and fertility, mineral elements, therefore, should not fall below or rise above the tolerable limits (Underwood & Suttle, 1999). In most of the cases forage based diets also do not supply sufficient amounts of protein to ruminant animals (Kiatoko *et al.*, 1982; Van Niekerk & Jacobs, 1985; Roberts, 1987; Dabo *et al.*, 1988; Kabaija & Little, 1988; Minson, 1990; Espinoza *et al.*, 1991a; Zinash Sileshi et *al.*, 1995).

Highland native pastures, being one of the major livestock feeds, can greatly influence the CP and mineral intake of grazing animals. Livestock without access to external mineral supplement generally portray the status of mineral elements in pasture and the soil on which the pasture is grown. Deficiencies of a particular mineral element in livestock often occur in areas where the same mineral element is found at low concentration in the soil and/or in the pasture (Reid & Horvath, 1980; Mtimuni, 1982; Grace, 1983; McDowell, 1985; Pastrana *et al.*, 1991a; b; McDowell, 1996; Underwood & Suttle, 1999; De Brouwer *et al.*, 2000). The mineral concentration of pastures is also influenced by the growth stage, season (Greene *et al.*, 1987; Pinchak *et al*, 1989; Espinoza *et al.*, 1991a, b; Pastrana *et al.*, 1991a,b; White *et al.*, 1992; Kume *et al.*, 2001; Lemma Gizachew *et al.;* 2002) and floristic composition (Forbes & Gelman, 1981; Greene *et al.*, 1987; Grings *et al.*, 1996). Forage CP concentration, like the minerals, also tend to vary markedly in response to the effect of soil fertility (Reid & Horvath, 1980; Buxton, 1996), stages of forage maturity (Kiatoko *et al.*, 1982; Roberts, 1987; Dabo *et al.,* 1988; Buxton, 1996; Kume *et al.*, 2001) and floristic composition (Dabo *et al.*, 1988; Kabaija & Little, 1988; Minson, 1990; Espinoza *et al.*, 1991a). The native pasture floristic composition, which markedly affects the available forage CP and mineral composition, responds to the intensity of grazing. Moderate grazing contributes to the maintenance of desirable species, while under or over utilization leads to the replacement of desirable species by less desirable ones (Hardy *et al.*, 1999). Despite such tangible influences on native pasture's CP and mineral composition, the above factors are little studied in Ethiopia. Investigating native pasture CP and mineral composition in relation to the underlying soil, grazing management, floristic composition and season, therefore, is important to understand the status and dynamics of these nutrients. These types of studies are also pre-requisites for the development and implementation of appropriate corrective measures for mineral nutrients that appear sub-optimum in native pastures.

Objectives

This study was undertaken to address the following objectives:

i) to assess the floristic composition, CP and mineral concentration differences between native pastures under different management systems

ii) to investigate any possible difference in CP and mineral concentration among native pasture genotypes grown on Pellic Vertisols and to identify desirable pasture species in terms of CP and/or mineral concentration

iii) to evaluate the seasonal change of CP and minerals in native pasture in relation to livestock requirements

iv) to determine the interrelationships of N and mineral elements in soil and native pasture

v) to generate base line information for future CP and mineral nutrition related studies

6.2. MATERIALS AND METHODS

6.2.1. Assessment of floristic composition

The determination of the relative abundance of pasture species provides relevant information needed for the evaluation of grassland condition (Hardy *et al.,* 1999). Both the YRG and SSE grasslands that were assessed for floristic composition, CP and mineral concentration have been under native pasture at least for the last five or more consecutive growing seasons (years) and share similar soil, climate, altitude, slope and aspect. The floristic composition for both grassland categories was determined from the same sampled herbage plants used for laboratory analysis. Due to a limited knowledge on the feeding value of identified native pasture species and a lack of similar floristic composition studies (such as benchmark descriptions), condition class assessments were not studied. Terms like desirable and less desirable were used to qualify species. This qualification was preliminary and subject to revision in the future. For the purpose of this study, criteria like leafiness, animal preference and response to grazing pressure were used to regard a species either as desirable or less desirable. Species that are leafier, selected by animals and which decrease in proportion under high grazing pressure were considered as desirable species. Species with the opposite characteristics were considered as less desirable species. The majority of the species listed in Tables 6.1 and 6.2 belong to the desirable species category. The species that fall strictly under the less desirable species group were *P. schimpri, Sporobolus pyramidalis* and *Eleusine jaegeri.*

For YRG grasslands, and also for that of SSE grasslands, the assessment of the floristic composition was made along two 50-m long perpendicularly intersecting transects during mid September 2001 (wet season). White painted pegs, driven into the opposing ends of the two transects the previous dry season, were used to guide the wet season native pasture sampling. Soil samples were collected during the early dry season (January) of 2001 for both YRG and SSE grasslands (see Chapter 5). In the YRG grassland category, all rooted herbaceous plants were harvested in 20 quadrats (0.25 m x 0.25 m) during the wet season. This was done for each of the 16 sites at a regular interval of 5 m along the length of the two transects just next to the soil sampling points. Live native pasture species present in each quadrat were identified and recorded before the above ground biomass was cut for laboratory analysis. The frequency of occurrence method was thus used to determine the floristic composition of the YRG grassland (ILCA, 1990). On the basis of its frequency of occurrence, a pasture species at a given site was assigned either to a dominant or minor species subgroup (Table 6.1). An arbitrary frequency occurrence value of five was taken as a dividing line between major and minor species. A species was considered as a dominant constituent of that particular site when it occurred in five or more of the 20 quadrats. Otherwise, it was entered into a minor species subgroup. The DM yield of component species in a quadrat was not determined for most of the sites because of the continued grazing that largely removed most of the material of the desirable species. The continuous grazing also did not allow most species to bear elaborate floral features. Species identification was thus largely made on the basis of the vegetative structures (leaf arrangement and shape and/or architecture of the stem and leaf). For some grasses, the identification of the species by experienced shepherds was used to compliment the incomplete taxonomic features.

In SSE grassland, samples required for the determination of floristic composition and laboratory analysis were obtained from 12 sites. Here the species rank of each site was determined based on DM weight contribution of individual species. The over all percent species composition was calculated by dividing the sum of each species dry weight by total dry weight of all species across the sampled sites (Table 6.2). The layout of transects were the same as that used in YRG grassland but here two herbage sub-samples of the standing crop were cut 0.5 m further away from each soil sampling spots in two opposite directions. One of these was sorted into the constituent species, while the other was maintained as such to represent the mixed herbage sub-sample. Wet weights of the individual species and mixed herbage sub-samples were taken on the site. Dry matter yields were determined after drying samples to a constant weight in a forced draft oven at 65 °C for 72 h. Plant identification of the SSE grassland was easier because most species were intact and in their reproductive phase (September 2001). The specimen of each native pasture species in its reproductive phase was taken to the herbarium for confirmation of field identification. The specimens were identified at international livestock research institute (ILRI), Holetta research centre and national herbarium in Addis Abba, Ethiopia.

6.2.2. Collection, pre-treatment and preparation of samples

For YRG grasslands, herbage samples needed for CP and mineral content determination were collected during February (dry season) and September 2001 (wet season). The February and September sampling periods coincided with the senescence and active growth stages of the pasture plants, which were expected to have the lowest and the highest concentration of CP and most minerals, respectively. The sampling sites and number of quadrat samples both during the dry and wet seasons were the same but the sampling spots were different. The clipped standing herbage material constituted only plants that were rooted inside the quadrats. In other economic crops there are certain parts of the plant that best reflect the nutrient status. In pastures, for practical reasons, the entire standing crops above 5 to 8 cm are harvested for chemical analysis (Kelling & Matocha, 1990). Due to heavy grazing, native pastures in the YRG grassland sites mostly did not exceed a height of 8 or 10-cm. This necessitated clipping the standing native pasture biomass at about 3-cm above the ground. To maintain uniformity, herbage samples from the SSE grasslands were also cut at a 3-cm height. The SSE grassland category, however, was sampled only during the wet season (mid September 2001).

Composite herbage samples belonging to the major species in SSE grassland and mixed herbage samples of both grassland categories were placed in perforated clean plastic bags and rinsed twice in de-ionised water so as to remove soil particles that often contaminate pastures during rain splashes and livestock treading. Samples were dried in a forced draft oven at 65 ^{0}C for 72 h and ground in a stainless steel laboratory mill fitted with a 1-mm screen. Ground samples were allowed to equilibrate with the air at room temperature overnight and stored in push-on lid plastic containers until the time of analysis.

6.2.3. Analytical methodology

The DM and ash concentration of herbage samples were determined according to the recommended procedures (AOAC, 1980). To determine DM in herbage, samples were dried at 105 °C for 16 h. Ash was determined following the combustion of samples at 550 °C for 16 h. The Kjeldahl digestion method (AOAC, 1980) and the auto-analyser

(ChemLab Instruments Ltd Continuous Flow Analysis, 1981) were employed to determine N and P in feeds as described below. A feed sample, weighing 0.3-g, was transferred into a micro-digestion tube of 100 ml. To this was added a 1-g catalyst mixture (Na_2SO_4 and $CuSO_4$) and 5 ml concentrated H_2SO_4. The tubes were then placed in a block digester and heated at 350 ^{0}C for 1.5 h or up until the colour of the digest changed to green. After cooling, the tube was filled with distilled water to its mark, shaken-well and allowed to settle overnight. Following dilution, NH_3 concentration in the digest was determined at 650 nm using an auto-analyser (ChemLab Instruments Ltd No CW2-008-17). The N value was multiplied by a factor of 6.25 to calculate the estimated CP concentration of the herbage material. The aliquot of the undiluted digest was used to determine P by the auto-analyser set at 660 nm (ChemLab Instruments Ltd. No. CW2-075-01). In this method orthophosphate reacts with molybdate in an acid solution to form phosphomolybdic acid, which was then reduced by ascorbic acid to molybdenum blue complex.

Mineral elements were analysed after wet ashing in nitric-perchloric-sulphuric acids (triple acid) (AOAC, 1980) as outlined below. A ground sample weighing 0.3-g was transferred into a micro-digestion tube of 75 ml. The tri-acid mixture of sulphuric, perchloric and nitric acids were then added to the sample at a ratio of 1.5:2:3. The tubes were then placed in a block digester and heated for 30 minutes at 270 ^{0}C. Following cooling, the volume of the tubes were adjusted with distilled water. The tubes were then shaken vigorously and the undigested material allowed to settle for 4 h. Concentrations of Na, Fe, Mn, Cu and Zn were read directly from the digest using AAS, but the analyses of Ca, Mg and K was performed following the dilution of the digest with 0.1 % $LaCl_3$.

6.2.4. Statistical analysis

Native pasture CP and mineral data were analysed with the aid of Statistical Analysis System (SAS, 1985). Wet season CP and mineral concentration data from YRG and SSE grasslands, and wet and dry seasons CP and mineral data from YRG grassland were analysed using the T-test. Crude protein and mineral data for mixed and species class herbage coming from the SSE grassland were analysed using one-way ANOVA with GLM model of SAS (1985). The model used was as follows:

$Y_i = \mu + S_i + \varepsilon$, where μ is the overall mean, S_i effect due to species and ε the residuals. Significantly different means were separated by Duncan's multiple range test.

Pearson correlation coefficients between soil and native pastures N and mineral elements were estimated using correlation analysis. Simple linear regression analysis ($Y = bx + a$) was performed using SAS regression procedure to determine parameter estimates for significantly correlated soil and herbage elements of YRG and SSE grasslands.

6.3. RESULTS

6.3.1. Effect of pasture management on DM yield and floristic composition

The influences of traditional pasture management practices (YRG versus SSE) on native pasture DM yield and relative abundance of desirable and less desirable species are presented in Fig 6.1, and Tables 6.1 and 6.2. This comparative assessment was conducted during the wet season of 2001.

The uncontrolled continuous heavy grazing on YRG grassland has altered the floristic composition (Table 6.1). Even though the mean wet season DM yield from YRG grassland was half of that recorded from the SSE grassland (Fig 6.1), the varying grazing management practices did not allow a valid comparison. The YRG grassland was under continuous grazing, while the SSE grassland was protected from grazing animals during the active growth period. High infestation of the unpalatable *P. schimpri* and low occurrence of desirable species were characteristic features of YRG grassland of almost all sites. Individual species DM yield measurements that were made on a few sites of YRG grassland helped to estimate the contribution of different species to the available herbage. With the exception of the severely waterlogged sites, *P. schimpri* constituted most (>85 %) of the available forage. During the growing season a number of herbs and grass species were observed to grow in association with *P. schimpri,* especially in landscape positions prone to seasonal inundation. The herbs appear to provide valuable forage to grazing animals. Sheep and equines in particular relish these succulent herbs, most of which belonging to the Cyperaceae family. They include the species of *Fimbristylis dichotoma, Cyprus rotundus* and *Schoenoplectus corymbosus.*

Although their contribution in terms of yield was low, species like *T. semipilosum* and *P. villosum* were also fairly frequent in YRG grasslands.

As it was shown in Table 6.2, removing grazing animals during the active growth and reproduction phases of the pasture species resulted in a remarkable improvement in relative proportion of the desirable pasture species. The change in the relative abundance of desirable species was quite striking. In all SSE grassland sites, *P. schimpri* have almost completely been replaced by more palatable grass and legume species. Among the grasses, *P. glabrum, Andropogon abyssinicus*, *H. hirta* and *Cynodon dactylon* were the ones that made an appreciable recovery with the release of grazing pressure (Table 6.2). Both these species are leafy and well accepted by grazing animals prior to flowering, but they become coarse and wiry once they are beyond their post flowering stage. The other herbaceous species that appeared dominant in swampy or seasonally inundated SSE grassland sites were *F. dichotoma, C. rotundus and S. corymbosus*. The two annual clovers, *T. tembense* and *T. rueppellianum*, whose occurrence frequency rarely exceeded 2 to 3 plants quadrat^{-1} in YRG grassland, constituted 3-24 % (DM bases) of the available herbage in SSE grassland. It must, however, be noted that the desirable species recovery following seasonal resting, especially for the perennials, was not appreciably large.

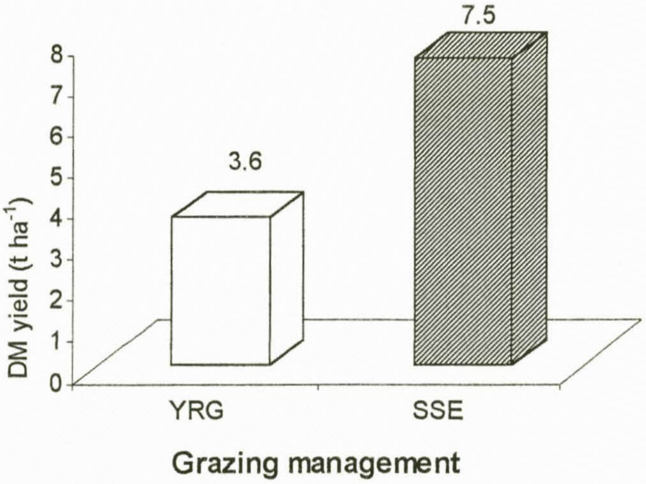

Figure 6.1. Mean DM yield of YRG and SSE native pasture growing on Pellic Vertisols of the Ginchi area in the wet season.

