EFFECTS OF PLANTING DENSITY AND WEEDING REGIMES ON FORAGE AND GRAIN YIELD OF MAIZE

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DECLARATION

I declare that this thesis is a record of my own research. The material has never been presented before in any academic institution for an academic award.

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To my parents, Mr. Kivuva Mutisya and Mrs. Ruth Kivuva who are a source of encouragement.

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ABSTRACT

Maize is a major food and forage crop in Kenya and planting density and weeding regime influence yield. The effects of weeding regimes and maize planting density on maize forage, grain yield and quality were evaluated during the 2001/2 short rains and long rains of 2002 at Kenya Agricultural Research Insitute, Muguga in Central Kenya. Weeding regimes were weed free (W1), weedy (W2), herbicide (W3) and hand weeding twice (W4). Maize densities were 9 (D1) and 18 plants m^{-2} (D2) intercropped with beans. Maize was thinned at 98 DAE at tasseling stage and assessed for forage yield and quality. Stover and edible weeds biomass yield and quality were also assessed. Soil moisture content down the profile, PAR interception, weed density, maize height and rate of tasseling was determined gradually over the season. Maize yield and bean biomass was also determined. The collected data was analysed using GENSTAT software and their means separated with LSD at $P = 0.05$.

Percent interception of photosynthetically active radiation (PAR) was significantly higher in D2 than in D1 before thinning time but was significantly higher in D1 than in D2 after thinning in both seasons. Interception of PAR was significantly higher in W2 compared to W1, W3 and W4, which were similar in both experiments. Soil moisture content was significantly lower in W2 but similar in W1, W3 and W4. D2 had significantly lower soil moisture content than D1 in season two through out the season. Thinnings biomass was higher where weeds were controlled and least in the weedy regime in both seasons. Thinnings biomass was significantly higher in D2 than D1 in both seasons and D1 had significantly higher maize grain yield than D2 in both seasons. Stover biomass was significantly higher in D1 than D2 in season one but was similar in season two. Total forage biomass from D1 was same as in D2 in season one whereas in season two was significantly higher in D2 than D1. Beans performed poorly due to low planting density and shading effects due to maize in both seasons. The tasseling rate was significantly lower in D2 than D1 while W2 had significantly lowest tasseling rate as compared to W1, W3 and W4, which had similar tasseling rate in both seasons. Maize plants were significantly short in W2 compared to W1, W3 and W4, which were similar. They were also shorter in D2 than in D1 in both seasons. Total weed biomass at 126 DAE was significantly higher in W4 than in W3 and in D1 than in D2 in both seasons. The cattle-edible weed biomass at the end of the two seasons was at least 55 % of the total. Thinnings had significantly higher digestibility (76 %) and crude protein (7 %) than stover. Two times hand weeding (W4) was two to three times more expensive than using herbicide (W3). Weeds competed for light and water leading to reduced thinnings, stover and grain yield but increased weed biomass, which was significantly lower than maize biomass in the weeded plots. High maize density increased intraspecific-competition (of maize in the hills) for water and light before thinning time (98 DAE) and significantly reduced plant height, tasseling rate and grain yield. Hand weeding is labour intensive and thus led to increased expenses than herbicide use. Planting maize at high density significantly increased forage quality and quantity, and overall light capture especially before thinning, but reduced weed biomass and grain yield.

Keywords

Maize, forage, weeding regimes, planting density, yield.

CHAPTER 1

INTRODUCTION

1.0 General introduction

Demand for maize in the developing world is expected to surpass both wheat and rice by 2020 meaning that maize supplies need to double to meet the demand (International Food Policy Research Institute (IFPRI), 2000). Global maize demand is expected to rise from 558 million tons in 1995 to 837 million tons in 2020, a 50 % increase. Maize requirements in the developing world alone will increase from 282 million tons in 1995 to 504 million tons in 2020, a challenge to the developing counties (IFPRI, 2000). Relative to 1995 level, annual maize demand in Sub-Saharan Africa is expected to double to 52 million tons by 2020 (Pingali, 2001). In Kenya, the estimated population growth rate is 2.9 % per annum (G.o.K. 1997 to 2001) and persistence poverty have maintained upward pressure on the demand for maize for food and animal feed (Kihanda, 1996).

By the year 2020 as many as 680 million people (half of whom will be in Africa), will suffer from hunger in developing countries (FAO, 1997). In Kenya, maize food consumption per capita between 1995 to 1998 was 103 kg year^{-1} and growth rate of maize consumption as food was 0.1 % year^{-1} while average maize imports year^{-1} were 427 tons (or 15 kg per capita per year) (Pingali, 2001). Given the limited opportunities for increasing maize production area due to population pressure (Semenye *et al.*, 1989) future output growth must come from intensifying production in current maize land.

Globally, maize is grown on approximately 140 million hectares whereby 96 million hectares (68 %) are in the developing world which produced only 46 % of total maize produced globally (600 million tons) in the year 1999 (Pingali, 2001). Developed countries have higher average maize yield production ha^{-1} than in the developing countries (Table 1). This causes a wide gap between global share of maize area and share of production in developed and developing countries. Wide disparities in climatic conditions (tropical and temperate) and farming technologies account for the yield differences between developed and the developing countries. Since majority of the world's poor people live in the tropics and a large proportion of them depend on maize as their staple food and for animal feed (Table 1), there is need for research and development programmes to intensify maize production. The trend of maize production and fertiliser use in Kenya and the leading corn producers in Africa and the world is shown below (Table 1).

Mixed small holder dairy farming is becoming increasingly popular in high potential areas of central Kenya (Omore *et al.,* 1999), Central rift valley, Nyanza and western provinces. In these areas land for forage is becoming increasingly scarce, a limiting factor to dairy production (Kinuthia, 1998; Kinuthia *et al.*, 1999). In central Kenya, maize is both a major food and forage crop thus is usually grown for both grain and forage (McLeod *et al.*, 2001). However maize production in these areas is constrained by drought, low soil fertility, low seed quality, weeds, pests and diseases. For instance weeds compete for plant resources, such as soil moisture, light and nutrients (Trenbath, 1974) causing 15 to 90 % loss in crop yield (Maina, 1997, Ngesa, 1993). However weeds infesting maize crops could be a source of animal forage (Onim *et al.*, 1992).

Table 1. World maize production trends in the year 1996 –1998.

Country	Area (million ha)	Total yield (million tons)	Average yield (t/ha)	% Cereal area under maize	% Used as food	% Used as feed	Growth rate of average yield (%/yr.)	Fertiliser area as a % of total maize area
The leading world corn producers								
China	25	121.4	4.9	27	11	76	2	96
Brazil	12	32.1	2.7	68	9	80	3.8	61
Mexico	7.5	18.1	2.4	71	58	25	3.3	43
Corn production in African countries								
S. Africa	3.7	8.5	2.3	74	48	39	1.6	88
Nigeria	4.1	5.4	1.3	22	58	25	-0.2	-
Tanzania	1.8	2.4	1.3	56	85	5	0.1	-
Kenya	1.5	2.3	1.5	77	91	3	-1.5	30
Zimbabwe	1.4	1.7	1.2	75	76	14	-3.2	-
Uganda	0.6	0.8	1.2	45	64	11	-1.1	15
World average	140.1	600.3	4.3	20	17	66	2.4	-

Source: (Pingali, 2001; FAOSTAT, 2000)

Agronomic research on maize focuses on maximising grain yield but ignores the stover and edible weeds as a source of forage for livestock production. Total eradication of weeds in the field is usually very expensive necessitating research for economical weed control regimes in maize production. Thus change of focus of agronomic research in maize is required to incorporate maize stover, thinnings and edible weeds as animal forage while maximising grain yield in smallholder dairy farming.

The smallholder dairy sector enterprise in central Kenya produces about 80 % of the total marketed milk (Omore *et al.*, 1999. Adequate forage quantity and quality throughout the year particularly in the dry season is paramount in maintaining high milk production in central Kenya (N.D.D.P. 1989). This calls for increased production and conservation of crop residue as forages.

1.1 Maize ecological distribution

Maize is the world's most widely grown cereal (Pingali, 2001). It is cultivated at latitudes raging from the equator to approximately 50° North and South, at altitudes raging from sea level to more than 3000 m elevation. It is grown in cool (12°C to 15°C) moderate (21°C to 28°C) and very hot climates (30°C to 40°C) (Rathore 1999), under moisture regimes raging from wet to semiarid on flat terrain and steep hillsides, in many different types of soil and using various production technologies (Pingali, 2001).

Maize germplasm is grouped into lowland tropical, sub tropical, temperate and tropical highland categories (Almelikinders and Louwaars, 1999). About 90 % and 25 % of the maize production is grown in temperate environments in developed (mostly China and Argentina) and developing world respectively. In the tropics, 65 %, 26 % and 9 % is grown in tropical lowlands, in the sub-tropics cum middle-altitude tropical zones and in the tropical highlands respectively (Pingali, 2001). Approximately 60 % of the tropical highland maize production is found in Latin America (Pingali, 2001). In the developing countries maize is mainly grown in the tropical lowlands however the tropical highlands and the tropical mid-altitude and sub-tropical ecologies are also important.

1.2 Maize production in Kenya

Maize is the main staple food for over 80 % of the Kenyan population. It occupies a number of Agro Ecological Zone's (AEZ's) in the country (KARI, 1991; Ngesa, 1993) compared to other crops. There exists potential for increased yields to over 6 t ha^{-1} through improved seed, fertiliser use, timely planting and weed control (Economic survey, 1999). Majority of land holdings in Central Kenya range of 0.5 to 2.5 ha per household with high population density ranging between 500 to 800 people km^{-2} (C.B.S, 1990). Thus small scale farming system, which ranges from 70 to 90 % (of the various types of farming systems) is mainly practised in these areas (C.B.S, 1990).

Maize production is the centre of economic activity for most small holder farmers with farms less than 2.5 ha (C.B.S, 1990). In most areas maize is intercropped with other crops such as beans (*Phaseolus vulgaris L.*), pigeon peas, soy beans, groundnut, dolichos beans, sweet potatoes, Irish potatoes and cowpeas (Almelikinders and Louwaars, 1999). Annual grain legumes offer a good compromise for meeting food security, animal feed, soil fertility, soil erosion and weed control on farm households.