Table 6.1. Major and minor herbaceous species (based on quadrat counts) in YRG grassland.

Site	Relative abundance	
	Major species	Minor species
1	*Pennisetum schimpri, P. villosum, Fimbristylis dichotoma, Trifolium semipilosum*	*P. glabrum, Eleusine jaegeri*
2	*P. schimpri, Hyparrhenia hirta, F. dichotoma, Sporobolus pyramidalis, Cynodon dactylon*	*T. rueppellianum, Medicago polymorpha, E. jaegeri, C. rotundus, Andropogon abyssinicus, P. glabrum*
3	*T. tembense, Cyperus rotundus, Schoenoplectus corymbosus, P. glabrum, C. dactylon, A. abyssinicus*	*P. schimpri, S. pyramidalis, F. dichotoma, T. rueppellianum*
4	*H. hirta, F. dichotoma*	*A. abyssinicus, T. rueppellianum*
5	*P. schimpri, T. semipilosum, T. schimperi*	*P. glabrum, A. abyssinicus, S. pyramidalis, T. decorum, T. tembense, T. rueppellianum, T. polystachyum*
6	*P. schimpri, T. semipilosum*	*Themeda triandra, P. glabrum, Eragrostis superva, T. rueppellianum, T. polystachyum, T. schimperi*
7	*P. schimpri, P. villosum*	*H. hirta, T. rueppellianum, A. abyssinicus, E. jaegeri, S. pyramidalis, P. glabrum*
8	*P. schimpri*	*H. hirta, T. rueppellianum, P. glabrum, F. dichotoma, S. pyramidalis*
9	*P. schimpri, F. dichotoma, P. glabrum*	*S. pyramidalis, H. hirta, T. rueppellianum*
10	*P. schimpri, P. villosum*	*T. decorum, H. hirta, F. dichotoma, C. dactylon, A. abyssinicus*
11	*P. schimpri*	*F. dichotoma, C. dactylon, A. abyssinicus, S. pyramidalis, T. decorum, T. rueppellianum*
12	*P. schimpri, T. schimperi*	*T. triandra, F. dichotoma, A. abyssinicus, H. hirta, T. rueppellianum*
13	*P. schimpri, F. dichotoma*	*P. glabrum, A. abyssinicus H. hirta, T. rueppellianum*
14	*P. schimpri*	*T.schimperi, F. dichotoma, P. glabrum, A. abyssinicus, H. hirta*
15	*P. schimpri, F. dichotoma, P. glabrum, T. triandra, A. abyssinicus, T. rueppellianum*	*C. rotundus, E. jaegeri, Phalaris paradoxa, S. pyramidalis, H. hirta, Helictotrichon elongatum, Aristida adscensionsis, Digitaria nuda, Setaria incrassa, S. acromelana, P. villosum*
16	*P. schimpri, T. triandra, H. hirta*	*A. abyssinicus, A.adscensionsis, S. incrassata, S. acromelana S. pyramidalis, H.elongatum, F. dichotoma, T. polystachyum, T. rueppellianum, M. polymorpha*

Table 6.2. Species rank (DM yield bases) in SSE grassland.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Species Comp. (%)
Hyparrhenia hirta	2	10		9	1					2	8	3	7.94
H. filipendula											11		0.11
Pennisetum glabrum	4	1	2	1	3	1	4	2	2	5	2		13.61
P. schimpri									8	5	1	1	2.88
P. salifex		5				3	2	5					3.69
Andropogon abyssinicus	9		4	2	2		1	1	2	1	5	5	10.61
A.chrysostachyus							9	6					0.46
Cynodon dactylon	4	6	5	7	5	5				8			4.72
Eleusine jaegeri	3	4	7	5						7	8		2.99
Sporobolus pyramidalis	6	13	7	5	8					10	10	11	1.27
Cyperus rotundus	9	1	3	4	8	3	7	8	6	9	7		6.69
F. dichotoma	1	8	7	9	3		5	3	5	2	3	4	7.96
S. corymbosus		10	6			7	3	8	1				5.65
S. incrassata												8	0.57
Helictotrichon elongatum										9			0.11
Themeda triandra											5	2	0.81
Trifolium rueppellianum	6	7	7	10	7	5	8	4	7	4	4	5	6.92
T. tembense		3	1	3	2	5	6	4					10.38
T. polystachyum		8		10	5	8						5	0.81
Medicago polymorpha	8	10	8									5	0.69
Others													10.07

6.3.2. Herbage CP and mineral concentration

6.3.2.1. Effect of pasture management on herbage CP and mineral concentration

The effect of pasture management practices on wet season CP and mineral concentrations is shown in Table 6.3. Mixed herbage CP concentrations of the SSE grassland herbage was significantly ($P<0.05$) higher than herbage CP from YRG grassland.

With the exception of Fe, the mean mineral concentrations of mixed herbage from SSE grassland exceeded those values from YRG grassland. The mean concentration difference, however, was significant ($P<0.001$) only for P. The Ca:P ratios of YRG and SSE grassland herbages were very close (Table 6.3). So were the K/(Ca+Mg) ratios.

Table 6.3. Mean wet season CP and mineral concentration of YRG and SSE grasslands herbages.

Variable (DM bases)	SSE[1, 2]	YRG	Significance level[3]
CP (%)	8.18±0.30	5.97±0.65	*
Ca (%)	0.64±0.03	0.49±0.05	ns
P (%)	0.15±0.01	0.11±0.02	***
Mg (%)	0.17±0.01	0.16±0.01	ns
K (%)	2.55±0.10	1.80±0.13	ns
K/Ca+Mg (meq)	1.42	1.22	
Na (ppm)	33.08±4.30	29.50±3.80	ns
Fe (ppm)	344.42±46.59	408.67±67.06	ns
Mn (ppm)	357.00±30.95	316.67±26.75	ns
Cu (ppm)	2.88±0.37	1.72±0.50	ns
Zn (ppm)	23.58±0.76	22.39±1.40	ns
Ca:P	4.27	4.46	

[1] Means were based on the following number of composite samples: YRG (18) and SSE (12); [2] Standard error of means; [3] ns (non-significant), * and *** indicate probability value of $P>0.05$, $P<0.05$ and $P<0.001$, respectively.

Pennisetum schimpri is the principal constituent of the YRG grassland. The dry season mineral composition of the leaf and stem fractions of this species is shown in Figs 6.2 and 6.3. Since only a small number of samples was analysed (n=2), statistical analyses on CP and mineral concentrations of the leaf and stem fractions are not performed. Concentrations of P, Na, Cu and Zn in both leaf and stem fractions, and Ca and Mg in the stem fraction were very low. As might be expected, mean concentrations of all examined minerals in the leaf exceeded those found in the stem fraction, as was the CP content of the leaf and stem fractions. The CP contents of the leaf and the stem components were 2.53 and 0.88 %, respectively.

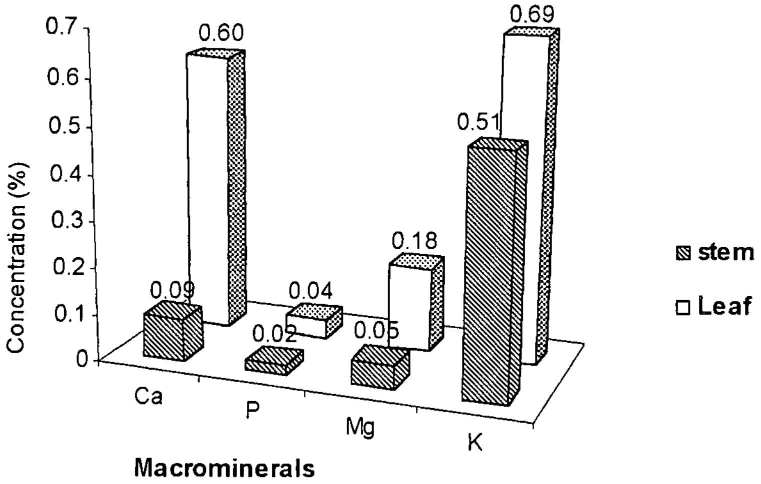

Figure 6.2. Macro-mineral concentrations in *Pennisetum schimpri* in the dry season

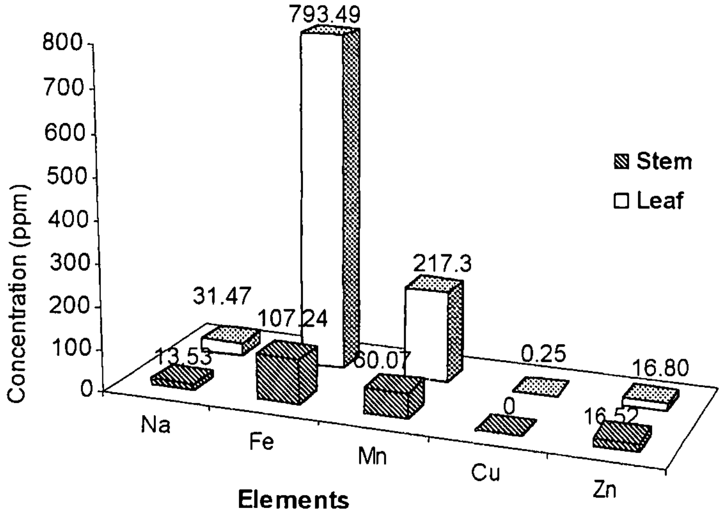

Figure 6.3. Sodium and micro-minerals concentrations in *Pennisetum schimpri* in the dry season

6.3.2.2. Effect of forage species on herbage CP and mineral concentration

Only species from SSE grassland were assessed in the wet season for CP and mineral composition (Tables 6.4 and 6.5). As a group the Leguminosae (*Trifolium* species and *Medicago polymorpha)* were rich, the Cyperaceae (*F. dichotoma, C. rotundus* and *S. corymbosus*) intermediate, and the Poaceae poor in CP and mineral concentration. The shade loving annual legume, *M. polymorpha*, contained significantly higher (P<0.01) levels of CP. The remaining *Trifolium* species were also rich in protein, all having more than 15 % CP. Mean CP values for *F. dichotoma, C. rotundus* and *S. corymbosus* were lower than the legume component but higher than that of the grasses (P<0.01).

Mineral concentrations of forage species differed significantly (P<0.01) for all examined elements, the differences being large for Ca, Na, Fe, Mn and Cu, and small for Zn. As might be expected, the legumes contained Ca at concentration much higher (P<0.01) than all the other forage species, with all samples from legumes having more than 1.20 % Ca. The lowest concentration of Ca was found in *P. salifex*. The remaining grass species, and herbs belonging to the Cyperaceae family, had intermediate Ca concentrations (Table 6.4).

In some forage species, the P concentration was significantly (P<0.01) different. For most forage species, however, within species variation of herbage P was large. *Medicago polymorpha* and *F. dichotoma* had the highest P concentration, while *H. hirta* had the lowest P concentration (P<0.01). Generally the grass species appeared to contain lower concentrations of P. As a group, the legumes had a fairly higher P concentration but they were not as rich in P as they were in Ca. As a result they had wider Ca:P ratios than any of the other forage species examined.

There were significant (P<0.01) differences in K concentrations between some of the examined forage species. In all species, K was the most abundant macro-mineral element. Generally the non-grass species had more K than grass species or mixed herbages. *Pennisetum salifex* was an exception because it had as high a K concentration as the non-grass species. In the non-grass species 73 % of the samples had more than 3 % K.

The leguminous species and *F. dichotoma* far exceeded the other forage species in terms of Mg concentration (P<0.01) and were rich in this element. Almost all samples from Mg rich species contained between 0.21 and 0.30 % Mg. SSE grassland mixed herbages were intermediate in Mg, with Mg concentration in all samples falling within a range of 0.15 and 0.22 %. Magnesium values ranging from 0.09 to 0.12 % were found in *H. hirta* and *E. jaegeri*. In the rest of the species, 85 % of the samples had Mg varying from 0.12 to 0.17 %. In legumes the relatively higher concentration of Mg corresponds with a similar high concentration of K and Ca. As a result their K/(Ca+Mg) ratios, expressed in milli-equivalents, were less than unity for most of the species. The non-leguminous forages, which proportionately contained less Ca and Mg than K, had relatively higher K/(Ca+Mg) ratios than their leguminous counterparts.

Sodium concentrations in some of the forage species were significantly (P<0.01) different. Between sites variation in Na concentrations was also wide for most forage species. Comparatively *M. polymorpha, C. rotundus* and *P. salifex* had higher Na content than the other forage species. *Cynodon dactylon* and *S. corymbosus* were intermediate, but differences between the remaining species and mixed herbage were very small. The distinction between the grass and legume groups in terms of Na concentration was also not clear-cut.

Some species differed considerably in Fe concentration ($P<0.01$). Between sites variations in Fe concentrations were wide for all forage species. Herbage samples from *F. dichotoma* were excessively high in Fe (Table 6.5). The concentration of Fe in this particular species ranged from 901 to 1 099 ppm, with half the samples having more than 1 000 ppm Fe. Intermediate amounts of Fe were observed in *T. tembense* and *C. rotundus.*

Considerable differences in Mn concentration occurred between some of the forage species ($P<0.01$) with *S. corymbosus*, *C. rotundus*, *F. dichotoma* and *P. glabrum* being the richest. Within species variation of Mn was apparent but not as pronounced as it was for Fe. The legume species in general, and *T. rueppellianum* and *M. polymorpha* in particular, were relatively low in Mn. Among grass species, *P. salifex, C. dactylon and E. jaegeri* were intermediate in Mn.

Copper concentration between some of the forage species was significantly ($P<0.01$) different. As a group, the legumes had higher Cu concentration than most grass species ($P<0.01$). Viewed individually, Cu concentrations in *C. dactylon* and *F. dichotoma* were similar ($P>0.05$) to the levels observed in the legume species (Table 6.5). *Cyperus rotundus*, *S. corymbosus* and most grass species were poor sources of Cu.

Significant differences ($P<0.01$) in Zn concentrations were found between some forage species. The species that contained relatively more Zn, namely *C. dactylon, T. rueppellianum* and *T. tembense,* had concentrations ranging from 23 to 35 ppm. Conversely, the Zn concentration in *P. glabrum, P. salifex* and *E. jaegeri* was below 20 ppm. The remaining species were intermediate.

Table 6.4. Least squares means of mixed and major species herbage CP and macro-minerals concentrations (DM bases)

Species[1]	CP (%)[2, 3]	Ca (%)	P (%)	Mg (%)	K (%)	[4]K/Ca+Mg (meq)
SSE mixed	8.18±0.43def	0.64±0.04c	0.15±0.02bcd	0.17±0.01b	2.55±0.12cde	2.32±0.24
H. hirta	4.91±0.61h	0.35±0.06def	0.09±0.02d	0.11±0.01cd	1.69±0.17f	2.65±0.34
A.abyssinicus	4.96±0.57h	0.38±0.06cdef	0.11±0.02bcd	0.13±0.01bcd	1.85±0.16ef	2.89±0.31
P. glabrum	5.70±0.57fgh	0.33±0.06ef	0.14±0.03bcd	0.16±0.01b	2.54±0.16cde	4.50±0.31
P. salifex	7.89±0.75efg	0.27±0.07f	0.12±0.02bcd	0.15±0.01bc	2.94±0.21bcd	5.73±0.41
C. dactylon	9.19±0.67cde	0.49±0.07cdef	0.15±0.02bcd	0.13±0.01bcd	2.27±0.19def	2.52±0.37
E. jaegeri	5.55±0.67gh	0.41±0.07cdef	0.10±0.02cd	0.10±0.01e	2.13±0.19ef	2.76±0.37
F. dichotoma	11.25±0.75c	0.60±0.07cd	0.25±0.03a	0.26±0.01a	3.00±0.21bcd	3.33±0.41
C. rotundus	8.81±0.67cde	0.59±0.07cde	0.16±0.02abcd	0.17±0.01b	3.84±0.19a	3.54±0.37
S.corymbosus	10.55±0.67cd	0.46±0.07cdef	0.18±0.02abcd	0.15±0.01bc	3.33±0.19ab	3.92±0.37
T.rueppellianum	15.60±0.57b	1.95±0.06a	0.18±0.02abcd	0.26±0.01a	3.20±0.16abc	1.06±0.31
T. tembense	18.01±0.57b	1.45±0.06b	0.19±0.02abc	0.23±0.01a	2.88±0.16bcd	1.21±0.31
T.polystachyum	15.75±0.75b	1.82±0.07a	0.20±0.03ab	0.27±0.01a	2.38±0.21def	0.91±0.41
M. polymorpha	20.92±0.67a	1.36±0.07b	0.24±0.02a	0.23±0.01a	3.48±0.19ab	1.39±0.37
CV (%)	15.8	19.90	34.30	15.36	16.66	30.89

[1] Means were based on the following composite samples: SSE mixed (12), *H. hirta* (6), *A. abyssinicus* (7), *P. glabrum* (7), *P. salifex* (4), *C. dactylon* (5), *E. jaegeri* (5), *F. dichotoma* (4), *C. rotundus* (5), *S. corymbosus* (5), *T. rueppellianum* (7), *T. tembense* (7), *T. polystachyum* (4) and *M. polymorpha* (4).

[2] Standard error of means. [3] Means followed by different letter (s) were significantly ($P<0.01$) different.

[4] Critical level for K/(Ca+Mg) is 2.2 (Kemp & t'Hart, 1957).

Table 6.5. Least squares means of mixed and major species herbage Na and micro-minerals concentrations (ppm in DM).

Species	Na[1,2]	Fe	Mn	Cu	Zn
SSE mixed	33.08±13.42e	344.42±44.44cbde	357.00±25.78c	2.89±0.55de	23.58±1.36abc
H. hirta	15.33±18.98e	105.83±62.85e	123.83±36.46de	2.43±0.77e	24.17±1.92abc
A.abyssinicus	19.14±17.57e	159.86±58.19de	131.00±33.75de	2.60±0.72e	23.00±1.78abc
P. glabrum	40.29±17.57e	210.57±58.19de	540.57±33.75b	2.09±0.72e	17.29±1.78cd
P. salifex	186.25±23.25c	151.25±76.98de	268.75±44.65cd	2.79±0.95e	19.25±2.35bcd
C. dactylon	120.60±20.79cd	250.80±68.85cde	208.40±39.94cde	6.22±0.85abc	29.80±2.10a
E. jaegeri	55.60±20.79de	117.40±68.85e	357.00±39.94c	1.44±0.85e	14.20±2.10d
F. dichotoma	54.00±23.25de	988.25±76.98a	602.25±44.65ab	6.03±0.95abcd	25.50±2.35abc
C. rotundus	267.40±20.79b	484.00±68.85bc	619.40±39.94ab	3.95±0.85cde	19.00±2.10bcd
S.corymbosus	117.40±20.79cd	179.00±68.85de	734.20±39.94a	4.69±0.85bcde	23.20±2.10bcd
T.rueppellianum	36.86±17.58e	258.43±58.19cde	78.29±33.75e	7.59±0.72ab	30.00±1.78a
T. tembense	49.14±17.57de	536.29±58.19b	110.29±33.75e	8.67±0.72a	27.29±1.78ab
T.polystachyum	28.00±23.25e	190.75±76.98de	123.50±44.65de	6.26±0.95abc	23.50±2.35abc
M. polymorpha	516.00±20.79a	315.00±76.95cbde	65.20±44.65e	6.66±0.95abc	23.00±2.10abcd
CV (%)	50.44	48.09	29.43	47.54	20.38

[1] Means were based on the following composite samples: SSE mixed (12), H. hirta (6), A. abyssinicus (7), P. glabrum (7), P. salifex (4), C. dactylon (5), E. jaegeri (5), F. dichotoma (4), C. rotundus (5), S. corymbosus (5), T. rueppellianum (7), T. tembense (7), T. polystachyum (4) and M. polymorpha (4).

[2] Standard error of means.

[3] Means followed by different letter (s) were significantly (P<0.01) different.

6.3.2.3. Effect of season on herbage CP and mineral concentration (YRG)

The assessment of seasonal change in CP and mineral concentration was conducted only for mixed herbage from the YRG grasslands. The results of this study are given in Table 6.6. The CP content of mixed herbage showed a marked (P<0.01) seasonal difference. The wet season CP concentrations were almost twice as high as the values observed in the dry season (P<0.01). Dry and wet season CP values ranged from 2.12 to 4.44 and 4.31 to 8.44 %, respectively.

The Ca concentration of dry season herbage was higher than the concentration noted in the wet season (P<0.05). Only about 38 % of wet season herbages had a Ca content above 0.50 % as compared to the 78 % of dry season samples exceeding this level. Among macro-minerals, Mg followed a similar trend to that of Ca, but the seasonal differences were not significant (P>0.05). The herbage levels of P and K in the wet season were twice those in the dry season. These differences, however, were only significant ($P<0.01$) for K. The P concentrations in the dry and wet seasons ranged from 0.03 to 0.09 and 0.07 to 0.14 %, respectively. For K the dry and wet season concentrations ranged from 0.63 to 0.95 % and 1.21 to 2.61 %, respectively. The seasonal change in herbage K content had a pronounced effect on K/(Ca+Mg) ratio. In the dry season the K/(Ca+Mg) ratio was less than half of the wet season ratio (Table 6.6). For herbages of both wet and dry seasons, the Ca:P ratios were fairly wide. The Ca:P ratios for the wet and dry season herbages were 4.5:1 and 12.2:1, respectively. Herbage Na concentrations did not seem to be affected by season ($P>0.05$). Irrespective of season almost all samples contained less than 50 ppm Na.

Iron and Mn concentrations differed little between seasons ($P>0.05$). Both dry and wet season herbages were rich in Fe and Mn, but across site variations were considerable. Iron concentrations in herbage varied from 229 to 680 ppm in the dry season and from 202 to 788 ppm in the wet season. Similarly, Mn in dry and wet season herbages ranged from 218 to 573 and 230 to 645 ppm, respectively. Wet season herbage contained twice as much Cu as the dry season herbage, but the seasonal difference was not statistically significant ($P>0.05$). The Zn concentration in herbage was significantly ($P<0.01$) higher in the wet than in the dry season. Herbage Zn concentration varied from 9 to 22 ppm in the dry season, while in the wet season it ranged from 19 to 28 ppm.

Table 6.6. Mean CP and mineral concentration of YRG grassland herbage as affected by season

Variable (DM bases)[1]	Wet season	Dry season	Significance level[2]
CP (%)	5.97±0.30	3.18±0.16	**
Ca (%)	0.49±0.03	0.61±0.05	*
P (%)	0.11±0.01	0.05±0.00	ns
Mg (%)	0.16±0.01	0.19±0.01	ns
K (%)	1.80±0.10	0.79±0.04	***
K/Ca+Mg (meq)	1.22	0.44	
Na (ppm)	29.50±4.30	30.51±2.41	ns
Fe (ppm)	408.67±46.59	426.23±40.82	ns
Mn (ppm)	316.67±30.94	357.00.±30.00	ns
Cu (ppm)	1.72±0.37	0.86±0.30	ns
Zn (ppm)	22.39±0.76	16.74±1.61	**

[1] Seasonal means were based on 18 composite samples.

[2] ns (non-significant), *, ** and *** indicate P>0.05, P<0.05, P<0.01 and P<0.001, respectively.

6.3.2.4. Effect of soil on herbage CP and mineral concentration

In most of the cases, the level of investigated soil extractable nutrients did not significantly (P>0.05) affect the corresponding concentration of N and some mineral elements in herbages of either YRG or SSE grasslands. The few significant correlations between soil and native pasture N and mineral elements were also inconsistent across the mixed herbage samples of the two grassland categories, and individual forage species of SSE grassland (Tables 6.7 and 6.8). The regression equations showing significant relationships between soil extractable nutrients and the corresponding nutrients in mixed herbage of YRG and SSE grasslands are presented in Table 6.9. Because of the small number of observations, similar regression analyses were not performed for individual forage species.

In YRG grassland, exchangeable Mg and Na were significantly correlated with Mg ($P<0.05$) and Na ($P<0.001$) levels in corresponding wet season herbage. In dry season herbage, a similar positive and significant ($P<0.05$) correlation was found between exchangeable Ca and herbage Ca, but the correlation between total soil N and herbage CP ($P<0.01$) for the same season was negative. The negative correlation of soil N with the CP content of herbage in the dry season may be related to maturity rather than the effect of soil N per se. For the other elements, soil and herbage correlations were not significant ($P>0.05$).

For mixed herbage of SSE grassland, the correlation between extractable P and herbage P was significant ($P<0.01$). For *A. abyssinicus,* extractable Fe was positively and significantly related to herbage Fe ($P<0.05$), while the correlation between extractable Mn and herbage Mn was negative ($P<0.05$). The correlation between extractable Fe and Fe in herbage was positive and significant ($P<0.05$) for *P. glabrum*. In *T. rueppellianum* the only significant correlation was the negative relationship obtained between extractable Cu and herbage Cu ($P<0.05$). For *T. tembense*, the correlations of exchangeable Mg with herbage Mg ($P<0.05$), and extractable Fe with herbage Fe were also positive and significant ($P<0.01$).

Table 6.7. Correlation coefficients (r) between soil and YRG native pasture for N and mineral elements

Variable[1]	Wet season herbage[2]	Dry season herbage[2]
N	-0.42	-0.66**
P	-0.09	-0.18
Ca	0.45	0.53*
Mg	0.48*	-0.10
K	0.40	0.10
Na	0.78***	0.15
Fe	0.22	0.14
Mn	0.07	-0.41
Cu	-0.18	0.33
Zn	0.13	0.19

[1] Number of observations (n = 18 for both wet and dry season).

[2] Significance level : * = $P<0.05$, ** = $P<0.01$ and *** = $P<0.001$.

Table 6.8. Correlation coefficients (r) between soil and SSE native pasture for N and mineral elements

Variable[2]	Mx[1]	Hh	Aa	Pg	Tr	Tt[3]
N	-0.06	-0.14	-0.20	-0.17	-0.63	-0.41
P	0.79**	-0.55	-0.04	0.72	0.71	0.65
Ca	0.15	0.79	0.17	-0.24	0.57	0.36
Mg	0.09	0.59	0.25	0.42	0.13	0.75*
K	0.16	0.15	0.09	0.27	0.44	0.49
Na	0.36	0.62	0.45	0.58	0.72	0.62
Fe	0.53	0.78	0.85*	0.88**	-0.28	0.88**
Mn	0.09	-0.66	-0.85*	-0.29	0.03	0.59
Cu	-0.02	-0.46	-0.65	-0.42	-0.83*	0.05
Zn	0.18	-0.25	0.33	-0.07	0.22	0.34

[1] Mx-Mixed herbage; Hh-*H. hirta*; Aa-*A. abyssinicus*; Pg-*P. glabrum*; Tr-*T. rueppellianum*; and Tt-*T. tembense*.

[2] Number of observations (n = 12 for Mx; n = 6 for Hh; n = 7 for Aa; n = 6 for Pg; n = 7 for Tr; and n = 7 for Tt).

[3] Significance level : * = $P<0.05$ and ** = $P<0.01$.

Table 6.9. Equation for estimating herbage N and macro-minerals from corresponding elements in soils

Component[1]	n[3]	Equation [4,5]	r	r^2 value	Significance level[6]
DYRG herbage Ca	18	0.02Ca + 0.05	0.53	0.28	*
DYRG herbage N	18	- 1.04N + 0.83	-0.66	0.44	**
WYRG herbage Mg	18	0.01Mg + 0.09	0.48	0.23	*
WYRG herbage Na	18	92.2Na + 5.48	0.78	0.60	***
SSE herbage P	12	1.21P + 5.88	0.77	0.59	**

[1] DYRG-dry season YRG mixed herbage, WYRG-wet season YRG mixed herbage.

[3] n: Number of observations.

[4] Soil nutrients expressed: N in %, Ca and Mg in meq, and P and Na in ppm.

[5] Herbage N and macro-minerals expressed: N, Ca, Mg and P in %, and Na in ppm.

[6] Significance level: * = $P<0.05$, ** = $P<0.01$ and *** = $P<0.001$.

6.4. DISCUSSION

6.4.1. Effect of pasture management on DM yield and floristic composition

In an environment with homogeneous climatic and soil conditions, grazing is a major factor that may alter the floristic composition of a grassland community (Hardy *et al.*, 1999). Distinct floristic composition differences were noted between YRG and SSE grasslands (Tables 6.1 and 6.2). As the wet season DM yield measurements for YRG and SSE grasslands were made in the present and absence of grazing animals, respectively, demonstrating the actual yield difference between these two pasture categories is not possible. Since the sites under both YRG and SSE grasslands were similar in major environmental factors, the observed differences in the relative species abundance were largely the consequences of the intensity and time of grazing. For the YRG grasslands , which are owned communally, there is little interest from the parties that have rights to usage to regulate the timing of use or stocking density. Maximum exploitation was the rule rather than the exception. Legumes being less competitive than grasses were most affected by the mismanagement of the YRG grasslands. The apparently high grazing pressure had led to the infestation of the YRG grassland by the coarse unpalatable *P. schimpri.* This grass was not only unpalatable, but was also poor in nutritional quality (Table 6.6, and Figs 6.2 and 6.3). An increase in less palatable species is one of the indications of range deterioration (Stoddart *et al.,* 1975). The frequency of desirable species in the YRG grassland was appreciably lower (Table 6.1). If the present high stocking rate is allowed to continue most of these species will most likely be totally eliminated. At this stage the most visible sign of degradation in the YRG grassland is a shift in floristic composition rather than a reduction in basal cover. But this did not mean that there is no threat of loss in vegetation cover. In fact, on some sites grazing animals, which resorted to consume the unpalatable *P. schimpri,* have already created bare areas. As a result, loss of soil due to erosion in YRG grasslands is increasing. Such conditions lower soil fertility and make future restoration of grassland very difficult. The danger of more serious degradation of these grasslands still looms.