The constraints of maize production include biotic factors; insects, diseases and weeds while abiotic factors include; water, light, temperature, soil fertility, lack of seeds, high prices of farm inputs and high cost and unavailability of farm labour (Almelikinders and Louwaars, 1999; Pingali, 2001). Pests and diseases contribute to major losses of maize yield (Pingali, 2001). Fertiliser use in Africa is about 10 kg ha^{-1} compared to 83 kg ha^{-1}, in the developed countries. Lack of adequate capital by farmers to buy inputs (seeds, fertiliser, herbicides and pestcides) has led to low productivity. About 40 % of the maize area is sown with improved maize seeds only in about ten countries in the whole of Africa of which Kenya is among them (Eicher and Byerlee, 1997).

In Kenya, intensive continuous cultivation with inadequate replacement of nutrients leads to low and declining soil fertility. Maize yields have declined by 30 % in the absence of fertiliser and manure application in a long term fertiliser trial in Kenya due to nutrient mining (Qureshi, 1987). The loss of nutrients through plant removal without replenishment, erosion, leaching, volatilisation and deterioration of soil physical conditions result in yield reduction (Lekasi *et al.*, 1998). Farmyard manure when added to the soil supplies nutrients and may act as a buffer, thus ameliorating adverse effects associated with low pH in some soils (Kimani *et al.*, 1998). However quantities of farm yard manure are usually low at farmer level (Lekasi *et al.*, 1998).

Farmers weed late or inadequately or do not weed the crop at all due to shortage of labour and capital leading to yield reduction (Jedidah Maina, 2002; personal communication). Kiambu district, in the central highlands of Kenya has a total of 84,496 farm families (Central Bureau of Statistics (C.B.S.), 2001) and nearly 100 % of them have dairy cattle (Staal *et al.*, 1997). Increased demand for animal forage has led to increased maize planting densities compounding soil nutrient mining by the crop. Thus these constraints among others require to be addressed for increased maize productivity.

High planting density would smother weeds in the field and combined with an appropriate thinning time would increase forage and grain yield if competition for soil moisture, nutrients, and light was properly managed. Also edible weeds that come up after hand weeding could be harvested as animal feed. Assuming an average family size of six persons the project findings therefore have a potential impact on over five million persons in central Kenya, (Central Bureau of Statistics (C.B.S.), 2001).

1.3 OBJECTIVES

1.3.1 Broad objective

The broad objective was to determine the effects of planting density and weeding regime on quality and quantity of maize forage and grain in a maize-bean intercrop in central highlands in Kenya.

1.3.2 Specific objectives

The specific objectives were to determine effects of planting density and weeding regimes on:

(i) Quantity of maize and bean forage, grain and bean yield and quality of maize forage.

(ii) Light and water use.

(iii) Weed biomass, edible weeds and cost of weed control.

1.3.3 Hypotheses

(i) Hand weeding and high planting density will not increase grain and forage quality of maize.

(ii) Planting density will not influence maize growth, yield and resource use (PAR interception and soil water uptake).

(iii) Hand weeding and high planting density will not influence weed biomass, composition and cost of control.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Maize *(Zea mays. L)* is an erect plant of 1.5 to5 m that forms very few tillers, used for human food, animal feed and forage (Almelikinders and Louwaars, 1999; Acland, 1971; Rathore, 1999). It is cross pollinated and matures within 3 to 6 months depending on variety, day length and temperature. The ear is formed mid way up the stem and contains 8 to 28 rows of grain each row containing 20 to 60 grains with grain colour of either white, yellow, red or blue and grain type either dent (soft) or flint (hard) (Rathore, 1999; Almelikinders and Louwaars, 1999). It is harvested when the seeds are hard and glazed with about 30 % moisture and shelling can be done at 22 to 25 % moisture. Further drying is required down to 12 % moisture for storage (Almelikinders and Louwaars, 1999).

Maize plant populations of 37,000 plants per hectare (spacing of 90 cm x 30 cm) are common for tall varieties but may go up to 70,000 (70 cm x 20 cm) for shorter varieties in high rainfall areas (Almelikinders and Louwaars, 1999). For hybrid 511, a spacing of (75 x 30 cm) is used giving a population of 44,444 plants ha^{-1} (KARI, 1992; Ininda, 2003; personal communication) and 20 to 35 kg ha^{-1} of seeds are required depending on seed size and desired population density (Almelikinders and Louwaars, 1999). Between row distance of 100 cm facilitates weed control and enables access to this tall crop for visual inspection of individual plants and hand pollination (Almelikinders and Louwaars, 1999). In Kenya, agricultural production is mainly on about 20 % of the total land area that is classified as having high to medium rainfall (Jaetzold and Schmidt, 1983). Maize (*Zea mays*) is the most important cereal crop in both high and medium potential areas of Kenya (Chui, 1987) and is produced under mono or multiple cropping (Andrews and Kassam, 1976).

In central highlands of Kenya shortage of forage usually occurs at dry season thus maize stover is used as forage to supplement napier grass (Macleod, 2001; Methu, 1998). A cow consumes 25 kg of silage per day during the dry season and produces 7 kg of milk per day without supplementation with concentrate feeds (Omore *et al.*, 1999). Maize stover can be used for silage making a valuable feed of the dairy cattle. In these areas maize is usually intercropped with beans. The common bean (*Phaseolus vulgaris*) is the most widely cultivated species of *Phaseolus*. The beans are a source of dietary protein to the smallholder mixed dairy farmers.

Multiple cropping enables intensification of agricultural production through more efficient use of growth factors such as light, water, nutrients, space and labour available for cultivation and suppression of weeds (Fageria, 1992). During tasseling of maize, limited moisture, low nitrogen, water logging, low light intensity and too high planting density cause delay in silk extrusion, kernel abortion and reduction in ear number (Almelikinders and Louwaars, 1999). These growth factors together with diseases, pests and weed control requires proper management in order to improve the yield of maize grain and forage quality and quantity.

2.1 Constraints to maize production

2.1.1 Water

Water is a major constituent of plant tissue solvent in which solutes including plant mineral nutrients are transported, a reactant in processes like photosynthesis and hydrolysis, is essential for maintenance of tissue turgidity and regulation of leaf temperature (Kramer, 1983). However no other environmental factor limits global crop productivity more severely than water deficit (Boyer, 1982). Plant growth and development can be affected by water deficit at any time during the crop life cycle but the extent and the nature of damage, the capacity for recovery and the impact on the yield depend on the developmental stage at which the crop encounters the stress. Moreover the sensitivity to water deficit is particularly acute during the reproductive development because reproduction involves several processes that are extremely vulnerable to change in plant water status (Saini, 1997).

Drought at any time during the reproductive phase reduces grain yield (Jamieson *et al.*, 1995). However the most dramatic yields loss has been recorded when water stress occurred during onset of meiosis and early grain initiation (Saini, 1997). Once the grain has been initiated, there is gradual decline in stress sensitivity as the grain develops (Aspinall, 1984). The reproductive phase starts with the transformation of a vegetative meristem into inflorescence and flower primordia, it ends when the seed reaches physiological maturity. The entire phase include, floral initiation, differentiation of various parts of an inflorescence and flower, and male and female meiosis, development of pollen and embryo sac, pollination, fertilisation and seed development. Water stress at tasseling reduced grain yields in maize by 50 % and 30 % at high N (413 kg ha^{-1}) and Low N (168 kg ha^{-1}) respectively (Saka, 1985). Mild water stress at leaf water potential of 0.6 mPa; a value at which stomata is still open, reduce maize leaf elongation (Acevedo *et al.*, 1971). Water stress also reduces photosynthesis through decreased CO_2 uptake and fixation (Macharia, 1990) and leaf area development (Kamoni *et al.*, 2000).

The productivity of a crop depends on the partitioning of water inputs between un productive losses of water (i.e. through direct evaporation from the soil, run off drainage) and water used for dry matter production (i.e. transpiration) in a cropping system (Mburu, 1996). The rate of dry matter production involves reduction of atmospheric CO_2 acquired through stomata under light. Mild water stress reduces the rate of CO_2 uptake partly through increased stomatal limitations, the carboxylation efficiency and rate of regeneration of CO_2 acceptor decreases under severe stress in maize (Macharia, 1990). In condition of ample soil water supply the potential transpiration and photosynthesis are both attained (de Vries *et al.*, 1989). Reduced soil water supply limits the N uptake from the soil and leaf expansive growth (Simmonds *et al.*, 1999).

Irrigation increased number of ears ha^{-1}, 100 grain weight, number of grains ear^{-1}, plant height, ear height and grain yields increased by an average of 750 kg ha^{-1} in maize (Boquet *et al*, 1987). Stewart, (1983) reported that the yields of maize and beans increased linearly with applied water until requirements were satisfied at 250 mm for beans; maize water requirements were not satisfied at 438 mm in which the estimated water requirements for maximum yield of maize was 589 mm. The yields in maize bean intercrop were 4.98 and 0.7 t ha^{-1} respectively at 438 mm water. However minimum rainfall of 500 to 600 mm during the growing season is needed to reach an acceptable production in maize (Rathore, 1999; Almelikinders and Louwaars, 1999). In drought conditions the roots become major sinks for the crops photosynthates resulting in yield losses that may vary from 20 to 100 % (Abayo *et al.*, 1998).

Drought is evenly distributed a cross the world major regions but is a severe problem for about one fifth of the tropical and Sub Saharan maize grown area in the developing countries (Heisey and Edmeades, 1999). Most tropical maize is produced under limited soil water (CIMMIT, 1999), which limit root water uptake (MC Gowan and Williams, 1989). Changes in soil profile water content are caused by combination of soil evaporation (E), transpiration (T), drainage (D), precipitation (P) and runoff (R) (Hillel, 1980). In the semi arid parts of Kenya at least 70 % of the rainfall water in the bean plots is lost through direct evaporation from the soil surface while the fraction of water transpired decreases in seasons with relatively low rainfall (Pilbeam *et al.*, 1995). The proportion of the total evaporation relative to transpiration in a maize-bean intercrop in a number of seasons in Kenya was 15 % in seasons with 150 mm rainfall and increased to 40 % in seasons with 400 to 500 mm rainfall (Pilbeam *et al.*, 1995).

Fernandez *et al.*, (1996) working on water use and yield of maize with two levels of nitrogen fertilisation in SW Spain reported crop evapotranspiration of 625 mm ha^{-1}. Lenga, (1979) reported that maize at Kabete used 518 and 619 mm in short and long rains with Water Use Efficiency of maize grain of 9.5 and 7.22 kg $ha^{-1}mm^{-1}$ in short and long rains respectively. This indicates more than optimal rain reduces water use efficiency.

High planting densities increase crop water stress. In central province of Kenya farmers practice maize dense planting (Methu, *et al.*, 2001). Berzsenyi, (1988) reported that increasing plant density consistently reduced harvest index while water stress during flowering reduced grain yield and harvest index even at optimum plant density. The duration of reproductive growth relative to total growth sets the upper limit for the harvest index (HI) in determinate genotypes. The ratio of the duration is about 0.5 to 0.6 for early cultivars of cereals and about 0.3 for late ones. However dry mater production slows down during the reproductive phase while dry matter is not always retranslocated which lead to reduced HI than the respective ratio (Squire, 1990).

A devastating drought in South Africa in 1991 to 1992 reduced maize yield by about 80 % (Heisey and Edmeades, 1999). Similarly banana sensitivity to moisture stress is reflected in the reduced growth, stomatal conductance and leaf size (Kallarackal *et al.*, 1990; Turner, 1995) increased leaf senescence (Bastalgia 1980), and reduced photosynthetic rate (Robinson, 1996). Moisture content of 18 to 21 % accelerated the growth rate of maize plant by 5 $mmhr^{-1}$ as compared to 1.4 $mmhr^{-1}$ at lower moisture content of 9 to 12 % (Rathore, 1999). Availability of adequate moisture at later stages has direct bearing on growth and yield of maize and thus under moisture stress application of irrigation is would increase maize yields (Rathore, 1999).

2.1.2 Temperature

Maize grows best at temperatures raging from 24°C to 30°C (Pingali, 2001; Rathmore, 1999; Acland, 1971). Temperatures below or above this range interfere with plants physiological processes, lowering yield. At temperatures above 38°C the plant fails to maintain adequate water into the system, evaporation from the soil and transpiration from the plant surfaces increase, increasing the drought effect (Rathmore, 1999; Pingali, 2001). Temperatures above 35°C cause pollen sterility in maize (Rathmore, 1999; Almelikinders and Louwaars, 1999) and at 45°C pollen desiccation and silk death occur. Selection for tolerance for high temperatures in tropical maize is receiving greater attention among research community. Poor weed control and high plant densities increase the temperature stress due to increased moisture transpiration on the maize crop (Rathmore, 1999).

Leaf temperature affects the vapour pressure of water in the leaf. The higher the leaf temperature the higher the vapour pressure and the more rapid the transpiration. Temperature has been shown to strongly influence developmental processes and the rate at which a crop attains maturity (Squire 1990). The temperature below which the growth of a crop ceases, is termed as base temperature (T_b). White and Montes-R (1993) working on the germination of the various bean cultivars established a mean T_b for germination of about 8°C while Hoogenboom and White (1991) cited in White and Montes-R (1993) reported T_b for leaf development of 5°C though there was no experimental evidence for choice of this value. Optimum temperatures for bean growth rage from 25°C to 29°C (White and Montes-R, 1993; Ristanovic, 2001). Temperatures below 10°C hinder maize germination and temperatures above 35°C reduce the yield (Acland, 1971; Rathmore, 1999; Ristanovic, 2001). Thus the base temperature for maize is 10°C (Acland, 1971; Ristanovic, 2001 Acland, 1971).

The cumulative difference of the mean daily temperature and the base temperature of crop over growth period is referred as thermal time. According to Squire (1990), thermal time is described by the equation:

$$\Phi = \sum_{i=1}^{i=n} (Ti - Tb)$$

Equation 2.1

Where;

Φ is thermal time in (^{o}C days),

i is the number of days,

Ti is the mean daily temperature (^{o}C),

Tb is the base temperature at which development process in consideration ceases.

2.1.3 Light

Light is required for growth of higher plants (Delvin, 1975). Solar radiation influences photosynthesis, sensible heat exchange and evapotranspiration thus uptake of nutrients (Squire 1990). The rate of transpiration depends on water supply and the amount of energy available to evaporate water from the leaves (Squire 1990). Thus partially shaded plants may be under less water stress than fully exposed plants (Paner, 1975). Shading in the intercropping systems or unweeded crop reduces the energy available to one or more of the crops. However some extreme-shade tolerant species benefit from being shaded by tall plants in the competition for light (Paner, 1975).

Leaf canopy orientation influences the light penetration through a crop canopy. Radiation penetration into plant canopies decreases extremely if the horizontal distribution of leaf elements is approximately random (Allen and Brown, 1965). The spectral qualities of light photsynthetically active radiation (PAR) change with depth into plant canopies because leaves at different heights intercept solar radiation differently. Changes in radiation quality affect plant photomorphogenic processes. A plant with unusually short shoot in a dense sole crop will experience unfavourable light regime, hence poor supply of photosynthates leading to a low root: shoot ratio

(Allen and Brown, 1965). The resulting small root surface area in return will compete less effectively for soil water and nutrients rendering the shoot inefficient throughout its growth period (Allen and Brown, 1965). Such negative response causes slow growing individuals of intercrop or monocrops in unweeded field to be out competed for soil water, nutrients and light and thus suppressed (Donald, 1963 and Milthorpe, 1961). For a tall crop, competition for light will start first if soil conditions are near optimal, but competition for soil factors start first with critical deficient of soil moisture and nutrients (Trenbath, 1974).

Reduced light intensity in potato results in reduced total dry matter accumulation in the tubers and therefore low yields compared to potato grown at high irradiance (Gawronska and Dwelle, 1989). Shaded plants produce small and irregular tubers however shading by an intercrop or relay crops and mulching lowers soil temperature and conserves water (Sale 1976; Menzel, 1985). Midmore *et al.*, (1983) found a linear reduction of soil temperatures (at 7 cm soil depth) with an increase in shade and this significantly hastened potato emergence in most cases. This reduces the light available but if properly managed, heat reduction offsets the effect of low light intensity (Midmore *et al.*, 1983). This may result to improved productivity of the potato crop.

Intercepted radiation is usually determined as a difference between light received at the canopy surface and that transmitted through the canopy as measured by arrays of solarimeters (Squire 1990). However light interception greatly reduces in crops under drought conditions without irrigation due to leaf rolling and senescence (Masri and Boote, 1988). Dry matter production is proportional to the total amount of incident

PAR that is intercepted by foliage and the efficiency with which it is converted to dry matter by green leaves (Squire 1990). Maize photosynthesis and biomass production are directly associated with canopy light interception (Muchow *et al.*, 1990). There is a linear relationship in the response of leaf photosynthetic rate to increasing solar radiation in maize canopies (Louwerse 1980) and maize does not exhibit light saturation in even at full sunlight (Hesketh and Moss, 1963).

2.1.4 Soil fertility

Tropical soils are known for their low soil fertility, particularly low nitrogen. Intensified land use, soil erosion, rapid decline in fallow periods and extension of agriculture into marginal land, has contributed to rapid decline in soil fertility (Sanchez *et al.* 1997). Soil erosion and degradation are often observed where population growth is rapid. Arid areas, upper hillsides in the semi arid and humid zones and areas with shallow sandy soils exhibit the highest levels of erosion (Sanchez *et al.* 1997). Soil acidity also contribute to poor soil fertility. Acidic soils are characterised by low pH, deficiencies of phosphorus, calcium and magnesium and toxic levels of aluminium. The remedy for this is application of lime (Sanchez *et al.* 1997).

Maize exhausts the soil and is very responsive to the well-prepared soil with high organic matter and nutrients (Almelikinders and Louwaars, 1999). Nitrogen (N) and phosphorous (P) deficiencies are the major nutrients that hinder small holder maize production (Sanchez *et al.* 1997; Smaling, 1993 and Bashir *et al.*, 1997). Continuous cropping, removal of field crop residues for feeding ruminants and overgrazing between cropping seasons with little or no external inputs, have reduced the productive capacity of arable lands. This threatens the sustainability of food production systems in the densely populated humid and subhumid highlands of East Africa (Smaling, 1993, Hudgens, 1996) and throughout sub Saharan Africa (Sanchez *et al.*, 1997). Thus there is great concern of soil fertility decline on arable land in the East African Highlands and Africa in general (Swift *et al.*, 1994). It has been estimated that average fertiliser application in Sub-Saharan Africa is a 7 kg ha^{-1}. Similarly calculations by Haisey and Mwangi (1996) gave an average of 10 kg ha^{-1} of fertiliser nutrients in central Kenya. Low grain to fertiliser price ratio and high levels of production risks are two of the underlying factors for the low use of fertiliser (Haisey and Mwangi, 1996). Even when fertiliser is applied in farmers' fields, it is often used inefficiently as measured by the grain yield response to the addition of chemical N and P fertilisers, which reduces its overall profitability (Kumwenda *et al.*, 1996).

Organic manures provide a low cost potential source of nutrients. Organic manures have one major advantage in that they contain all essential nutrients plus carbon, the source of energy for soil biota that regulate nutrient recycling (Kapkiyai, 1996; Sanchez *et al.*, 1997). Soil organic matter (SOM) helps retain mineral nutrients in the soil and makes nutrients available to plants in small amounts over many years (Woomer *et al.*, 1994). However farmyard manure in the central Kenya has insufficient nutrient quantities to maintain soil fertility and this needs to be supplemented with inorganic fertilisers (Jama *et al.*, 1997).