The exclusion of animals from SSE grassland during the active vegetative growth stage up to and including flowering/heading appeared to have had a positive influence on the relative abundance of desirable pasture species (Table 6.2). The observed reasonable recovery also show that the damage done by overgrazing thus far is not irreversible. Among annuals, legumes showed a remarkable recovery. As legumes generally have a lower resistance to breakdown during chewing, which is mainly due to the smaller quantity of cell wall constituents than grasses, pasture with reasonable content of legume would lead to a higher DM intake. Furthermore, in grass-legume mixtures, legumes complement nutrients that are often low in the grass component. Hopkins *et al.* (1994), for instance, have found higher Ca, Mg, K, Cu and Zn in mixed swards of *T. repens/Lolium perenne* than in pure *L. perenne* swards. Generally most species in SSE grassland bore more leafy and green herbage material. Animals that have access to such herbage are thus expected to have a higher DM intake. Stobbs (1973) has observed an increase in the amount of herbage consumed per bite with an increase in the amount of green leaf material in the sward. The superiority in feeding value, of the forage species presently showing remarkable recovery, has been confirmed from the results of feeding studies conducted in Ethiopia. The inclusion of 30 % *T. tembense* hay in a dairy diet has increased milk yields by 10 % (Kahurananga, 1982). Similarly, supplementing the same legume to tef and wheat straws has improved the overall DM digestibility of forages in sheep (Mosi & Butterworth, 1983). An alteration in floristic composition of grasslands can thus have a direct influence on livestock productivity. It is, however, important to note that appreciable recovery of desirable species takes a longer time. For the SSE grassland sites monitored during this study, the annual resting has been applied for at least the last five consecutive growing seasons. Compared to the annuals, the proportion of desirable perennial pasture species (e.g. *T. triandra, C. dactylon, P. salifex, etc.*) was, however, still relatively low. Little is known of how long it would take for these perennials to make a meaningful recovery following proper utilization. Given the inherently good fertility of the Vertisols (with the exception of P), such species should continue to increase in abundance over years if overstocking and grazing at critical stage of development are avoided in a sustainable manner.

In both YRG and SSE grasslands the observed legume species belong largely to the genus *Trifolium*. Native pastures in the highland of Ethiopia, generally have a rich diversity of endemic *Trifolium* species. A total of at least 28 *Trifolium* species are present in Ethiopia, of which 9 are endemic (Thulin, 1983). Of these, only a few were recorded in the present floristic composition survey (Tables 6.1 and 6.2). Although the prevailing high stocking rate may be blamed for eliminating the more grazing sensitive species, the present low *Trifolium* species diversity may, in part, be related to the unsuitability of the climate of the study area. Temperatures in the cool highlands proper are much lower than the temperatures experienced in the study area. Of the commonly occurring *Trifolium* species, *T. tembense* is adapted to waterlogged conditions and out competed the other legume species or accompanying grass species. *Trifolium rueppellianum*, on the other hand, appears to perform much better in relatively well-drained landscape positions. Among grasses, the species belonging to the genus *Pennisetum* were more abundant. In terms of cover, the heavily stocked and over grazed communal grazing areas (YRG grassland) were dominated by *P. schimpri*. With the exception of *P. villosum,* the remaining *Pennisetum* species are confined to SSE and/or waterlogged grassland sites. Species belonging to the genera of *Andropogon* and *Hyparrhenia* also have a wider distribution.

6.4.2. Herbage CP and mineral concentration

6.4.2.1. Effect of pasture management on herbage CP and mineral concentration

The consequences of uncontrolled grazing go beyond effects such as the deterioration in DM yields and the replacement of desirable species with less desirable ones. As palatable and nutritious species become weaker and are eventually eliminated from the pasture, herbage quality declines below the point considered adequate for optimum livestock production. This can be seen from the CP and mineral composition data of YRG and SSE grasslands of mixed herbage in the wet season (Table 6.3) and the CP and mineral composition of mixed herbages of YRG grassland and *P. schimpri* in the dry season (Table 6.6, and Figs 6.2 and 6.3). Herbages from SSE grassland were also generally leafier than herbages from YRG grassland. Since leaves have a higher DM intake than the stem fraction, animals grazing on such leafier swards would have a better performance (Chacon *et al.,* 1978).

Herbage from YRG grassland in the wet season falls far short of the minimum of 7 % CP concentration required by rumen micro-organisms (Minson & Milford, 1967). Conversely, SSE grassland from which animals are excluded during the active growing period had a higher proportion of legumes and hence higher CP values. Livestock that have access to these pastures can thus have better CP intake, but the limited areas of SSE grassland do not provide such quality herbage for an appreciable length of the dry period in amounts sufficient to make up the deficiencies.

The NRC (1989; 1996) suggested critical values for minerals. These are given in Appendices 6.1 and 6.2. In both grassland categories; Ca concentrations in mixed herbage in the wet season were adequate for all classes of beef and dairy cattle (Appendices 6.1 and 6.2), whereas the Mg levels would be marginal for lactating beef and dairy cattle. The concentration of K was generally in excess of the dietary needs of cattle. These high herbage K concentrations did not, however, raise the K/(Ca+Mg) ratios above the acceptable safe limit. A K/(Ca+Mg) ratio exceeding 2.2 was reported to suppress Mg absorption from the alimentary tract of grazing animals (Kemp & t'Hart, 1957). The Ca:P ratios in both SSE and YRG grasslands were close to 4:1 and herbage P concentrations in neither group were adequate, even for beef cattle. Phosphorus deficiency in forages has been reported worldwide (Mtimuni, 1982; Greene *et al,* 1987; Kabaija & Little, 1988; Woldu Tekle-Debessai *et al.,* 1989; Khalili, 1991; Jumba *et al.*, 1995a; McDowell, 1996; Brouwer *et al.,* 2000; Lemma Gizachew *et al.,* 2002). In diets with adequate P, Ca:P ratios as wide as 10:1 may be tolerable (Underwood & Suttle, 1999), but in the event of P deficiency, high Ca:P ratios could exacerbate a P deficiency. In diets marginal in P, 66 and 33 % lower rumen P and serum P levels were observed in sheep kept on diets containing 0.68 rather than 0.35 % Ca, respectively (Wan Zahari *et al.,* 1990). Sodium was the other severely deficient macro-mineral. For equines, animals that profusely sweat and lose large amounts of Na via sweat; the likelihood of becoming severely deficient in Na is thus particularly high. Earlier studies in Ethiopia and Malawi have documented similar Na deficiencies in forages (Mtimuni, 1982; Kabaija & Little, 1988; Woldu Tekle-Debessai *et al.*, 1989; Khalili, 1991). The levels of Ca, K and Na recorded in the present study are comparable to levels reported by Khalili (1991) for native pasture and grass hays of the central north of the Ethiopian highlands.

Mixed herbages from both grassland categories would supply Fe and Mn far in excess of cattle requirements, but not beyond the tolerable limit (Appendix 6.1). The herbage of neither pasture management category had Cu at concentrations sufficient to meet requirements of grazing beef cattle (Appendix 6.1). Mixed herbage from SSE grassland would satisfy only 33 % Cu needs of beef cattle, while the corresponding herbage from

YRG grassland would only be sufficient to meet 20 % of these requirements. The high concentrations of Fe in herbage may further reduce Cu that is absorbed from the alimentary tracts of grazing animals. In both grassland categories, Zn concentrations were below the requirement of beef cattle (30 ppm). The present results agree well with the findings of Faye *et al.* (1983) and Lemma Gizachew *et al.* (2002) who also found Cu and Zn deficiencies in native pastures of Ethiopia.

Based on the mineral composition data in the wet season, the difference in mineral concentration between mixed herbages of YRG and SSE grasslands was generally not large. However, grazing animals that have access to mixed herbages of SSE grassland will undoubtedly have a better mineral intake because: the SSE grassland contains twice the available herbage of the overgrazed YRG grassland, and most species in the SSE grassland are more leafy and palatable as compared to the unpalatable and wiry *P. schimpri* in YRG grassland, both factors that have profound influence on DM intake of grazing animals. As most SSE grasslands were cut for hay at flowering, the assessment of dry season CP and mineral composition for mixed or individual species from this pasture category was not undertaken. Low CP and mineral elements concentrations, however, were recorded for *P. schimpri* and mixed herbages from YRG grassland in the dry season. Grazing animals relying solely on *P. schimpri* dominated YRG grassland are thus likely to be under a negative protein and mineral balance. Data in Figs 6.2 and 6.3 show that both leaf and stem fractions *P. schimpri* were deficient in P, Na, Cu and Zn. Calcium and Mg concentrations in the leaf component were adequate for growing cattle in the dry season, but the levels of these elements in the stem fractions were extremely low. The only elements in both leaves and stems, which met beef cattle requirements, were K, Fe and Mn. The less than 3 % dry season CP, even in the leaf fraction, also suggests the extremely poor nutritional quality of *P. schimpri.*

6.4.2.2. Effect of forage species on herbage CP and mineral concentration

Forage species vary in the extent to which they can extract nutrients from the soil and accumulate them in their tissues. This effect is particularly pronounced under a situation where nutrient uptake is impaired by soil factors like poor soil aeration. Efficiency in nutrient uptake is important both in terms of optimum plant growth and the supply of essential nutrients to grazing animals, which in the study area virtually have no access to regular supplementation.

The provision of essential nutrients that are required in large amounts should first be ensured before the mineral status becomes a major concern. Only animals with a good supply of protein (and also energy) in their diets can benefit appreciably from mineral supplementation (Van Niekerk & Jacobs, 1985; McDowell, 1996). In protein deficient feed, increasing the intake of deficient elements through supplementation can often do more harm than good. Since sub-optimum protein concentrations in mature forage depresses DM intake (Minson & Milford, 1967; McDowell, 1996), it reduces the total amounts of nutrients (including minerals) consumed by herbivores. Most of the grass species examined in the present study were deficient in CP. The two grass species that had CP above the critical level of 7 % suggested by Minson & Milford (1967) were *C. dactylon* and *P. salifex*. Seventy-one percent of *P. glabrum* and all the *H. hirta, A. abyssinicus* and *E. jaegeri* samples had a CP concentration below 7 %. Of these four grasses, the latter three were in an advanced stage of maturity (100 % heading) at the time of sampling and this may in part have contributed to their low CP content. At a similar phenological stage as in the present study Akundabweni (1984) reported mean CP contents of 17 and 15.7 % for *T. rueppellianum* and *T. tembense,* respectively. Although in the present study more CP was recorded in *T. tembense* than in *T. rueppellianum,* the mean CP contents of these native clovers did not differ markedly from the previous observations. All the legume species, *F. dichotoma, C. rotundus* and *S. corymbosus* were rich in CP and could have a potential to offset the protein deficiency in most grass species. The fairly reasonable concentration of CP in SSE grassland mixed herbage supported this assertion (Table 6.4). Large differences in CP concentration among forage species, and most notably the superiority of legumes over grasses, has been shown in the extensive review of Minson (1990).

In close agreement to the east African studies (Long *et al.,* 1970; Kabaija & Little, 1988; Jumba *et al.,* 1995a) marked Ca concentration differences were found among forage species. Of all the species analysed, the legumes were exceptionally high in Ca (>1.20 %). Minson (1990) also reported similar levels of Ca for the two legume genera (*Trifolium* and *Medicago*) examined in the present study. On the bases of the NRC guidelines (Appendices 6.1 and 6.2), Ca levels in the leguminous forages were adequate for all classes of beef and dairy cattle. In almost all the remaining forage species, Ca would meet the requirements of beef cattle, but would be marginal for lactating dairy cows. Oxalate, an organic compound that occurs in many grasses, can depress the absorption of Ca when present at high concentrations. High oxalate levels and a corresponding reduced Ca availability have been documented in some tropical grass species (Blaney *et al.*, 1982; McKenzie & Schulze, 1983). Unfortunately, the oxalate status of forages was not studied in the present study.

Fimbristylis dichotoma was the only forage species of which all the samples contained P above the minimum beef cattle requirement of 0.17 % (NRC, 1996). The entire herbage samples of *H. hirta, P. salifex, E. jaegeri, A. abyssinicus,* 85.7 % of *P. glabrum,* 80 % of *C. dactylon,* 75 % of *T. polystachyum,* 85.71 % of *T. rueppellianum*, 60 % of *C. rotundus,* 57.14 % of *T. tembense*, 20 % of *M. polymorpha* and *S. corymbosus* had P below the recommended minimum quantity. No single herbage sample had P value exceeding 0.36 %. Similar low P concentrations have been reported in grass species in Kenya (Jumba *et al.*, 1995a) and Ethiopia (Kabaija & Little, 1988), but higher P levels were documented for forage species from Uganda (Long *et al.*, 1970). Higher P values in the latter case were due to sampling in an early growth stage, which had proportionately more leafy material. Phosphorus concentrations in forage species in these earlier studies did not, however, differ greatly. The wider Ca:P ratio (5.7:1 to 10.8:1) presently observed in the leguminous species may further accentuate the P deficiency.

With regard to K, it would be the over abundance rather than the shortage that appears to affect the mineral nutrition of livestock that depend on SSE grassland. *Hyparrhenia hirta*, the species that was observed to have the lowest K concentrations, contained nearly three times the K level recommended for beef cattle. These results compare well with previous observations on native pastures of Ethiopia in which high K levels were recorded (Khalili, 1991; Lemma Gizachew *et al.*, 2002). For SSE grassland of the study area where the K rich species such as *T. rueppellianum, M. polymorpha, P. salifex*, *F. dichotoma, C. rotundus* and *S. corymbosus* make up a significant proportion of the available herbage in the wet season the likelihood of excess K ingestion by grazing stock is high.

Previous studies from east Africa have demonstrated both large (Kabaija & Little, 1988) and small (Long *et al.*, 1970; Jumba *et al.*, 1995a) differences in Mg content between forage species. Small Mg concentration differences among most grass species were observed in the present study. The Mg concentration differences between grass and non-grass species, however, were appreciably large. In a review Minson (1990) pointed out that waterlogging and low temperature depresses plant Mg uptake. In spite of the waterlogging problem in the study area, all the legumes and *F. dichotoma* contained above 0.20 % Mg. At such a level, Mg would meet the requirements of all classes of beef and dairy cattle (Appendices 6.1 and 6.2). In the SSE grassland mixed herbage and the rest of the forage species Mg would be sufficient for growing and finishing beef cattle, but could become marginal for lactating cows of both beef and dairy cattle. As indicated earlier, the nutritional adequacy of Mg in forages is affected by the relative amount of K. High K intake would depress the absorption of Mg in the alimentary tracts of animals (Kemp & t'Hart, 1957; Wylie *et al.*, 1985). In the present case it was only in *P. salifex*, *C. rotundus* and *S. corymbosus* that the K/(Ca+Mg) ratios exceeded the critical value of 2.2. Feeding ruminants with monensin would increase Mg retention and avert the potential risk of reduced Mg absorption due to high dietary K intake (Greene *et al.*, 1986). Magnesium absorption from gastrointestinal tracts of ruminants could also be depressed when forages are low in Na:K ratio (Martens *et al.*, 1987). As the presently studied forages were low in Na and high in K, the chances for impairment of Mg absorption is high.