Better maize growth is achieved when some of the N is supplied in the NH^{+}_{4} form and some in the NO^{-}_{3} (Alexander *et al.*, 1991). In warm and well-aerated soils NH^{+}_{4} - N is rapidly converted NO^-_3 - N (Hageman, 1984). In cereal crops, absorption of NO^-_3 - N is closely related with K^+ absorption (Tisdale *et al.*, 1985). However, excessive N supply is associated with lodging when K supply is inadequate. There is long-term decline in fertility related to increased cropping intensity on smallholder mixed farms (crops and dairy) due to increased population in central Kenya (Lekasi *et al.*, 1998). Increased planting density would increase competition for the available nutrients. Similarly the type of weeding regime would determine the weed density and thus weed competition for plant resources. Thus fertility problem could be severe with poor weed control or increased planting density. Thus application of farmyard manure back to the farm is necessary more so for the farmers who feed crop residues to the animals. This would avoid nutrient mining.

2.1.5 Weeds

Weeds are as old as domesticated plants, which today we use as food. Man began a long process of selecting what he could preserve and what he could discard. Some plants easily change roles between weed, crop and animal forage (Onim *et al.*, 1992). Weeds are a serious constraint to optimum crop production, often causing greater losses than any other pests (Nabaiwa and Nabawanuka, 1988). The significance of weeds is easily overlooked because unlike other pests and diseases weeds can substantially reduce crop yields without obvious sign of damage. Weed control constitutes one of the expensive exercise in farming particularly to the small-scale farmers. The presence of weeds on farms indicates to the farmer the pending drudgery ahead for relatively less rewards (Akobundu, 1991). Weeds in maize, as in other crops, cause adverse effects such as reduced yields, increased pests and diseases incidence and interference with cultural practices such as irrigation, fertiliser application and harvesting (Alden, 1975, Zimdhal, 1980). Farmers in central Kenya recognise weeds as a major problem (Gethi *et al.*, 1998).

Methods of weed control include; manual and mechanical weeding, hand pulling, relay cropping and intercropping, mulching, slashing, mowing, burning, chemical weed control, and biological weed control. In central Kenya most weeds found in maize crops are eaten by livestock. These include weeds such as *Amaranthus spp*, *Bidens pilosa*, *Galinsoga parviflora*, *Commelina bengalensis*, thus a farmer could harvest and feed them to the animal. Weeds influence crop yields (Barrentine, 1974), quality, harvesting efficiency and subsequent weed populations (Appleby *et al.*, 1975). For every crop, weeds must be kept below a certain competitive level in order to obtain maximum crop production during a period (Barrentine and Oliver, 1977). After planting in a well-prepared seedbed, a crop requires time to grow and acquire competitiveness to be unimpaired by developing weeds or newly emerged seeds. After the first weed control, the competitive potential of the crop is usually sufficient to minimise deleterious effects of weeds (Barrentine, 1974).

Weeds compete with crops for nutrients, moisture, light and space, adversely affecting crop growth (Sebuliba-Mutumba *et al.*, 1997). About 10 % yield losses due to weeds of major crops has been recorded world wide (Roberts, 1982) but 15 to 95 % have been recorded on maize in many parts of Africa. Yield reductions of up to 40 to 53 % due to weed interference has been reported on mixed cropping systems (Parker and Frier, 1975). Weeds also have been reported to cause 5 to 90 % yield loss in maize if not efficiently controlled (Rathore, 1999). Mabasa and Nyahunzvi (1994) found that weed biomass at 4 weeks after emergence (WAE) was inversely related to crop yield indicating that crop competition was high at this period. Bhushan *et al.*, (1984) reported that three weeks after sowing weeds from the weedy crop had taken up to four times as much nutrient (N, P, K, Ca and Mg) as was taken up by corresponding weed free crops. But with early weeding done at 3 to 4 WAP the weeds that grow after this are suppressed by the already established crop but the suppression is more in the denser crop canopy (Maina, 1997). For instance *Striga hermonthica* and *Striga asiatica* parasitic weeds negatively affect the livelihood of more than 100 million Africans and inflict crop damage totalling to approximately US$ 7 billion annually to the African economy (Berner *et al.*, 1995). It has been also estimated that 42 % of the total production costs in maize based cropping systems is due to weeds (Vernon and Parker, 1983).

Weed management is a critical constraint in subsistence small holder dairy farmers owning between 1 to 2 ha of land in mid altitude potential areas. Thus many farmers in the region practice cereal and grain legume intercrop to control weeds (Chui, 1987). Considerable progress in weeds management in small subsistence holding through farmer oriented research has been done over the years (Muthamia, 1989; Chui 1987). Weed control affects the availability of soil moisture to the crop and therefore needs to be incorporated as a key element in conservation tillage (Mabasa *et al.*, 1998). A survey in central Kenya demonstrated that 89 %, 8.8 % 1.7 % of the farmers used hand hoe, both hand hoe / herbicides and only herbicides respectively (Gethi *et al.*, 1998). Shumba (1989) demonstrated that reduced tillage in maize depended on conjunctive use of herbicides such as Atrazine. Because of high costs, adoption of herbicides by small holder farmers has been very low. Pre-emergence herbicide use control the weeds effectively during the early growth of the crop before the intercrop has grown an effective canopy to control the weeds (Maina, 1997). Some weeds such as striga causes most of its damage to the crop before it emerges (Parker and Riches, 1993). This calls for use of herbicides to control such weeds. Several pre and post emergence herbicides are available for various weed controls however they are often too expensive to resource poor farmers.

Yield reduction due to a given density of weeds are often greater when soil fertility is low than when it is high (Nieto and Stanforth, 1961). Low plant densities favour weeds; generally the weed density decrease as the planting density increases (Maina, 1997). Intercropping system have been found to reduce weed growth (Moody, 1978). The ability of a crop to smother weeds depends on the planting density, rate of growth and establishment of crop canopy, competitive ability, the weed species, fertility and moisture status of the soil (Bantilan *et al.*, 1974; Moody and Sheddy, 1981).

Weeding accounts for 60 % of the preharvest labour input for maize production in central Kenya, hence considerable strain is placed on household supplied labour (Maina, 1997). A detailed survey in central Kenya found that (66 %) and 22 % of the farmers weeded their maize twice and once in a season respectively (Gethi *et al.*, 1998). However, Maina (1997), working on use of intercrops to control weeds reported that one weeding in all the cropping systems reduced labour requirements and increased the crop yield per unit area. The crops used for intercropping with maize were potatoes (*Solanum tuberosum L.)* and dry beans (*Phaseolus vulgaris. L*) and a second weeding did not increase the grain yields of maize and beans at Kabete but at Thika it increased the yield of maize significantly but not the beans (Maina, 1997).

Most resource poor farming house holds in Kenya face an acute labour constraint, which affect the timeliness of weed control mostly in the initial crop growth stages (Maina *et al.*, 2001). This leads to late and poor weed control that results in substantial crop losses. However use of herbicide that require less labour can reduce this labour requirement (Maina, 1997). A mixture of alachlor and linuron is suitable for maize intercropped with beans (Maina *et al.*, 2001). Hand weeding in maize is laborious, time consuming and expensive and sufficient labour may not always be available for timely weed control. Maina (1997) reported that the cost of controlling weeds using pendimenthalin herbicide costed Kshs 5,328. Use of two hand weedings spent 70 mandays ha^{-1} each at shs 91.50 totalling to Kshs 6,368. Therefore use of appropriate herbicides for maize production is a practical and appropriate alternative.

2.1.6 Pest and Diseases

2.1.6.1 Diseases

The actual number of maize diseases is not known but at least 90 infectious and 40 non-infectious diseases could affect maize in the world. In Kenya maize is infected by a number of diseases (Murithi, 1993). Turcicum blight caused by *Exserohilum turcicum*, is most serious in relatively cool and humid regions, specifically in the tropical mid altitude areas (Pingali, 2001). It causes large lesions on the leaves that affect the photosynthesis and therefore causes yields losses of around 15 to 20 %. The only known economical solution to the problem has been resistant cultivars. Maize streak virus (MSV) is a major disease of maize in Africa and is most prevalent in tropical lowlands and parts of tropical mid-altitude maize growing areas (Almelikinders and Louwaars, 1999). The pathogen is transmitted by leafhoppers and causes serious yield losses, but its occurrence is sporadic. A severe outbreak in Kenya in 1988 for example destroyed more than half the crop over large areas (Pingali, 2001). Practices such as timely planting, proper weed control and treatment of seeds with systemic insecticides can help control yield losses due to the disease (Almelikinders and Louwaars, 1999).

Grey Leaf spot caused by fungus *Cercospora zeaemaydis* has become a serious leaf blight pathogen in temperate, subtropical and mid altitude maize growing areas world wide during the past 30 years. When infection occurs at flowering, maize losses of 30 % or more can occur attributable to both losses of leaf area and subsequent stalk lodging (Pingali, 2001). Maize downy mildew caused by *Peronosclerospora sorghi*, is mostly found in the tropics. Depending on infection levels, farmers can lose more than 80 % of their crop to this disease (Pingali, 2001). The disease can be treated using Ridomil TM though too expensive for poor resource farmers. Resistance varieties are being developed.

2.1.6.2 Insects

Preharvest and post harvest losses of maize crop and grain due to insect pests are a significant burden to small holder farmers. Insects reduce annual maize production by attacking roots (root worms, white grubs, and seed corn maggots), leaves (aphids, armyworms, stem borers, thrips, spider mites, and grass hoppers), stalks (stem borers, termites) ears and tassels (stemborer, and army worms) and grain during storage (grain weevils, grain borers, Indian meal moth and the Angoumois grain moth). Among these the most destructive to maize are; armyworm, earworm, cutworms, stem borers and the Indian meal moth and the Angoumois meal moth (Pingali, 2001).

These insect pests could be controlled by removal of stubble, crop rotation and preventive spraying (Almelikinders and Louwaars, 1999).

Insect damage can occur at any stage of maize production and storage. For instance during physiological maturity of maize crop, rain coupled with strong wind results in severe lodging of the crop (Almelikinders and Louwaars, 1999). The lodged crop has poor PAR capture which lead to reduced yield. More so this leads to cob destruction by rodents and porcupines. Severe lodging would lead to yield reductions of up to 23 % (Cooper, 1971). However, the extent of crop losses due to lodging depends on germplasm used, cultivation practices, levels of pest manifestation, control strategies used and climate.