Medicago polymorpha, C. rotundus and *P. salifex,* the species that appeared to have a higher ($P<0.01$) Na concentration, could supply only 86, 44.6 and 31.04 % of the minimum beef cattle requirement for Na, respectively. All investigated species were thus severely deficient in Na. Deficiencies of this element have been reported for forages from Ethiopia and Uganda (Long *et al.*, 1970; Kabaija & Little, 1988; Khalili, 1991). In soil enriched with Na, grasses could be identified as accumulators or non-accumulators of Na on the basis of their ability to accumulate this element (Minson, 1990). The same author has stated that legumes lack the ability to accumulate Na in their tissues. In the light of this, the presently observed Na concentration superiority of *M. polymorpha* over the other forage species under low soil Na warrants further investigation.

In reference to the suggested cattle feed Fe concentration of 50-ppm of the NRC (Appendices 6.1 and 6.2), mixed and most species herbages would supply Fe far in excess of requirement. Iron levels exceeding 1 000 ppm are, however, undesirable for it becomes toxic to grazing cattle (NRC, 1996). Half of the samples from *F. dichotoma* have already exceeded this critical limit. The high level of Fe in mixed, *F. dichotoma, T. tembense* and *C. rotundus* herbages also raise some concern with regards to Cu utilization. High Fe in feed can cause a marked decline in Cu utilization (Bremner *et al.*, 1987; Phillippo *et al.*, 1987; Underwood & Suttle, 1999). Previous studies in east Africa have also reported large variations in Fe among tropical forage species (Long *et al.*, 1970; Kabaija & Little, 1988; Jumba *et al.*, 1995b). The differences in Fe concentration in the different sources of herbage may not be entirely attributed to genotype factor. Soil contamination of herbage was claimed to be responsible for much of the variation in forage Fe concentration (Jumba *et al.*, 1995b; Underwood & Suttle, 1999). Repeated rinsing of collected samples with de-ionised water in the present study was, however, expected to minimize variation due to soil contamination.

Differences in Mn concentration between some of the forage species were remarkably high. For instance, Mn concentration in *S. corymbosus* was more than 11-fold that of Mn in *M. polymorpha*. This observation is supported by earlier east African work, which showed marked variation in Mn between forage species (Long *et al.*, 1970; Jumba *et al.*, 1995b). In a review, Minson (1990) indicated that when Mn concentrations in forages exceed 60 ppm, grasses tend to surpass legumes in Mn. The present result closely agrees with this assertion. All forage species examined in this study would meet the Mn requirements of all forms of beef and dairy cattle production (Appendices 6.1 and 6.2).

Low concentrations of Cu in forages are reported for both tropical and temperate environments (Forbes & Gelman, 1981; Faye *et al.*, 1983; Grace, 1983; Kappel *et al.*, 1985; Kabaija & Little, 1988; Kabaija & Smith, 1988; Minson, 1990; Espinoza *et al.*, 1991b; Khalili, 1991; Pastrana *et al.*, 1991b; Jumba *et al.*, 1995b; Lemma Gizachew *et al.*, 2002). In agreement, almost all the forage species investigated in the present research contained Cu below the minimum of 10 ppm recommended for beef cattle (NRC, 1996). The magnitude of this deficiency, however, varies among species. While 57.2 % of *T. tembense* and 28.6 % of *T. rueppellianum* samples meet Cu requirements of beef cattle, all grass samples with exception of *C. dactylon* fail to satisfy even 50 % of the requirement. For *C. dactylon,* Kappel *et al.* (1985) recorded a slightly higher mean (8 ppm) Cu concentration. The superiority of legumes over the grass species in the present work agrees with the findings of Forbes & Gelman (1981), who also reported higher Cu concentration in clover (*T. repens*) than in grasses and non-leguminous herbs. Other investigators have also reported variations in Cu concentration among tropical forage species (Long *et al.*, 1970; Kabaija & Little, 1988; Kabaija & Smith, 1988; Jumba *et al.*, 1995b). Manipulating the floristic composition of a pasture in order to increase the proportion of species with high Cu content has the potential of at least lessening the likelihood Cu deficiency in grazed herbage. The relatively higher Cu concentration presently observed in *F. dichotoma*, *C. dactylon*, *T. tembense* and *T. rueppellianum, however,* appears to be nominal as these species were also high in Fe. As indicated earlier, increased intake of Fe would decrease the biological availability of dietary Cu.

Species differences in Zn concentrations have been documented for tropical forages (Long *et al.*, 1970; Kabaija & Little, 1988; Kabaija & Smith, 1988; Jumba *et al.*, 1995b). This is in agreement with the present study. Even though there was a tendency for the legumes to contain more Zn than the grass species, this distinction was not as clear-cut as it were for the other micro-minerals. A total of 71.7, 60 and 57.2 % of *T. rueppellianum, C. dactylon* and *T. tembense* samples, respectively, meet the recommended 30-ppm Zn requirement of beef cattle. All the remaining forage species had Zn below this critical concentration.

6.4.2.3. Effects of season on herbage CP and mineral concentration (YRG)

The investigation of the seasonal variation in CP and mineral concentrations was confined to mixed herbage of the YRG grassland category in the present study and did not include changes in leaf and stem fractions or individual grass and legume species.

Seasonal changes do affect the CP content of both stem and leaf fractions of forages, though the effects are less in leaves than in stems (Dabo *et al.*, 1988). Similarly, with the advance of the growing season, the level of CP in herbage declines in both grass and legume species (McDowell, 1985; Roberts, 1987; Dabo *et al.*, 1988; White *et al.*, 1992; Zinash Sileshi *et al.*, 1995; Buxton, 1996; Kume *et al.*, 2001), although grasses are more affected by season than their legume counterparts (Coates *et al.*, 1990). Earlier work on native pasture of the Ethiopian highlands demonstrated a sharp fall in both the ME and CP levels at the end of the rainy season. The extent of this drop, however, was more critical for CP than the level of ME because the latter remained within the acceptable range of cattle ME requirements, for almost the entire dry season. This finding holds true for well-managed native pasture that is stocked at its optimum carrying capacity, i.e. 2-3 TLU ha^{-1}. For the overgrazed YRG grassland, the amount of available forage is as important as the decline in quality. Under such circumstances, providing protein supplements along with catalytic level of ME sources would likely improve feed intake and digestibility of poor quality native pasture. In the present study only the aspects of CP were investigated. All herbage samples in the dry season and 60 % of samples in the wet season contained CP below the minimum critical value of 7 % (Minson & Milford, 1967). Crude protein concentrations below this critical value depress DM intake (Minson & Milford, 1967; McDowell, 1996) and hence reduces the total amount of nutrients (including minerals) consumed by herbivores animals. The CP release from mature pastures within the rumen may be limited further due to the possible association of protein with lignin or silica in the cell wall structure. Dry season lignin and silica levels of 9 and 4 % respectively, have been demonstrated for native pasture of the central Ethiopian highlands (Zinash Sileshi *et al.*, 1995). The drop in CP concentration in mature forages with a corresponding increase in fibre content, following flowering, is a universal phenomenon. This periodic fall in pasture CP level is mainly associated with the drop in the leaf to stem ratio (Buxton, 1996). As maturity progresses or the dry season advances, the protein rich leaves tend to decline further in relation to the stem fraction. The superiority of the leaf over the stem fraction in terms of CP remained valid at this late stage of devolvement. For *P. schimpri*, the predominant grass species in YRG grassland, the leaf and sheath contained almost threefold the CP content of the stem fraction in the dry season (Figs 6.2 and 6.3). The CP level of herbage in the wet season remained low because of non-selective sampling, which included all standing biomass (senescent and coarse stems) in a quadrat above 3-cm height. Grazing animals, unless forced by forage shortages would normally avoid over matured *P. schimpri*. Therefore, they would ingest herbage materials with a higher CP than indicated in the presented data. Seasonal differences in CP and also in most minerals concentrations have a distinctive association with floristic, morphological and physiological variables. The presence of legumes (mainly *T. semipilosum* and *T. schimperi*) and the non-leguminous succulent forages (mainly *F. dichotoma*), and also live tissues and leafy materials, which were either absent or scanty in the dry period, would make the herbage relatively richer in protein in the wet season. The mean leaf to stem ratios for *P. schimpri* in the wet and dry seasons was 3.65 and 2.36 %, respectively.

The present high concentrations of Ca and Mg in herbage in the dry compared to the wet seasons contrasts to the findings of Pastrana *et al.* (1991a) who reported higher amounts of these elements in the wet season. Higher dry season Ca concentrations are not limited to the present study. An increase in forage Ca (Hendricksen *et al.,* 1992; White *et al.,* 1992; Hopkins *et al.,* 1994; Lemma Gizachew *et al.,* 2002) and Mg (Mtimuni, 1982) concentrations with the advance of the growing season have been well documented. Unless its availability is affected by some anti-nutritional factors, such as oxalate, Ca levels observed presently in both wet and dry seasons would be more or less adequate for all classes of beef and dairy cattle (Appendices 6.1 and 6.2). In both wet and dry seasons Mg concentrations in herbage would be adequate for growing cattle, but appeared marginal for lactating beef and dairy cows. The YRG grassland, irrespective of season, was deficient in P and had high Ca:P ratios. In diets low in P, wider Ca:P ratio exacerbate P deficiencies (Wan Zahari *et al.,* 1990). The appreciable drop of P and K in dry season herbages is consistent with the results of other workers (Kiatoko *et al.,* 1982; Mtimuni, 1982; Greene *et al.,* 1987; Pinchak *et al.*, 1989; Espinoza *et al.,* 1991a; Pastrana *et al.,* 1991a; Hendricksen *et al.,* 1992; White *et al.,* 1992; Grings *et al.,* 1996; Lemma Gizachew *et al.,* 2002). Being mobile elements, the labile P and K are translocated or leached to the root zone with the advancement of the growing season. The concentrations of K, during both seasons, exceeded the requirements of any class of beef cattle. The relatively high wet season K concentrations, in relation to that of Ca and Mg, has resulted in a more than two-fold increase in the K/(Ca+Mg) ratio, but not to the extent that raises concern on the availability of Mg to grazing animals (Table 6.7). On the basis of a minimum of 0.06 % Na recommended for beef cattle, herbages were extremely deficient in this element. In neither wet nor dry seasons did herbage supply even 10 % of cattle Na requirements. The results of this study are in agreement with those of Pastrana *et al.* (1991a) who observed similar low concentrations of Na in wet and dry seasons forages of Colombia.

From the published studies, the effect of season on forage Fe or Mn concentrations was inconsistent. While Espinoza *et al.* (1991b) and Grings *et al.* (1996) found marked seasonal changes in Fe and Mn concentration in forage, no significant seasonal differences were observed by McDowell *et al.* (1982) and Lemma Gizachew *et al.* (2002). In the present research, season had no effect either on herbage Fe or herbage Mn. Both Fe and Mn were present in herbages at concentrations substantially exceeding beef cattle requirement, but were below the tolerable limits.

The lack of significant difference in Cu concentration between the relatively leafier and greener wet season herbage, and the corresponding mature dry season herbage may be due to the large variation exhibited across sites. Contrasting results have been reported concerning the seasonal concentration changes of Cu in forages. Hendricksen *et al.* (1992) and White *et al.* (1992) did not find differences in Cu concentrations between wet and dry season forages, while Mtimuni (1982), Espinoza *et al.* (1991b) and Lemma Gizachew *et al.* (2002) noted a decline in forage Cu with the advance of the growing season. In a review Minson (1990) indicated that Cu levels in young and leafy herbages exceeds that in mature forages proportionately high in stems. Since entities like lignin and other fibre components, that bind and render nutrients unavailable, increase with maturity, it would be logical to expect a reduced availability of Cu and other minerals or organic nutrients with the progress of the growing season. Grazing animals, which select leafier and greener herbage in preference to coarse and mature herbage, would most likely ingest herbage material of different Cu concentration and availability than those shown in the present study. During both seasons, herbages were clearly deficient in Cu. The presence of high concentrations of Fe in both wet and dry season herbage may interfere with Cu utilization and further exacerbate Cu deficiency.

In the present study, higher Zn concentrations were found in the wet season herbages, but levels were still below the 30-ppm recommended for beef cattle. The extent of the deficiency, however, was more severe in the dry season. In the wet season herbage Zn could, for instance, satisfy over 60 % of beef cattle's need. Conversely, over half of the dry season herbages could not meet 50 % of the recommended Zn requirement. Higher level of Zn in spring forage, and deficiencies of the same element in both spring and fall harvested forages, were also reported from Florida, USA (Espinoza *et al.,* 1991b). For forages of this region, similar seasonal effects on Zn concentration in forage were not evident in an earlier study (McDowell *et al.*, 1982).

6.4.2.4. Effect of soil on herbage CP and mineral concentration

Despite the more than two-fold variation in soil extractable elements concentrations, the correlations between soil and herbage elements were largely weak and non-significant ($P>0.05$). The inconsistency of significant correlations across forage sources and low r^2-values indicate the presence of other soil and non-soil factors influencing forage mineral concentrations. The low r^2-values also undermine the predictive potential of the regression equations of significant soil and herbage N and mineral element relationships (Table 6.9). Lack of significant relationships in most soil and herbage mineral elements was also reported for forages of Kenya (Jumba *et al.,* 1995a, b) and Ethiopia (Lemma Gizachew *et al.,* 2002). The generally weak relationships in the present case may be due to higher levels of most elements in the soil, which were above the critical values suggested for optimum plant growth. For those elements, which were adequate in the soil but low in forage (e.g. Cu), factors other than soil element status may have affected plant uptake. Levels of exchangeable Na and extractable P in both YRG and SSE grasslands, and that of extractable Zn in SSE grassland were low (see Table 5.1). These low soil Na, P and Zn levels were reflected in corresponding herbage mineral concentrations. The low level of Zn in most of the examined forages may be related to impaired plant uptake of Zn, which occurs in soils high in exchangeable Ca (Giordano *et al.*, 1974; Tisdale *et al.*, 1993). Soil P with mixed herbage of SSE grassland, and soil Mg and Na with mixed herbage of YRG grassland was significantly correlated (Tables 6.7 and 6.8). Kerridge *et al.* (1990) also found strong correlations of soil P with grass and legume P, with the soil-grass associations having higher r^2-values than that of soil-legume association. The few significant correlations found between soil and forage mineral in the present study were not confined only to soil nutrients having low extractable values. For Mg and Fe, soil nutrients that were well above the critical level, significant correlations were noted between the levels of soil Mg and Fe and the concentration of corresponding elements in herbage. The contribution of soil exchangeable Mg to herbage Mg variation, however, was not large (Table 6.9). In the case of herbage Fe, soil extractable Fe accounted for much of the variation. This may partly be associated with the characteristics of species to absorb and accumulate this element in their tissues. This, however, needs to be further substantiated with a more detailed intensive study. For some Vertisols of Ethiopia, similar significant relationships have also been found between soil and plant (cereal crop) elements (Fisseha Itanna, 1992).

High levels of exchangeable Ca (Minson, 1990) and flooding (Currier *et al.*, 1983) were claimed to increase forage Ca concentration. Even though the levels of Ca in the investigated forages were moderate to high, its concentration in species that thrive best in heavily waterlogged lower landscape sites (e.g. *T. tembense*, *S. corymbosus*, *C. rotundus* and *P. salifex*), however, did not appear to exceed that of species occupying higher landscape positions. The type of parent material and pH considerably influence forage Mg concentrations. Soils developed from basic rock are higher in Mg than soil derived from acidic igneous rocks (Minson, 1990). Vertisols of the study site, which are derived from weathered basalt, as confirmed by the level of exchangeable Mg and mild soil reaction, appear to supply sufficient amounts of Mg to plants. The same applies to K. The presently observed herbage Mg and K status more or less reflect the level of exchangeable Mg and K in the soil. For forages capable of accumulating Na, the levels of Na and K in the soil markedly influence forage Na concentration. High soil K in relation to Na, however, depresses forage Na concentration (Minson, 1990). The relatively high level of exchangeable K in the studied grassland soils has likely interfered with absorption of Na by pasture plants.

Available Fe and Mn levels in the studied soils were far in excess of crop requirements (Katyal & Randhawa, 1983). Apart from that taken up by plant roots, soil contamination inflates the level of these elements in forages (Jumba *et al.,* 1995b; Underwood & Suttle, 1999; Lemma Gizachew *et al.,* 2002). In the present study, an effort was made to remove adhering soil contaminants from herbage samples. High variations in forages belonging to the same species or mixed herbage category indicate the ineffectiveness of this exercise. This undoubtedly discounts the reliability of the significant correlation that was found between extractable Fe and herbage Fe.

Soils developing from basalt are generally rich in Cu (Grace, 1983; Katyal & Randhawa, 1983) and the same is expected from Ginchi Vertisols that originated from weathered basalt. Extractable Cu levels in soil were well above the critical value of 0.20 ppm suggested for crop growth (Katyal & Randhawa, 1983), but this did not prevent the deficiency of this element in forages. Low forage Cu may in part be related to the relatively high OM content of the soil. In soils high in OM, Cu is claimed to form a less soluble organic complex with soil OM (Reid & Horvath, 1980; Katyal & Randhawa, 1983; Tisdale *et al.*, 1993). The problem may also be associated with poor drainage and growth stage. Copper deficiency in crops is reportedly accentuated in poorly drained soils (Reid & Horvath, 1980; Katyal & Randhawa, 1983). The Vertisols on which the studied forages grow are well known for their poor internal drainage. High Cu concentrations at the early stage of growth and lower Cu level towards maturity in plants are also well documented (Katyal & Randhawa, 1983; Minson, 1990). Since presently examined forages were cut in the reproductive phase, the observed low herbages Cu concentration may, in part, be due to physiological maturity. The only micro-mineral that tends to be insufficient for optimum plant growth was extractable Zn. This was particularly true for SSE grassland soil, in which the extractable Zn was below the critical level of 0.60 ppm (Katyal & Randhawa, 1983). The low concentrations of Zn in studied forages thus correspond to the low level of available Zn in soil. Changes in forage Zn concentrations in response to the level of Zn in the soils has been documented elsewhere (Minson, 1990). High exchangeable Ca has also been reported to interfere with plant Zn uptake (Giordano *et al.,* 1974; Tisdale *et al.,* 1993). For the soil of the study area, which was fairly high in exchangeable Ca, this could also be a possibility.

6.5. CONCLUSIONS

Overstocking has reduced the proportion of desirable species and favoured the domination of YRG grassland by the less palatable and low quality *P. schimpri*. The change in floristic composition further lowered the nutritional quality of the available herbage. A modest improvement in pasture management, such as resting at the critical stages of forage development, will encourage the recovery of desirable species and restore pasture productivity. Among the desirable species, an increase in the proportion of native clovers enhances the supply of nutritious herbage and improves soil fertility through biological N-fixation. Since almost all of these native clovers are annuals, conserving herbage rich in these species in the form of hay would avoid leaf loss that follows flowering. Setting aside a small portion of the clover stand as a seed crop is also crucial to produce seeds needed to re-establish clovers in grasslands where the soil seed reserves have been depleted.

Large CP and mineral concentration differences between the examined forage species signify the considerable influence of floristic composition on the nutritional quality of native pastures. Since all the investigated species had K, Fe and Mn concentrations several times higher than that required by grazing animals, the species difference for these elements have little practical importance. Species differences are of great practical significance for elements like N, Mg, P, Na and Cu that were found to be below the requirements of beef or dairy cattle in mixed and most forage species herbages. Under such circumstances, species variation could be exploited to overcome or lessen the likelihood of CP and/or mineral deficiencies. Species of merit in this regard are *M. polymorpha*, *Trifolium* species, *C. dactylon*, *P. salifex, F. dichotoma*, *C. rotundus* and *S. corymbosus.* The benefit of these apparently nutritious species depends upon the absence of anti-nutritional factors, which warrant further study. Furthermore, the usefulness of these forage species to correct CP and mineral inadequacies is governed by the severity of the deficiency and the availability and cost of alternative dietary supplements.

The concentration of CP and most mineral elements in YRG grassland tend to change with season, with wet season herbage having relatively higher concentrations of CP and mineral elements. In none of the seasons, however, did CP, P, Na, Cu and Zn levels meet beef or dairy cattle requirements. The observed CP and minerals profile thus calls for the need to identify and test effective and economic supplements that correct deficiencies and counteract nutrient imbalances. Comparative seasonal studies on mixed and major forage species of SSE grassland also deserve future consideration. The status of soil extractable N and most mineral elements appear to have a limited value in predicting the CP and mineral content of native pastures. Exchangeable Na and extractable P were the only elements of reliable predictive merit.

In addition to the observed low concentrations, the reduced utilization of some elements in herbage by livestock is expected to occur due to antagonistic interaction between elements. Mineral elements, the utilization levels of which are likely to be depressed by high concentrations of their antagonistic minerals in herbage or soil are P, Na and Cu.

CHAPTER 7

CRUDE PROTEIN AND MINERAL STATUS OF CROP RESIDUES AND LOCAL SUPPLEMENTAL FEEDS

7.1. INTRODUCTION

In contrast to agriculturally advanced countries, where crop residues are regarded as problematic agricultural wastes, in Africa and Asia these crop by-products are valued as much as the grains and constitute the major parts of ruminant livestock diet (Nordblom, 1988). In the mixed cereal livestock farming systems of the Ethiopian highlands, crop residues are claimed to provide 50 % of all ruminant feeds (Jutzi *et al.*, 1987). Among ruminants, cattle derive up to 45 % of their total annual feed intake from crop residues and their contribution rises up to 80 % during the critically feed deficit dry period (Sandford, 1988). As more and more of the native grasslands are cultivated, to satisfy the ever-increasing human population needs, a further increase in the dependence of livestock on crop residues is expected.

In the mixed farming systems of the central Ethiopian highlands where this study was conducted, various cereal straws and haulms of pulse crops are used to feed ruminant livestock. Of these residues, tef straw stands first in terms of volume of production and contribution to basal diet of ruminant animals (see Table 4.1). The haulms of grass pea, chickpea and other pulse crops are fed together with tef straw to augment its low nutritional quality. It is argued that crop residue based diets hardly supply balanced nutrition and that ruminants solely dependent on such residues have poor productivity (Leng *et al.,* 1991). Sub-optimum macro-nutrient concentrations, low intake and digestibility have been documented for crop residues produced in Ethiopia (Seyoum Bediye & Zinash Sileshi, 1998). The mineral status of most crop residues is not satisfactory. Deficiencies of some mineral elements have been reported for crop residues of tropical and temperate origin (White *et al.*, 1981; Kabaija & Little, 1988; Durand, 1989; Khalili, 1991). The occurrence, or extent, of these minerals deficiencies in crop residues varies considerably. There exists a marked difference in CP and mineral concentration between crop residues of different genotypes (White *et al.*, 1981). Factors other than genotype also affect the mineral composition of crop residues. Such differences stem from soil and climatic variations and have been noted on crop residue of a single crop genotype grown at different locations of the Ethiopian highlands (Kabaija & Little, 1988; Khalili, 1991). In addition to concentration, the absolute amount of minerals consumed by herbivores from forage is related to the level of DM intake (Kiatoko *et al.*, 1982). In fibrous feeds, DM intake is largely a function of the CP content of feed, but most crop residues are deficient in this nutrient. Depressed DM intake in mature forages, of low CP content, is well documented (Minson & Milford, 1967; McDowell, 1996).

To support reasonable livestock production these fibrous residues need supplementation and/or some form of treatment (Smith *et al.,* 1980; Kahurananga, 1982; Lemma Gizachew, 1992). In the study area smallholders who appreciate the nutritional limitations of crop residues, and also who have the means, provide preferred species and classes of livestock with locally produced supplements. The two commonly used supplements in the study area are noug seedcake and whole crop or grains of grass pea. Production responses of animals receiving these supplements are quite encouraging. Impressive animal performance has been noted when noug seedcake was fed alone or in combination with an energy supplement to animals kept on a diet of tef straw (Lemma Gizachew, 1992). Similarly the use of grass pea in straw based dairy diets has been shown to result in an appreciable improvement of milk production and milk composition (Akbar *et al.,* 2000). The causes of this positive effect of these supplemental feeds may relate to their chemical composition.

Since the CP and mineral composition of crop residues tend to be affected by genotype and location, or soil factors, studying the status of these nutrients in relation to soil mineral element composition on which they grow would allow the demarcation of areas with potential mineral deficiencies. More importantly such studies would permit the identification of those mineral element(s) most likely limiting livestock production and contribute towards the development and implementation of an appropriate corrective measures in the future. As work relating CP and mineral concentration of crop residues with soil factors is non-existent in Ethiopia, this type of study merits investigation.

A study was subsequently undertaken with the following objectives:

i) to assess the adequacy of CP and minerals in major crop residues and local supplemental feeds of the Ethiopian highlands, and

ii) to determine the interrelationships of N and mineral elements in soil and the major crop residues

7.2. MATERIALS AND METHODS

7.2.1. Collection, processing and analysis of soil and feed samples

The location and detailed description of the study site is given in Chapter 3. The sampling of topsoil and the corresponding tef straw and grass pea haulm and grain samples were made from crop fields lying on Vertisol proper. Among the cereals, tef and among the pulses, grass pea make up the largest share of crop residues that are fed to livestock. This was why the present study dealt specifically with the residues of these two crops.

Adjacently situated ten tef and nine grass pea plots were sampled from Olonkomi up to Meti along the main Addis Ababa-Ambo road. At physiological maturity, 20 sub-samples of both tef and grass pea whole crops were taken per plot from every spot of soil coring. A quadrat measuring 0.25 m X 0.25 m was used to obtain each sub-sample. Soil sample collection, processing and analysis procedures followed are presented in Chapter 5. For tef, the harvest was made in mid January, whereas the grass pea harvest took place in early February 2001. Stainless steel scissors were employed to harvest the whole crop. The harvested crop sub-samples were allowed to dry in the field for a week before they were threshed and the residue and grain composite samples retrieved. After threshing, the residue constituting the chaff, leaf and the stem fractions were carefully sampled for both tef and grass pea. The composite crop residue samples of each crop were then placed in perforated plastic bags, rinsed in deionised water and dried immediately in a draft oven for 72 hours at a temperature of 65 °C. During March and April 2001, four composite noug seed cake samples were also collected from mechanically oil extracting plants operating in the study area. As the oil extracting plants buy and mix noug seeds from Vertisol and non-Vertisols areas, it was not possible to get noug seed cakes samples exclusively originating from farms of the Vertisol proper. Crop residues of tef and grass pea, grass pea grain and noug seedcake samples were ground to pass a 1-mm screen for chemical analysis. For the details of the laboratory analysis see Chapter 6.

7.2.2. Statistical analysis

Statistical analysis on soil and crop residue data was performed using Statistical Analysis System (SAS, 1985). Crude protein and mineral concentration data from grass pea and tef crop residues were analysed using the T-test. Pearson correlation coefficients between soil and crop residue N and mineral element concentrations were computed by correlation analysis.

7.3. RESULTS

7.3.1. Feed CP and mineral concentration

Mean CP and mineral concentrations of crop residues and the local feed supplements are given in Tables 7.1 and 7.2.

Crude protein levels of the examined feed types exhibited moderate variability, with tef straw, grass pea haulm, grass pea grain and noug seedcake containing values that ranged from 2.31-5.69, 6.19-8.81, 20.50-35.63 and 29.56-37.75 %, respectively. Grass pea haulm had a higher CP level than tef straw, but the difference was not significant ($P>0.05$). Tef straw could be regarded as a poor source of CP, though the CP content of grass pea haulm was not high either disapprovingly. Noug seedcake and grass pea grain, on the other hand, were rich in CP (Table 7.2).

Calcium concentrations in tef and grass pea residues were significantly different ($P<0.001$). As compared to tef straw, grass pea haulm contained four times more Ca. Noug seedcake contained negligible amounts of Ca. The Ca concentration in grass pea grain was also low. The concentrations of Ca in grass pea haulm, tef straw and grass pea grain ranged from 1.31 to 2.37, 0.37 to 0.59, and 0.16 to 0.22 %, respectively. A single value of 0.01 % was recoded across all noug seedcake samples.

Phosphorus concentrations in tef straw were significantly (P<0.001) higher than those of grass pea haulm. Between sample variation in P was very large for tef straw, but was small for the other feed sources. The P level ranged from 0.04 to 0.16 % in tef, 0.03 to 0.05 % in grass pea haulm, 0.15 to 0.20 % in grass pea grain and 1.05 to 1.35 % in noug seedcake. Noug seedcake was very rich in P. The Ca:P ratios were extremely high in grass pea grain and very low in noug seedcake. The Ca:P ratios for grass pea haulm, tef straw, grass pea grain and noug seedcake were on the order of 53.33, 4.78, 1.06 and 0.01, respectively.

There was no significant (P>0.05) difference between the Mg levels of tef and grass pea residues. Noug seedcake had an extremely low amount of Mg. The mean Mg concentrations in the other three feed sources were comparable (Tables 7.1 and 7.2). Within each examined feed, variability between samples was narrow.

Potassium concentrations in tef and grass pea residues did not differ significantly (P>0.05). With the exception of noug seedcake, the studied feeds were high in K. Potassium concentration varied for grass pea haulm, tef straw, grass pea grain and noug seedcake from 1.60 to 2.49, 1.02 to 1.44, 1.17 to 1.56, and 0.01 to 0.02 %, respectively. Since the high K concentration in crop residues and grass pea grain coincided with a corresponding high Ca concentration, the K/(Ca+Mg) ratios were maintained at low levels (Tables 7.1 and 7.2).

The two crop residues varied markedly (P<0.001) in their Na concentration, grass pea haulm containing five-times more Na than tef straw. For both residue types the across sites variation was wide. Similar wide variations were also exhibited for grass pea grain and noug seedcake. The Na concentration varied from 175.94 to 372.37 ppm in grass pea haulm, from 34.84 to 79.52 ppm in tef straw, from 69.15 to 92.20 ppm in grass pea grain, and from 0.15 to 0.44 ppm in noug seedcake.