Mode of storage could lead to damage of the stored grains. Losses during storage vary from undetectable levels in commercial silos to 80% in tropical on farm stores in many developing countries. Grain is usually most susceptible to damage when it is stored under high grain moisture content. *Aspergillus flavus* is a dangerous fungus that may develop on moist maize. It produces aflatoxin, which is hazardous to humans and animals (Almelikinders and Louwaars, 1999). Thus it would be advisable to dry the grain to the recommended moisture (12 to 13%) before storage.

2.2.7 Seed quality

Lack of high quality seed is a constraint to maize production, especially in intensive cropping systems in tropical lowlands. High quality seed is key to agricultural progress while other inputs such as fertilisers, pesticides, herbicides and overall crop management help to realise the production potential of seeds (Srivastava and

Simarski, 1986). Thus to realise increased productivity of maize will require good viable seeds. Variety development programs at research centres produce improved seeds. Breeders seed is multiplied several times to become the certified seed which may be acquired and used by farmers. Small holder access to good quality seed has been an important strategy for agricultural development in Kenya for several decades (ICA, 1961).

The most severe constraint is that farmers acquire initial amounts of commercial quality seed and then recycle this rather than purchasing fresh supplies each season, thus lowering demand for commercial seeds considerably (O'Leary, 1984). The main factors that affect demand for commercial seeds are yield potential or quality advantage over traditional seeds, price, price of substitutes (e.g. on farm produced seeds), price of other inputs such as fertilisers, price of farm produce, seasonal forecasts and the cost of reaching stockists (Kimenye, 1998). Supply of seed is determined by production costs and expected price. Variety development, field and post harvest operations, distribution and marketing represent the major proportion of the cost of seed production (Kimenye, 1998).

2.1.8 Inter crop competition

As in most African countries, intercropping often involves cereal and a legume, with the cereal being considered as the main crop (Almelikinders and Louwaars, 1999). This is mainly because, in most cases, the cereal is the main food source and its yield is much higher than that of legume while the legume fix N which benefit the cereal (Willey, 1979). Mixed cropping ensures higher yields per unit area of land, better use of resources and reduces soil erosion while maintaining soil fertility (Mochoge, 1993;

Willey, 1979). Intercropping systems using cowpea and maize were found to increase maize grain yields and suppressed Striga emergence (Kasembe *et al.*, 1999).

Reduction of maize yield by intercropping has also been reported (Chui and Keter, 1997, Mochoge *et al.*, 1997). Nevertheless any additional yield of the main intercrop depends on the level of interspecific competition between the intercrops for available mineral nutrients, water and light (Willey, 1979). Competition between species in crop mixtures is influenced by the length of time the crops overlap in the field, the spatial arrangement, the plant population and the relative competitiveness of the cultivars in each species (Golds worthy and Fisher, 1984). Competition between species is greatest when the components share time and space in field throughout most of their growth (Golds worthy and Fisher, 1984). Most intercropping systems are designed to utilise the spatial arrangement and time dimension more completely (Obuo *et al.*, 1997; Ocaya, 1998). At the seedling stage of an intercrop, the roots of the component crops are far enough not to interfere with supplies of soil resources to the nearest neighbour. However since the surface area of the root system may be over 100 times that of the shoot the soil soon becomes crowded by roots and competition for soil moisture and nutrient begin as the plant grows (Dittmer, 1937).

The success of one member of the intercrop in competition for one soil factor, usually leads to enhanced absorption of other soil factors (Litav and Seligman, 1970; Hall, 1974). On a low-nitrogen soil under legume / non-legume intercrop system, the non-legume is often either suppressed (Stern and Donald, 1962) or has little advantage (Macleod and Bradfield, 1963). On high nitrogen soil, the strong growth response of the non-legume usually causes it to dominate the legume by shading it (Macleod and

Bradfield, 1963). A vigorously growing non-legume, takes up large amounts of nutrients such as phosphorus, potassium and sulphur, the last two sometimes with luxury component (Macleod and Bradfield, 1963), and the legume may suffer deficiency on soils low in these. The effects of these combined competition for light and P, K or S can sometimes be corrected by appropriate fertiliser applications (Macleod and Bradfield, 1963; Macleod, 1965).

If the deficiency of a given soil factor in an intercrop is responsible for yield reduction of the less competitive crop, provided this crop is not shorter than the other, it is possible to supply the factor such that the yield is restored to the level of sole crop. This has been achieved experimentally in several crops where the depression was due to weeds (Blackman and Templeman, 1938; Myers and Lipsett, 1958) or due to added plants of a second crop (Kurtz *et al.*, 1952). Except in very wet soils, diffusion of molecular oxygen is sufficient to supply the respiratory needs of roots (Grable, 1966). The proportion of a component dry matter that is allocated to harvestable yield may vary with the degree with which its plants are suppressed through competition with neighbours (Williams 1964; Trenbath, 1974).

Intercropping suppresses weeds better than a sole crop because it has a larger canopy that covers the ground faster than sole crop (Enyi, 1973). The planting pattern influences the average number of contact points of the components and the few these contacts are the less the competition leading to higher yields. Intercropping systems, (mixed, row, strip and relay) differ greatly in the frequency of individual crop contact. Interactions between plant neighbours may involve the action of toxic plant exudates (allelopathy). Allelochemicals may either inhibit more the growth of other plants other than the producer species (allo-inhibition), (Newman and Rovira, 1975) or inhibit more strongly plants of the producer species itself (auto-inhibition).

Beans are commonly intercropped with maize, but also with companion of other crops such as cassava, potatoes, coffee, and faba beans (Goldsworthy and Fisher, 1984) as an essential source of protein for human consumption (Njuguna *et al.*, 1981). Intercropping reduced the yield of maize by 45 % and of bean by 51% respectively compared to sole crops (CIAT, 1978). Leaf area development on a maize-bean intercrop were evident on beans at 37 days after sowing where the maximum leaf area produced was smaller than that of the sole cropped beans (CIAT, 1978). A rapid decline in leaf area of maize caused by the heavy shading on a maize bean intercrop relative to maize monocrop was observed from the flowering onward (CIAT, 1978). The intercrop formed a closed canopy three weeks earlier than the crop of maize on its own (Clark, 1979).

Fisher (1977) found that competition for water at critical growth stage resulted in large yield reductions in both maize and beans intercropped in particularly poor short rain season at Kabete Field Station, Kenya. He concluded that if the major risk for a crop is drought, then intercropping might not be advisable. Also Clark, (1979) reported that nutrient uptake by intercrops may be considerably higher relative to uptake by single crop in early growth. For a mixture of beans and maize to yield more than the individual mono crops if other factors were not limiting, Clark (1979) demonstrated that mechanical manipulation of the canopy of maize (the dominant crop) to reduce light competition was required.

The recommended beans spacing is 45 to 60cm x 15 cm (depending on the variety) resulting to a population of 110,000 to 145,000 plants ha^{-1}, which yields 220 to 1,100 kg ha^{-1} (Acland, 1971). The national bean yield average is between 600 to 800 $kgha^{-1}$ however potential productivity could rise to 1500 kg ha^{-1} (Muigai and Ndegwa, 1991). The physiological process that reduce bean seed yield include photorespiration (to meet high energy cost for protein and oil synthesis), diversion of carbohydrates to support symbiotic nitrogen fixation and high energy cost for protein (Fageria, 1992). About 30 % and 10 % of legume photosynthates are consumed in photorespiration and N fixation respectively causing reduction in potential seed yield (Fageria, 1992). Nitrogen deficiency and water deficits also reduce bean seed yield (Mburu, 1996).

Beans get saturated with light at low light intensity since they are C_3 plants (Laing *et al.*, 1984). Thus in a maize bean intercrop where the maize crop is densely planted, early vegetative establishment would improve the yield. Approximately 80 % of the root system of beans occur in the top 45 cm (Mburu, 1996) while those of maize may extend to a depth of 3.5 m in well drained, fertile soils with adequate rainfall (Acland 971). Thus there is reduced competition for nutrients within the soil profile in a maize bean intercrop. Thinning of the densely planted maize in a maize bean intercrop at the time when shading is maximum probably would increase the PAR capture by the beans and improve the bean yield.

2.2 Maize use

In the central Kenya maize is the major cereal crop usually grown at high densities 4 seeds $hill^{-1}$ and thinned to two plant $hill^{-1}$ for animal feed (Methu *et al.*, 2001) but its grain is used for human food (Morris 1998). However the effect of increased maize planting density with various weeding regimes has not been evaluated. Due to increasing human population more research is required to improve the maize yields. Maize stover is an important livestock feed particularly in the dry seasons (Methu et *al.*, 2001). Approximately 80 % of dairy animals in central Kenya are kept under zero grazing system. They are fed mainly on napier grass supplemented with mainly maize crop residues because increased population has led to increasingly reducing farm sizes (0.9 to 2 ha) (Gitau *et al.*. 1994. Mwangi 1994 and Staal *et al.*, 1997). Approximately 40 to 80 % of the feed for dairy cattle in central Kenya comes from napier grass (*Pennisetum purpureum*) and 24 % comes from the maize crop (Mwangi 1994; Staal *et al.*, 1997; McLeod *et al.*, 2001). In these areas 0.2 ha (15 % of the available land) is planted with Napier grass (*Pennisetum purpureum*) while maize is the major food crop (Staal *et al.*, 1997). Napier grass yields between 10 and 40 tonnes dry matter ha^{-1} depending on soil fertility, climate and management (Schreuder *et al.*, 1993). Maize stover yields of 2.2 to 3.8 t ha^{-1} DM at Muguga at maize population range of 29,000 to 40,000 has been reported (Abate, 1990).

Mixed maize cropping is highly practised in central Kenya, therefore there is need to ensure efficient use of the crop residues as feed. During the dry season, the quantities of the available forage become limiting. At such times farmers result to alternative types of basal diets, mainly maize crop residues. Crop residues provide a link between crops and animals (Devendra, 1989). The utilisation of maize stover, which is the main roughage during the dry season (Mwangi, 1994; Said and Wanyoike, 1987) is constrained by low crude protein and low digestibility (CP) (Little and Said, 1987 and Methu, 1998).

Seasonality of forage supply plays a major role in milk marketing as milk supply changes drastically from dry to wet season leading to price fluctuations. Stover dry matter of 25g, 50g and 70g per kg liveweight increased milk yield by 10, 12 and 12.2 kg per day respectively (Methu, 1998). Feeding forage of higher digestibility improves milk yield and composition (Broster *et al*., 1986). Milk yield increased by about 3 kg day^{-1} as a result of feeding higher quality forage (Omore et *al*., 1999). Supplementing hybrid cows fed with napier grass containing crude protein of 6.4 % DM with varying levels of *leucaena leucocephala* improved milk production by 28 % (Muinga *et al*., 1995). Protein rich forages such as *Desmodium intortum*, *Leucena leucocephala*, Kenya white clover (*Trifolium semipilosum*) have crude protein of above 17 % (D'mello and Devandra, 1995). It is apparent therefore, that milk production in central Kenya is limited by both the quantity and quality of feeds available (Gitau *et al*., 1994).

Crop residues like maize stover and barley straw usually become an important feed source during times of scarcity when the supply of high quality forage becomes limiting. Thus managing the maize crop so as to produce increased fodder and grain is highly required. Maize is grown during the short (September to October) and long (April to May) rains but dense planting to thin for animal forage is practised mainly during the short season. Scarcity of arable land hinder improving animal nutrition in the tropics (Yousef, 1986). Natural grazing land in the tropics is of low productivity and is usually over or understocked (Yousef, 1986). Additionally the growth patterns of such pastures is highly seasonal and highly variable, resulting in cyclic growth patterns of the animals. In Kenya, such variations have negatively affected the liveweight gain in growing animals (Sanda *et al*., 1998) and lactating dairy cattle

(Methu *et al.*, 2001). The poor nutritive value of crop residues limit intake but if their utilisation efficiency is improved, animal output could be enhanced (Methu, 1998). Crop residues are low in readily available energy, nitrogen, minerals and vitamins and have low intake and digestibility thus offer inadequate amounts of nutrients to maintain the animal (Singh and Oosting, 1993). Supplementation with concentrates therefore improves utilisation of such crop residues more efficiently.

Voluntary feed intake and thus digestibility decrease with decrease in forage quality. The quality of feed available for animals can be improved by manipulating factors such as forage species, supplementation and stage of harvesting. Improving soil fertility, moisture availability and weed control affect quality of forage. Harvesting the forage at the stage of growth when the quality is highest also improves forage quality. It is also important to note that increased N intake drops digestibility though the food passes faster in the gut. The digestibility of tropical livestock species ranges from 40 to 70 % (Kariuki, 1998). Digestible DM and CP content and the extent of degradation influence forage intake (Chaparro and Sollenberger, 1997). The digestibility of forages in the rumen is related to the proportion and extent of lignification (Van Soest, 1994). Maize stover has a relatively higher nutrient content and digestibility than most other straws.

The cell wall consists primarily of the structural carbohydrates, cellulose and hemi-cellulose and influence forage utilisation (Van Soest, 1994). It is important to note that as forages mature, the cell wall constituents increase thus lowering their digestibility. In vitro dry matter digestibility for the dwarf napier grass range between 65 to 79 % while crude protein ranges between 5 % to 9 % DM (Schreuder *et al.*, 1993; Chaparro and Sollenberger, 1997; Kariuki, 1988). Appropriate and adequate information on the nutritive value of forages at different stages of growth facilitate feed formulation, allow more reliable prediction of subsequent animal performance and assist in the planning of suitable feeding strategies for the resource poor dairy farmers (Kariuki, 1988). The quality thus determines how much an animal eats (intake) and how much of the intake is digestible.

CHAPTER 3

MATERIALS AND METHODS

3.0 Site characteristics

A field study was carried out at the National Agricultural Research Centre (NARC), Muguga of the Kenya Agricultural Research Institute (KARI), about 27 km north west of Nairobi, latitude 1° 13' South, longitude 36° 38' East, altitude 2096 meters above sea level (ASL). The area receives on average 900 to 1000 mm rainfall annually in two distinct seasons; long rains (mid March to June) with an average precipitation of 550 mm and the short rains (mid October to December) with an average of 400 mm. Temperature ranges are, minimum 7°C maximum 20°C, mean 15°C. The agro-climatic zone is subhumid. The soil is a well drained, very deep, dark reddish brown to dark red, friable clay (Appendix 1) classified as humic nitisols (FAO-UNESCO, 1977) or an oxicpaleustaf (USDA 1975). It is locally known as Kikuyu red clay loam and is derived from basic volcanic rocks. The soil has moderate to high inherent fertility though with phosphorus deficiency (Appendix 1). The experiment was conducted during short rains and long rains, 8th of November 2001 to March and 20th of May to September planting seasons respectively of years 2001and 2002.

3.1 Experimental design

The plots were ploughed at the beginning of the rain season and harrowed to produce good tilth for maize. The blocks were laid across the slope each with eight plots of size (4 m x 4 m) (Figure 1). Measurement were made marking with pegs the positions of the furrows at a spacing of 75 cm x 30 cm and a sisal twine was held along and the furrows made using a hoe. Holes (diameter 45mm) were augured and aluminium access tubes, one per plot for measuring soil moisture using neutron probe, inserted (internal diameter 45 mm and 150 cm long) in between maize and beans rows at the middle of each plot. Soil samples to analyse soil macro nutrients and soil weed seed bank were taken diagonally at 5 random points in each plot at a depth of 20 cm before sowing, big crumps broken down, air-dried, mixed thoroughly sub sampled and sieved to pass 2 mm sieve and analysed for pH (H_2O), total organic carbon, nitrogen, available P and K following the procedures described by Okalebo *et al.*, (1993). The soil was deficient of phosphorus which led to use of diammonium phosphate (DAP - 18:46:0 N:P:K) during planting. The experiment was laid out as randomised complete block design replicated four times. The treatments included four weeding regimes (weed free, weedy, pre-emergence herbicide use, two times hand weeding at two and six weeks after emergence, W1, W2, W3 &W4 respectively) and two planting densities, D1 of 9 plants m^{-2} (2 plants $hill^{-1}$) and D2 18 plants m^{-2} (4 plants $hill^{-1}$) factorially combined. The maize spacing was 75 cm x 30 cm). Beans (GLP2; Rose cocoa) were planted between the maize rows (37.5 cm away from the maize row), in all the plots at density of 9 plants m^{-2} (2 plants $hill^{-1}$ at spacing of 75 cm x 30 cm). Normal bean planting density (spacing) is 40cm x 30cm or 50cmx 20cm.

Plots were maintained weed free until sowing time. Phosphorus was applied round the maize hills on the furrows as DAP before each sowing period at rate of 25 kg $P_2 O_5$ ha^{-1}, half the recommended rate of 50 kg $P_2 O_5$ ha^{-1} in central Kenya because the technology is targeting resource poor who usually don't use fertilisers. Short duration maize (140 to 150 days to maturity) seeds (H511), from Kenya Seed Company were sown at about 5 cm soil depth. Six and four seeds per hill were covered with soil and thinned to four and two per hill respectively at 14 days after emergence.

Block 1

Plot 1	2	3	4	5	6	7	8
W4 D2	W2D1	W1D1	W3D2	W 1D2	W2D2	W4D1	W3D1

1 m path Block 2

Plot 9	10	11	12	13	14	15	16
W1D1	W2D1	W4D1	W3 D1	W 1 D2	W3D2	W2 D2	W4D2

Block 3

Plot 17	18	19	20	21	22	23	24
W2 D2	W4 D1	W3 D1	W 1 D2	W3 D2	W4 D2	W 1 D1	W2D1

Block 4

Plot 25	26	27	28	29	30	31	32
W3D1	W4 D2	W1D1	W3 D2	W1 D2	W4 D1	W2 D1	W2 D2

Direction of gradient

Figure 1. Field layout of the experiment.

Key

W1 – Weed free, W2 – Weedy, W3 – Herbicide use (Alachlor; 170 ml / 20 l and Linuron; 70 g / 20 l), W4 – Two Hand weeding (2 and 6 WAE), D1 – Low density of planting (9 plants m^{-2}), D2 – High density of planting (18 plants m^{-2})

Immediately after sowing bean and maize, soil moisture at field capacity, pre-emergence herbicides (Alachlor and Linuron) to control broad and narrow leafed weeds were applied (as a mixture) at the rate of 170 ml / 20 l and 70 g / 20 l of (Alachlor and Linuron) respectively using a Knapsack sprayer (Alachlor 48 EC at 1.2

kg a.i. ha^{-1} and Linuron at 0.6 kg a.i. ha^{-1}). The Knapsack sprayer was calibrated as described in section 3.2. Stem borer was controlled using Bullock.

3.2 Knapsack spray emission calibration

Knapsack spray emission calibration exercise was carried to determine the herbicide application rate. A 20 l Knapsack sprayer was filled with water, which was dispensed as one walked at constant speed as the one used in the actual spraying, between pegs placed 50 m apart in 5 return trips. The distance covered 5 times to and fro is equivalent to 500m. Assuming the spray width coverage on ground was 1m the area covered was $500m^2$ a twentieth of one hactare. The amount of water used was determined (found to be 15l) and multiplied by 20 to get the amount of water that would have been sprayed in one hectare of land. The calculation was as shown below;

Amount of water sprayed during 5 return trips = 15 l.

Therefore one hectare required 15 x 20 l = 300 l

For 20 l sprayer it will be filled: 300 ÷ 20 =15 times

Amount of herbicide per hectare

= Amount recommended/20 l sprayer x15, (when using 20 l sprayer).

In the case of this experiment:

Linulon 15 x 80 g = 1200g (1.2 kg)

For the active ingredient ha^{-1} = 1.2 kg x active ingredient

(Alachlor 15 x 170 ml = 2550ml (2.55 l)

For the active ingredient ha^{-1} =2.55 l x active ingredient

The experimental plot was $400m^2$, thus required only 16 l of the herbicide spray.