Iron concentrations in grass pea and tef residues were significantly (P<0.05) different. A wide variation in Fe concentration among sites was also observed for both tef and grass pea residues. The mean Fe concentration in grass pea haulm was about twice as high as those of grass pea grain and tef straw ($P<0.05$). Noug seedcake had a very low mean Fe concentration. Iron concentration ranged from 87.93 to 206.88, 53.72 to 109.87, 67.34 to 97.31, and 28.00 to 47.41 ppm in grass pea haulm, tef straw, grass pea grain and noug seedcake, respectively.

Tef straw contained a significantly ($P<0.001$) higher Mn concentration than the grass pea haulm. The mean noug seedcake and grass pea grain Mn levels were very low. Tef straw samples were rich in Mn but exhibited wide variation. Manganese levels varied from 12.68 to 26.51 ppm in grass pea haulm, 27.69 to 176.91 ppm in tef, 5.19 to 8.61 ppm in grass pea grain and 1.00 to 1.85 ppm in noug seedcake, respectively.

Copper concentrations in the residues of tef and grass pea did not differ significantly ($P>0.05$). Copper variability within a feed group was also wide for the residue-based feeds. The concentration of Cu in grass pea haulm, tef straw, grass pea grain and noug seedcake ranged from 1.75 to 5.07, 2.56 to 9.22, 4.09 to 4.55, and 0.09 to 0.21 ppm, respectively. Copper levels were low in all feeds examined in the present study (Tables 7.1 and 7.2).

There was no significant ($P>0.05$) difference in Zn content between the residues of tef and grass pea. Based on mean values (Tables 7.1 and 7.2), the Zn concentration was relatively high in tef, intermediate in grain and haulms of grass pea, and low in noug seedcake. Concentrations of Zn in grass pea haulm, tef straw, grass pea grain and noug seedcake varied from 15.35 to 37.39, 27.84 to 45.45, 25.68 to 34.24, and 0.59 to 0.79 ppm, respectively.

Table 7.1. Crude protein and mineral concentration of tef and grass pea residues.

Parameters (DM bases)	Grass pea haulm[1, 2]	Tef straw	Significance level[3]
CP (%)	7.46±0.28	4.69±0.22	ns
Ca (%)	1.60±0.10	0.43±0.02	***
P (%)	0.03±0.00	0.09±0.01	***
Ca:P	53.33	4.78	
Mg (%)	0.14±0.01	0.12±0.01	ns
K (%)	1.99±0.09	1.28±0.05	ns
K/Ca+Mg (meq)	0.56	0.96	
Na (ppm)	273.72±21.58	49.43±4.37	***
Fe (ppm)	151.50±13.54	76.48±5.94	*
Mn (ppm)	20.40±1.77	82.24±15.62	***
Cu (ppm)	4.12±0.72	6.27±0.60	ns
Zn (ppm)	24.06±2.55	32.99±1.67	ns

[1] Means were based on the following number of composite residue samples: grass pea (9) and tef (10).

[2] Standard error of means.

[3] Significance level: ns (non-significant) = P>0.05, * = P<0.05 and *** = P<0.001.

Table 7.2. Crude protein and mineral concentration of local supplemental feeds.

Parameters (DM bases)	Noug seedcake[1, 2]	Grass pea grain
CP (%)	32.83±1.77	27.97±1.57
Ca (%)	0.01±0.00	0.18±0.01
P (%)	1.17±0.06	0.17±0.01
Ca:P	0.01	1.06
Mg (%)	0.01±0.00	0.15±0.01
K (%)	0.02±0.00	1.32±0.09
K/Ca+Mg (meq)	0.39	1.58
Na (ppm)	0.24±0.04	77.79±5.05
Fe (ppm)	36.58±3.23	77.64±6.73
Mn (ppm)	1.12±0.11	7.43±0.77
Cu (ppm)	0.17±0.02	4.60±0.30
Zn (ppm)	0.66±0.03	28.89±1.88

[1] Means were based on four composite samples each for noug seedcake and grass pea grain.

[2] Standard error of means

7.3.2. Inter-relationships of soil and crop residue N and mineral elements

The summary of the correlation analysis between soil and crop residues is given in Table 7.3. Significant ($P<0.05$) positive correlations were observed between exchangeable Na and crop residue Na for both grass pea and tef. The correlation between P in tef straw and extractable P was also significant ($P<0.01$), while the corresponding correlation for grass pea was poor. Both Na and P were appreciably low in the soil (see Table 5.1). For the remaining elements, no significant correlations were found between extractable soil nutrients and their counterparts in residues of tef and grass pea (Table 7.3).

Table 7.3. Correlation coefficients (r) between soil and crop residues for N and mineral elements

Variable[1]	Grass pea haulm	Tef straw
N	0.63	0.50
P	0.09	0.72*
Ca	-0.51	-0.24
Mg	0.02	-0.06
K	0.11	0.28
Na	0.80**	0.74*
Fe	0.48	0.06
Mn	0.62	-0.43
Cu	0.09	0.23
Zn	-0.31	-0.06

[1] Number of observations (n = 9 for grass pea; n = 10 for tef straw).

[2] Significance level: * = $P<0.05$; and ** = $P<0.01$.

7.4. DISCUSSION

7.4.1. Feed CP and mineral concentration

All tef straw samples and 22.2 % of the grass pea haulm samples had CP values below the suggested 7 % critical value (Minson & Milford, 1967). The low CP value in tef straw in the present study is in close agreement with values reported earlier by other workers (Kabaija & Little, 1988; Seyoum Bediye & Zinash Sileshi, 1998). A low level of CP in a feed depresses DM intake (Minson & Milford, 1967; McDowell, 1996), which in turn reduces the absolute intake of minerals and other nutrients. Without proper protein supplementation, reasonable animal production from a tef straw based diet was thus inconceivable. In contrast, grass pea haulm, grass pea grain and noug seedcake contained moderate to high levels of CP (Tables 7.1 and 7.2). Despite their local availability, the protein rich local feed supplements are little utilized to augment protein and other nutrient deficiencies in the smallholder mixed crop livestock production system of Ginchi area. Very few smallholders feed these local supplements to selected group of animals such as working oxen, milking cows or sheep intended to be sold at a premium price. Grass pea is widely grown on the poorly drained Vertisols of the study area because it completes its life cycle on residual moisture and improves soil fertility. The utilization efficiency of the grain and haulms of this important pulse crop may be sub-optimum due to the presence of anti-nutritional factors. For the grain, the negative effects of these organo-active compounds have been suggested to be negated by heat treatment (Hanbury *et al.*, 2000). The improvement of grass pea grain feeding value with heat treatment is well recognized by the farmers in the study area who never fed it to animals prior to boiling. No such anti-nutritional factor was reported in noug seedcake. The major problem constraining noug seedcake utilization under smallholder condition is high market price. Its popularity in peri-urban dairying and feedlot programs has increased its demand and made it less affordable for most smallholders. The reportedly positive response of animals receiving noug seedcake may be related to its ability to supply both rumen degradable protein and by-pass protein, the type of proteins that are often inadequate in cereal residues. Oil seedcakes had the reputation to bear adequate amounts of both rumen degradable and by-pass proteins (Meissner, 1999).

As shown in Table 7.2, noug seedcake was extremely low in Ca. Grass pea haulm was a good source of Ca, though tef straw also contained a reasonable level of Ca. Other workers from Ethiopia reported mean Ca concentrations in tef straw similar to the current study (Kabaija & Little, 1988; Khalili, 1991). Depending on body size and physiological state, beef and dairy cattle require between 0.19 to 0.66 % Ca (NRC, 1989; 1996). Calcium level in grass pea grain was marginal for growing beef cattle, while the Ca level in tef straw would be sufficient for all classes of beef and non-lactating dairy cattle, and the concentration of Ca in grass pea haulm would fulfil the needs of all classes of beef and dairy cattle.

The deficiency of P in crop residues has been reported in Ethiopia (Kabaija & Little, 1988). Phosphorus concentrations in half of the grass pea grain and all the tef and grass pea residue samples were below the suggested (0.17 %) beef cattle requirements (NRC, 1996). The examined feeds did not only contain a low amount of P, but also had considerably wide Ca:P ratios. With reference to the optimum Ca:P ratio, there is much debate in the literature. Generally in diets high in both Ca and P, ruminants may tolerate wider Ca:P ratios (Underwood & Suttle, 1999). Wider Ca:P ratios, however, are detrimental in feeds apparently deficient in P (Wan Zahari *et al.,* 1990). In the present case, feed based on crop residues, specifically that of grass pea haulms, had an extremely high Ca:P ratio. Since noug seed cake was very high in P and very low in Ca, its use as supplement to tef straw or grass pea haulm can overcome the Ca:P imbalance that was apparent in these crop residues.

Khalili (1991) and Kabaija & Little (1988) have reported mean Mg concentration in tef straw of 0.15 and 0.19 % from Ethiopia, respectively. In the present study slightly lower concentrations of Mg were obtained, both from tef and grass pea residue samples. While the concentration of Mg in grass pea haulm, tef straw and grass pea grain was adequate for growing and finishing cattle; it would be marginal for lactating beef cows and all classes of dairy cattle (Appendices 6.1 and 6.2). As noug seedcake contained negligible amount of Mg, its supplementation to the crop residues under investigation would contribute very little towards the improvement of Mg intake.

Potassium levels in grass pea haulm, tef straw and grass pea grain were well above beef or dairy cattle requirements, a finding similar to that reported by other workers for crop residues produced in the highlands of Ethiopia (Kabaija & Little, 1988; Khalili, 1991). Excessively high K concentrations in a feed are not desirable. This is because high K level in relation to Ca and Mg depresses Mg absorption. Potassium reduces Mg absorption when the K/(Ca+Mg) ratio, expressed in milli-equivalent (meq), exceeds 2.2 (Kemp & t'Hart, 1957). In the present case, this critical level was not exceeded in any of the feed types.

In addition to the role that Na plays in regulating osmotic pressure, acid-base and water balance in the animal body, its status in feed affects Mg absorption. A low level of Na in feeds, apparently high in K, markedly reduces the absorption of Mg (Martens *et al.,* 1987). In none of the analysed feeds did Na concentration reached the minimum 0.06 % suggested for beef cattle (NRC, 1996). Only half of the samples from grass pea haulm would meet 50 % of the minimum beef cattle requirement for Na, while samples from the remaining feed types would only meet less than 14 % of the minimum dietary need for Na. It is, therefore, very clear that feeds produced in the study area cannot supply adequate amounts of Na to ruminant animals. Compared to most mineral elements, Na can be cheaply supplied to animals. If offered regularly, common salt or Na rich local mineral sources such as mineral water (*hora*) or mineral rich soil can rectify the deficiency of Na in the above feeds.

According to the NRC (1989; 1996) guidelines, 50-ppm Fe in a feed is adequate for all classes of beef and dairy cattle. The crop residues and the grass pea grain contained Fe well above the indicated value (Tables 7.1 and 7.2). It was only in noug seedcake that Fe was found to be below this critical level. A previous study reported Fe concentration in tef straw twice that observed in the present investigation (Kabaija & Little, 1988). Soil contamination is often responsible for the inflated values of Fe in forages (Jumba *et al.*, 1995b). In the present study, repeated rinsing of the crop residue samples in de-ionised water was expected to minimize soil contamination. Such sample treatment, however, had not been undertaken in the earlier study.

The present study revealed that 44 % of grass pea haulm and the entire noug seedcake and grass pea grain samples contained <20 ppm Mn recommended for growing or finishing beef cattle (NRC, 1996). With the exception of 30 % of the samples, which may be marginal for lactating cows, tef straw samples could supply an adequate level of Mn for all classes of beef and dairy cattle. Slightly lower but adequate Mn concentrations in tef straw have been reported previously (Kabaija & Little, 1988).

A low level of Cu in tef straw and other cereal residues was reported previously (Kabaija & Little, 1988). This finding agrees with the results of this study. Over 80 % of tef straw samples could supply half of the beef cattle Cu requirements, while 66.7 % grass pea haulm and 75 % of grass pea grain samples had Cu below 50 % of beef cattle dietary requirement. The level of Cu was negligible in noug seedcake. Copper nutrition in livestock is further complicated because of its interaction with elements like Fe, Mo, and/or S (Bremner *et al.*, 1987; Phillippo *et al.*, 1987; Underwood & Suttle, 1999). Unfortunately feed Mo and S levels were not determined in the present study but Fe concentration in all examined feeds was not high enough to interfere with Cu absorption. Animals that were kept on overgrazed native pasture, however, are likely to ingest soil-contaminated herbages high in Fe. Since Cu concentrations in the studied feeds were low, a slight drop in Cu absorption could have serious negative repercussions.

The NRC (1996) suggested a feed Zn concentration of 30-ppm as a critical level for beef cattle. For dairy cattle, a much higher (40 ppm) feed Zn concentration is required (NRC, 1989). Thirty percent of tef, 77.8 % of grass pea haulm and 75 % of grass pea grain samples, however, had Zn below 30 ppm. This is consistent with the findings of a previous study that reported Zn deficiency in crop residues produced in Ethiopia (Kabaija & Little, 1988). As for noug seedcake, the concentration of Zn was extremely low.

7.4.2. Inter-relationships of soil and crop residue N and mineral elements

For most of the studied elements, there were no significant ($P<0.05$) correlations between soil nutrients and the mineral composition of the corresponding crop residues. The exceptions were those of P and Na. The occurrence of a high level of nutrients in soil and wide across site soil and crop residue mineral element variations can be put forward as the prime causes of the poor relationships of elements in soil and in crop residues. However, it was striking to note that these apparently high soil nutrient levels did not prevent the concentration of Mn in grass pea grain, Cu in grass pea grain and residues of tef and grass pea, Zn in grain and haulms of grass pea from falling below the suggested minimum cattle requirements. For P and Na, elements that are found at very low level in the soil, the increase in the level of these elements in soil resulted in the corresponding increase in crop residues.

The relationships between N and mineral elements in soils and crop residues may be complicated by the translocation of elements into the grain and the residue component of the crop or of leaching of some elements into the root zone in the course of advancing physiological development. Even in whole crops such as forages, reports of strong relationships in soil mineral composition and forage mineral composition are very limited. Many studies in the temperate and tropical regions have failed to observe strong soil and forage mineral element relationships (Kiatoko *et al.*, 1982; Roberts, 1987; Khalili, 1991; Pastrana *et al.*, 1991b; Jumba *et al.*, 1995b). A poor soil and plant mineral elements relationships in addition to plant maturity, can be affected by plant nutrient uptake limiting soil and climatic factors (Reid & Horvath, 1980). Impaired crop nutrient uptake in poorly drained Vertisols of the study area is thus expected to affect soil and crop residues mineral element relationships.

7.5. CONCLUSIONS

The grass pea and tef residues that are widely utilized to feed livestock in the study area exhibited appreciable differences in CP and mineral concentration. This difference is important to augment an element low in one of these crop residues by the other. Such complementarities are particularly important for CP, Ca, Mn and Zn.