Source: Weed Science Society of East Africa, 1987.

3.3.0 Data collection

3.3.1 Weather data

Data on daily rainfall, minimum and maximum temperature on both seasons was obtained from a nearby met station at Muguga.

3.3.2 Soil moisture determination

Soil moisture content was measured using neutron probe Didcot Wallingford from sowing at a 14 day interval for the entire season. Neutron count in water was taken prior to taking soil measurements. Ten aluminium tubes 150 cm deep were watered with water varying from 100 to 500l and mulched overnight. Neutron probe counts were taken and soil core samples taken at same depths down the soil profile up to 150 cm at intervals of 20cm. Soil moisture content was gravimetrically determined and soil bulky density determined. A graph of relative counts versus volumetric moisture content drawn and the equation of the curve taken as the calibration equation.

Soil samples were taken from each plot and moisture content in the top soil (0 to 30 cm) gravimetrically determined by oven (model number TV80 UL 508032, Memmert, Germany) drying the samples at 105°C. The dry weight of the dried sample was measured and moisture content determined using the formula;

$$WW - DW = MC \qquad \textit{Equation 3.1}$$

Where; WW- wet sample weight

DW- Dry sample weight

MC- moisture content all in grams.

3.3.3 Evapotranspiration and water use efficiency determination

$$WUE = Y / ET \qquad \textit{Equation 3.2}$$

Evapotranspiration and Water use efficiency were determined (Bolton, 1981):

Where:

WUE is water use efficiency kg ha^{-1} mm^{-1}

Y is total dry matter yield in kg ha^{-1}

ET is evapotranspiration (mm)

ET is the amount of water lost through both evaporation from the soil beneath the crop canopy and transpiration in a season expressed as;

$$ET = T + E_s \qquad \textit{Equation 3.3}$$

Where;

E_s is the evaporation from the soil beneath the crop canopy (mm)

T is transpiration (mm).

Thus from the soil water balance equation (Hillel, 1980);

$$\Delta S = P - E_s - T - D_r - R_{off} \qquad \textit{Equation 3.4}$$

$$ET = P - (\Delta S + D_r + R_{off}) \qquad \textit{Equation 3.5}$$

Where;

ΔS-change in storage water (mm),

P- is precipitation (rainfall and irrigation; mm),

Es-is soil evaporation in mm,

T- is transpiration in mm,

D_r-is drainage (mm),

R_{off}- is run off in (mm).

3.3.4 Solar radiation interception

Crop photosynthetically active radiation (PAR) interception was measured using a sunfleck ceptometer (SF-80 Decagon, Pulman, Washington) every two weeks from 42 DAE. The interception of photosynthetically active radiation (PAR) was measured between 11.30 a.m. and 1.30 p.m. (local time). The ceptometer was held perpendicular to the rows and nine PAR measurements per plot were taken 5 cm above the maize canopy 5 cm above the beans canopy and below the both maize and beans canopy. The PAR intercepted by maize was calculated by subtracting the ceptometer reading below the maize canopy (reading at 5cm above bean canopy) from the ceptometer reading 5 cm above the maize canopy. Then the % PAR was calculated using the formula,

$$\%\ PAR\ intercepted = \{(PAR_a - PAR_b) \div PAR_a\} \times 100 \qquad \text{Equation 3.6}$$

Where;

PAR_a = PAR above the canopy.

PAR_b = PAR below the canopy.

3.3.4 Beans biomass

Beans were harvested separately from each plot and threshed into the forage dry matter and the grains at 105 DAE. Fresh weight was taken and then dried to constant weight at 60°C and the dry weight taken.

3.3.6 Maize biomass

At 96 DAE, at full vegetative growth, maize was thinned by cutting at the base using a sharp panga to 1 plant hill^{-1} in all the plots. Total fresh weight of thinnings in each plot was determined. At physiological maturity, (132 DAE), maize stover was harvested and fresh weight determined. The fresh weight of the shelled maize grain was taken. Ten plants per plot of thinnings and stover were sampled. The plants were separated into the vegetative (leaves and stems) and reproductive parts (cobs and husks), and oven dried at 60°C to constant mass to determine DM content. Harvested maize per plot was shelled and separated into the grain and empty cobs and their fresh weight taken and dried at 60°C to constant mass and the dry weight taken. Harvest index (HI) (ratio of grain to the total above ground biomass) was determined. The dried thinnings and stover samples were ground for quality analysis.

The digestibility was determined using Pressure Transducer Technique (PTT). Two fistulated Friesian steers (Live weight = 386 $\pm$ 76 kg; average age = 55 $\pm$ 8 months) were used to get the rumen liquor. The animals were fed using chopped napier grass. Samples of rumen liquor were incubated in 125 ml serum flasks, which were flushed with CO_2 prior to the addition of approximately 1.0 g thinings and stover dry matter (DM). Three flasks (replicates) per substrate were used. 90 ml of reduced basal medium (Goering and Van Soest, 1970) was added to each flask, which were then sealed (Butyl rubber stopper held in place by an aluminium crimp seal) and stored at 4°C overnight.

Rumen fluid was obtained prior to the morning feeding, by hand squeezing rumen contents and transferred to the laboratory in prewarmed thermos flasks. This was then strained through two layers of muslin and held in a water bath at 39°C under CO_2 for further use. The flasks were warmed to 39°C and 10 ml of prepared rumen fluid injected through the stopper using a 1.3 mm needle and swirled to mix the contents. All the flasks were inoculated within one hour of the rumen fluid being obtained.

Gas pressure was measured by piercing the stopper using a 0.6 mm needle attached to a hand held pressure transducer. The readings (typically 14 during a 96 hour incubation period) were taken and the accumulated gas was released by venting after each reading. The contents were then mixed and the flasks returned to the incubator. Fermentation was terminated by placing the flasks at 4°C and substrate degradability estimated by filtering the fermentation residues using sintered glass crucibles (100 to 160 μm diameter) under vacuum. Residue DM content was assessed by drying at 100°C for 24 hours and organic matter by difference following ashing (6 hours at 500°C). Calibration of the pressure versus the volume of the gas was also done and a curve determined whereby the pressure–volume relationship equation was determined this equation was used to determine the volumes of the gas produced using the pressure readings. The crude protein was determined using Kjeldahl technique (Anderson and Ingram, 1989).

3.3.7 Weed species composition, dry matter establishment and timing of weeding and cost

Weed species identification and quantification (fresh and oven dry mass) was done at 14 and 42 DAE using quadrants (0.5 m x 0.5 m) in triplicates per plot. At the end of the season the available weeds in the experimental area was harvested and were sorted into edible and non-edible (to livestock) and their fresh weight taken. The three major edible weed species were sorted out and a sample of 500 g of each species drawn and then dried at 60°C to constant mass. The dried weed samples were ground for crude protein analysis and digestibility determination using Pressure Transducer Technique (PTT) described above.

Timing (in minutes) of the weeding for each plot (16 m^2) was done and converted to mandays (1 manday = 8 hours). The labour cost was shs 158 per manday. The cost of herbicides weed control was Kshs 5,000; (Kshs 1,750 (Alchlor)+ Linuron (Kshs 2500) + Kshs 750 for labour). The cost of the Knapsack and the hoes were not included.

3.3.8 Plant height

Plant height of the maize crop was measured repeatedly at a two week interval from 42 DAE till the end of the season. The height of maize from the base of the maize to the tip of the last leaf was taken using meter rule. The heights of nine randomly selected plants per plot were taken and the mean determined.

3.3.9 Rate of tasseling

Tassels in each plot were counted at intervals of four days from anthesis to until 100 % tasseling. The tasseling percentage at each time was calculated using the following formula;

$$\% \, Tasseling = (T_n / P_t) \times 100 \qquad \text{Equation 3.7}$$

Where,

T_n = number of tasseled plants.

P_t= total number of plants per plot.

3.4 Data analysis

Analysis of variance was done using GENSTAT (Genstat 5 Release3.2 Lewis Agricultural Trust. Rothamsted Experimental Station, 1995). Significantly different means ($P \leq 0.05$) were separated using LSD test and are presented in chapter four.

CHAPTER 4

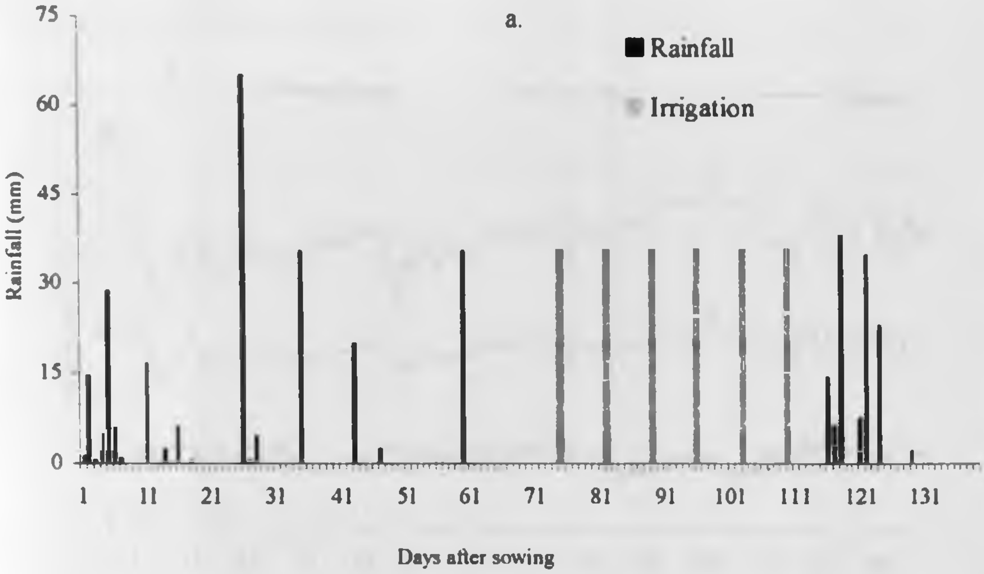
RESULTS

4.0 Weather conditions

The first season experiment was planted on 8th of November 2001 and was irrigated in December (two times), January (four times) and February (two times), 35.3 mm per irrigation. Rainfall availability was low in both seasons (thus in season one was supplemented with irrigation). The months of December, January and February got rainfall of 22.1 mm, 0 mm and 22.4 mm respectively and irrigation water of 71 mm, 141 mm and 71 mm respectively.