The two local protein supplements could have a potential to alleviate protein deficiency in crop residues and native pastures. The use of noug seedcake would also offset the Ca:P imbalance and rectify P deficiencies in the examined crop residues. When considering grass pea grain as feed supplement to livestock, it is important to give due attention to the anti-nutritional factors present in this feed and measures needed to reduce their negative impacts. Even though heat treatment prior to consumption has been reported to reduce the levels of these anti-nutritional factors more research is required to maximize the benefit of its use.

From the present study it was clear that Cu and Na in all studied feeds; P in grass pea haulm, tef straw and grass pea grain; Zn in noug seedcake, grass pea grain and haulm; Mn in noug seedcake and grass pea grain; and Ca, Mg, K and Fe in noug seedcake were below the requirements of beef cattle.

SUMMARY AND RECOMMENDATIONS

The study was conducted in the Vertisol area of Ginchi, situated west of Addis Ababa. In this area, as in the other parts of the central Ethiopian highlands, insufficient supply and poor quality of feeds constitutes the major technical constraint to ruminant livestock production. The main aim of the study was to assess the CP and mineral status of feeds produced in the Vertisol area of Ginchi by relating them to pasture management, seasonal and/or soil factors. The farming systems of the study area were also studied with emphasis on the understanding of feed resource management and utilization practices, and identifying feed related constraints and opportunities.

The study on the farming systems was executed in two localities (Borodo and Asgori) encompassing six peasant associations between May and June 2001 employing participatory rural appraisal techniques. The most common production system of the study area is a well-integrated mixed farming system where both crop and livestock enterprises operate in a single farm unit. Strong inter-dependence exists between the two subsystems. Livestock provide draught power and manure to the crop subsystem, while the latter supply the former with much needed crop residues. Because of poor internal drainage and difficult workability of Vertisols, vast areas of the Ginchi area are still found under native pastures. On the basis of ownership, and timing and intensity of use, two types of native pastures were identified. These were communally owned YRG and privately owned SSE grasslands. Stocking rates on YRG grasslands were high and visible signs of overgrazing were apparent. Crop weed, crop stubble and SSE grassland grazing complement the low forage supply from YRG grassland during the early to mid dry period (November-February). The use of conserved crop residues is deferred up until the late dry season (March-May) and their utilization continues until the middle of the wet season (July). Working oxen, milk cows and livestock in a fattening scheme are the priority classes of animals that receive crop residues and supplemental feeds. Throughout the year the available feed did not match the existing livestock population. Severe feed shortages are particularly experienced during late dry to mid wet seasons. Smallholders try to cope with the feed shortage problem during this period through the use of conserved and locally available supplemental feeds, and less frequently along with mineral sources such as common salt, mineral rich soil or mineral water (*hora*). In order to make livestock less of a threat to the environment and of a greater value to their owners, much more needs to be done with respect to balancing the nutrient supply with the nutrient need of the livestock population. To achieve this objective it is important to adopt appropriate and effective remedial measures. This may involve reducing the household herd size preferably replacing the less productive animals with fewer more productive animals, raising grassland productivity by adopting sound management practices, growing productive and nutritious forages in association with food crops, and identifying and correcting the most limiting nutrient(s) using locally available, or bought in, supplements.

Surface soil samples (0-15 cm) from 18 YRG grassland, 12 SSE grassland, 10 tef and 9-grass pea plots were collected during January and February 2001. The samples of the tef and grass pea residues, grass pea grain as well as the dry season mixed herbage samples of YRG grassland were gathered during the same period where the respective plots were sampled for soil. Determination of floristic composition and wet season DM yield of YRG and SSE grasslands, and collection of wet season herbage samples of major pasture species of SSE grassland and mixed herbage samples of YRG and SSE grassland were conducted during September 2001. The levels of N, P, Ca, Mg, K, Na, Fe, Mn, Cu and Zn in soil, mixed and major pasture species, crop residues and local supplemental feeds were determined along with related soil parameters, namely soil particle class, pH, OM, and CEC following standard laboratory procedures.

Clay was the predominant particle class in all examined land use types, with its level ranging from 47-77 %. Soil under grasslands, by the virtue of their relatively lower position on the landscape, had a significantly higher clay content and lower sand content ($P<0.01$). In 80 % of the samples the soil pH varied from 5.7 to 6.8 and thus was mildly acidic. Compared to cultivated soil, soil under grassland had a lower pH ($P<0.01$). There was a positive association of pH with exchangeable Ca in soil under tef, grass pea and SSE grassland ($P<0.01$). The OM contents of the grassland soil were about twice as high as those under cultivation ($P<0.01$). Soil OM level under cropland and grassland was rated moderate and high, respectively. In all land use types, OM was positively correlated ($P<0.05$) with total soil N and negatively correlated ($P<0.05$) with exchangeable Ca. The healthy soil OM balance in the grassland system needs to be emulated in the crop culture through the integration of native clovers into the cropping system. The mineralization of soil OM and subsequent release of nutrients held in OM is, however, dependent on the availability and adoption of appropriate surface draining implements. The CEC varied from 33.2 to 48.3-meq (100 g soil)$^{-1}$ and the level was similar across the different land use types ($P>0.05$). The CEC status in all land use types was high. The base saturation percentages also ranged from moderate to high. Calcium was the predominant exchangeable cation, followed by Mg and K. The contribution of exchangeable Na to the CEC was negligible. With the exception of soil under YRG grassland, CEC was positively correlated with exchangeable Ca ($P<0.05$). Levels of exchangeable cations across the different types of land uses were similar ($P>0.05$). The amounts of exchangeable Ca, Mg and K were sufficient for optimum plant growth. Although there was no established critical crop Na requirement level to compare against, the level of exchangeable Na in the soil solution was appreciably low. In close agreement to the OM content of the soil, total soil N in grassland soil was about double that in cultivated soil ($P<0.01$). The observed total N level was moderate to high, but poor soil drainage may inhibit mineralization and favours loss due to de-nitrification. The lowest and highest mean extractable P levels were recorded for YRG grassland and tef plots, respectively ($P<0.05$). Extractable P levels in all land use types, however, were very low. Judicious use of P bearing fertilisers, preferably the domestically available rock phosphate, would thus benefit both crop and pasture production. Levels of Fe, Cu and Zn in some land use types were different ($P<0.05$). With the exception of Zn in SSE grassland, the levels of extractable micro-nutrients were adequate to support optimum plant growth.

Pasture management practices appeared to affect floristic composition and mineral concentration of native pastures. Continuous overstocking of YRG grassland, while decreasing the proportion of desirable species, favoured the infestation of this grassland by the less nutritious and unpalatable *Pennisetum schimpri*. The results further suggest that the effects of overgrazing of YRG grassland extend beyond decreasing the proportion of desirable species, and include the marked decrease in CP and mineral concentrations of the available herbage. As it was verified from the SSE grassland, resting highland grassland at a critical stage of development encouraged desirable species. However, such management practices had little practical applicability on collectively owned YRG grassland. Collective ownership of YRG grasslands is currently a disincentive for sustainable use and application of corrective management measures.

Among the native clovers, *Trifolium tembense* and *T. rueppellianum* made remarkable recovery with resting. Other forage species that constituted a significant share of the available herbage in SSE grasslands were *P. glabrum*, *Andropogon abyssinicus*, *Fimbristylis dichotoma, Hyparrhenia hirta, Cyprus rotundus, Schoenoplectus corymbosus* and *Cynodon dactylon*. Although significant ($P<0.05$) concentration differences were confined only to CP and P, the observed mean wet season CP and mineral (except Fe) values were all higher in herbages from SSE grassland than in herbages from YRG grassland. Crude protein and mineral deficiencies in SSE grassland appeared to be associated with floristic composition. A high proportion of species from the Leguminosae and Cyperaceae families in native pasture indicates an adequate level of CP and minerals such as Ca, Mg, K, P, Fe and Mn, while their decline and the corresponding increase in the proportion of species from Poaceae family was indicative of P and Mg deficiencies. For mineral elements like K, Fe and Mn, that were abundant in herbage, the plant species difference have little practical importance. Plant species differences for N, Mg, P, Na, Cu and Zn, elements that were found to be below cattle requirements in most species, can be exploited to lessen or overcome the low concentration of these elements in herbage available to grazing animals. Species of immense potential in this regard are *Medicago polymorpha*, *Trifolium* species, *C. dactylon*, *P. salifex, F. dichotoma*, *C. rotundus* and *S. corymbosus*. Among the examined species, the level of CP in *H. hirta*, *A. abyssinicus*, *P. glabrum* and *Eleusine jaegeri*; P in grass species and *C. rotundus*, Na and Cu in all species; Zn in all species excluding *T. rueppellianum* and *C. dactylon* were below the nutritional requirement of all classes of beef cattle. In YRG grassland, lower herbage CP, P, K, Cu and Zn were recorded during the dry than the wet season, while the reverse was noted for Ca, Mg, Na, Fe and Mn. These seasonal differences were, however, only significant ($P<0.05$) for CP, Ca, K and Zn. In both seasons' CP, P, Na, Cu and Zn contents of YRG grassland herbages were below the recommended cattle requirements. Significant ($P<0.05$) positive correlations were found between wet season's YRG grassland herbage Na and Mg and the corresponding soil Na and Mg; dry season's YRG grassland herbage Ca and soil Ca; SSE grassland mixed herbage P and soil P; *T. tembense* Mg and soil Mg; and *A. abyssinicus*, *P. glabrum* and *T. tembense* Fe and soil Fe. Negative significant ($P<0.05$) associations were noted between dry season's YRG grassland herbage N and soil N; *A. abyssinicus* Mn and soil Mn; and *T. rueppellianum* Cu and soil Cu.

The haulms of grass pea had significantly ($P<0.05$) higher levels of Ca, Na and Fe than the straw of tef, while the opposite was noted for P and Mn ($P<0.001$). Crude protein, Mg, K, Cu and Zn concentrations in these two crop residues, however, did not differ significantly ($P>0.05$). From the viewpoint of cattle requirements, both grass pea and tef residues were severely deficient in Na, Cu and P. The concentration of Mn and Zn in grass pea haulm and of CP in tef straw also would not meet cattle dietary needs. Significant ($P<0.05$) positive correlations were found between exchangeable Na in soil and Na in both grass pea and tef residues. Extractable soil P was also positively correlated to P in tef straw ($P<0.05$). Noug seedcake was rich in CP and P, but was extremely poor in the rest of the examined minerals. Grass pea grain had adequate concentrations of CP, K and Fe. It was, however, marginal in Ca, P and Mg, and deficient in Na, Mn, Cu and Zn.

For mineral elements such as P, Na, Cu and Zn that were found to be deficient in most of the feeds studied, further investigation of these elements in body tissues, fluids or faeces of domestic herbivores appears worth considering. If such investigations on animal body tissues, fluids and/or faeces confirm mineral deficiencies in presently studied feeds, opportunities do exist to correct the problem by using locally available mineral rich supplements. One or more of these elements could be supplied by bone and meat meals from local abattoirs and/or home-grown leguminous forages following laboratory assessment and animal response studies. Noug seedcake, being rich in P, has an enormous potential of rectifying P deficiency and the detrimental effects of a wide Ca:P ratios in native pasture and crop residues. Sodium, a mineral element that was deficient in all feeds, can possibly be supplied regularly from cheap sources such as common salt, locally available mineral rich soil or mineral water.

Optimum utilization of minerals and other nutrients from the studied feeds and/or suggested mineral supplements can only be achieved when the currently low CP in tef straw and YRG grassland herbage is raised appreciably through the provision of additional protein supplements or effectively increasing the proportion of legumes in native pastures. Both noug seedcake and grass pea grain make ideal protein supplements. Pasture management practices that encourage legume build up in native pasture, however, are the preferred alternative for they can simultaneously increase the protein and mineral intake of grazing animals. These pasture management practices, as indicated above, may include improving the growing condition (e.g. draining excess water, correcting P deficiency), applying an optimum (lower) stocking rate and resting native pasture at a critical stage of development.

The wide variation in soil and feed N and mineral elements, and the absence of a consistent strong correlation between soil and feed indicates that soil analyses will be of limited value in determining the N and most mineral elements status of feeds produced in the Vertisol area of Ginchi. This assertion, however, needs to be verified with a larger number of samples.

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APPENDICES

Appendix 4.1. Semi-structured interview checklist on the farming systems of the Ginchi Vertisol area

I. General information

- Peasant association
- The land use pattern: Arable land
  Pastureland
  Forestland
  Wasteland

II. Physical Environment:

- Average rainfall
- Av. Temperatures (minimum & maximum)
- Altitude
- Topography
- Soil type
- Natural vegetation

III. Livestock production

- Livestock number by HH: cattle, small ruminant, equine and poultry
- Trends in livestock number & productivity over the last 10 years period
- Purposes of livestock in the HH (by livestock class)
- Breed type and breeding practice
- Type of animal husbandry (tethering, herding)
- Seasonal pattern of livestock productivity (parturition, milk yield, conception, condition)
- Reproductive performance (age at sexual maturity, calving interval, rate of abortion)

IV. Feed resources

- Major local feed resource
- Productivity of native pasture (floristic composition & yield)
- Use right and control & management of natural pastures
- Use and conservation of crop residues
- Seasonal availability of feed resources
- Peak feed shortage period & local coping strategies
- Utilization strategy of locally produced feed resources
- Production & use of improved forage crops
- Type of feed supplements and feeding priority by class of livestock

V. Animal health

- Major disease types & prevalence (occurrence & seasonal prevalence)
- Incidences of internal & external parasites

- Vaccination & other health cervices
- Major disease outbreak
- Feed related livestock health problems

VI. Crop production

- Types of crop species grown in the area
- Cropping calendar
- Average cultivated area for different crop species
- Type & amount of crop inputs used

VII. Agricultural service available

- Credit
- Inputs supply

VIII. HH size

IX. HH landholding

X. Labour

- HH division of labour by age and gender
- Peak labour shortage & slack period
- Labour calendar

Appendix 6.1. Concentration of minerals in forage required for satisfactory nutrition of beef cattle[1]

Variable	Unit	Growing/ Finishing	Gestating cow	Lactating cow	Maximum tolerable concentration
Ca	%	0.19-0.72	0.20-0.32	0.15-0.36	
P	%	0.12-0.34	0.17-0.23	0.11-0.23	
Mg	%	0.10	0.12	0.20	0.40
K	%	0.60	0.60	0.70	3.00
Na	%	0.06-0.08	0.06-0.08	0.10	2.00
Fe	ppm	50	50	50	1000
Mn	ppm	20	40	40	1000
Cu	ppm	10	10	10	100
Zn	ppm	30	30	30	500

[1]NRC (1996)

Appendix 6.2. Concentration of minerals in forage required for satisfactory nutrition of dairy cattle[1]

Variable	Unit	Growing heifers & bulls	Dry pregnant	Lactating cow	Maximum tolerable conc.
Ca	%	0.29-0.52	0.39	0.43-0.66	2.00
P	%	0.23-0.60	0.24	0.28-0.41	1.00
Mg	%	0.16	0.16	0.20-0.25	0.50
K	%	0.65	0.65	0.90-1.00	3.00
Na	%	0.10	0.10	0.18	-
Fe	ppm	50	50	50	1000
Mn	ppm	40	40	40	1000
Cu	ppm	10	10	10	100
Zn	ppm	40	40	40	500

[1]NRC (1989).