The second experiment was planted on 20th of May 2002 and was not irrigated. The total rainfall in the first season was 298 mm and irrigation was 283 mm thus totaling to 581 mm while in the second season was 201 mm (Figure 2). The average 10 year rainfall for first season (short rains) was 476 mm while for second season (long rains) was 414 mm respectively indicating that 63 % and 48 % of the average rainfall was received in the first and the second season respectively.

The mean minimum daily temperature for season one was 6°C and season two was 4°C while mean maximum daily temperature for season one was 23°C and season two was 20°C. The mean temperatures for season one and two was 14°C and 12°C respectively (Figure 3).



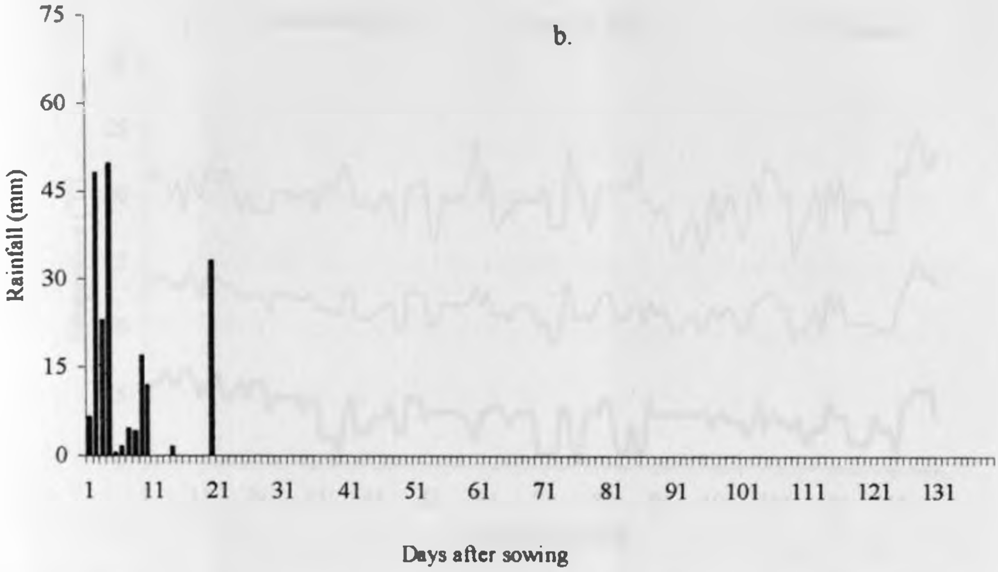


Figure 2. Seasonal daily rainfall (mm) in season one (a) and two (b) respectively where in figure (a) black shaded bars indicate rainfall and dotted bars indicate irrigation water.

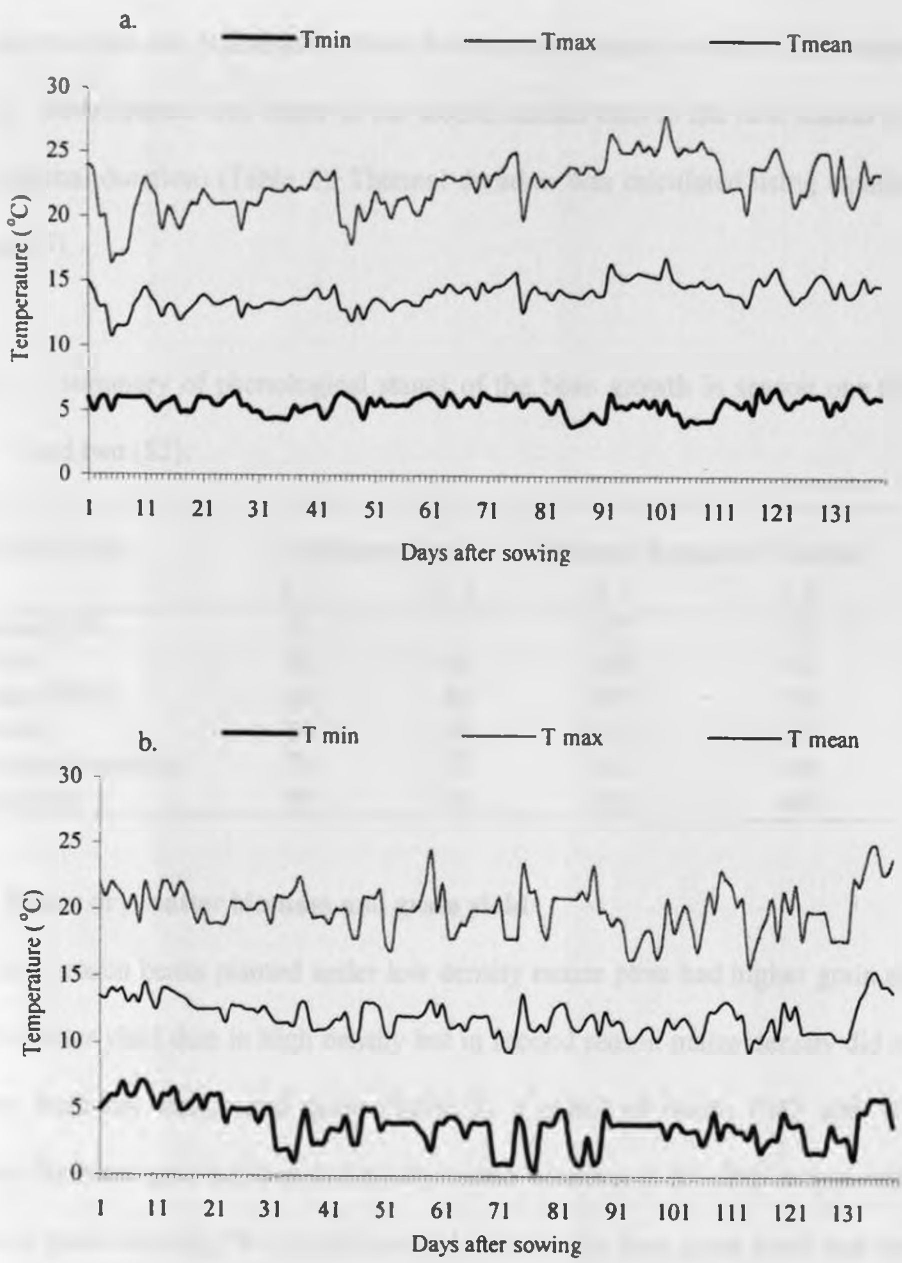


Figure 3. Seasonal daily mean temperatures in °C in season 1 (a) and two (b) respectively.

4.1 Bean phenological development

There was no clear cut difference in bean development stages in days in the seasons (Table 2). Development was faster in the second season than in the first season (i.e. shorter thermal duration) (Table 2). Thermal duration was calculated using equation 2.1 (page 15).

Table 2. A summary of phenological stages of the bean growth in season one (S1) and two (S2).

Phenological stage	Duration (days)		Thermal duration (^{o}C days)	
	S 1	S 2	S 1	S 2
Emergence 50%	8	7	37	37
Vegetative	38	41	195	192
Flowering (50%)	45	47	237	213
Pod growth	61	58	315	257
Physiological maturity	75	73	413	309
Dead maturity	95	99	536	400

4.1.1 Beans dry matter biomass and grain yield

In the first season beans planted under low density maize plots had higher grain and total dry matter yield than in high density but in second season maize density did not influence bean dry matter and grain (Table 3). Control of weeds (W3 and W4) increased the bean grain yield and total dry matter biomass in the first season while only twice hand weeding (W4) significantly increased the bean grain yield and total dry matter biomass in the second season (Table 4). In the first season both W3 and W4 methods of weed control had same beans grain yields, while in the second season use of herbicide reduced the bean grain yield and total dry matter biomass relative to twice hand weeding (W4). Treatment interactions were not significant on bean dry matter and grain yields in both seasons (Appendix 2).

Table 3. The effect of planting density on bean biomass and grain yield (kg ha^{-1}).

Planting density	Season one		Season two	
	Total dry matter	Grain	Total dry matter	Grain
D1	130	74	103	77
D2	100	48	114	82
F value	0.041	<.001	0.265	0.572
LSD_D	29	20	20	17

Table 4. The effect of weeding regimes on bean biomass and grain yield (kg ha^{-1}).

Weeding regime	Season one		Season two	
	Total dry matter	Grain	Total dry matter	Grain
W1	124	71	121	83
W2	15	1	85	61
W3	174	92	84	61
W4	146	81	144	112
F value	<.001	<.001	<.001	<.001
LSD_W	41	42	28	24

4.2 Maize phenological development

The reproductive stages were shorter in season two (days and ° C days) because of water stress (Table 5).

Table 5. A summary of phenological stages of maize growth in season one and two.

Phenological stage	Duration (days)		Thermal duration (°C days)	
	S 1	S 2	S 1	S 2
Emergence	8	8	21	28
Vegetative	49	49	158	125
Tasseling (50 %)	78	71	249	163
Grain filling	99	92	349	197
Physiological maturity	120	112	452	227
Dead maturity	132	126	510	245

4.2.1 Rate of tasseling

The rate of tasseling was high in the low density treatments (D1) in both seasons. Weeding regime significantly influenced tasseling (Appendix 3). Failure to control weeds (W2) significantly reduced the tasseling rate but method of weed control (W1, W3 and W4). did not did not influence rate of tasseling at 50 % tasseling stage in both seasons (Figure 4). There was no significant interaction between density and weeding regime on the rate of tasseling (Figure 4).

4.2.2 Maize height

Weeding regime and planting density significantly influenced the plant height (Appendix 4). Weeds reduced maize height in both seasons (Figure 5). High planting density reduced plant height only at 105 DAE and 120 DAE in season one. In season two, high planting density only reduced plant height at 56 DAE and 77 DAE (Figure 5). There was no significant interaction between density and weeding regime on height (Appendix 4).

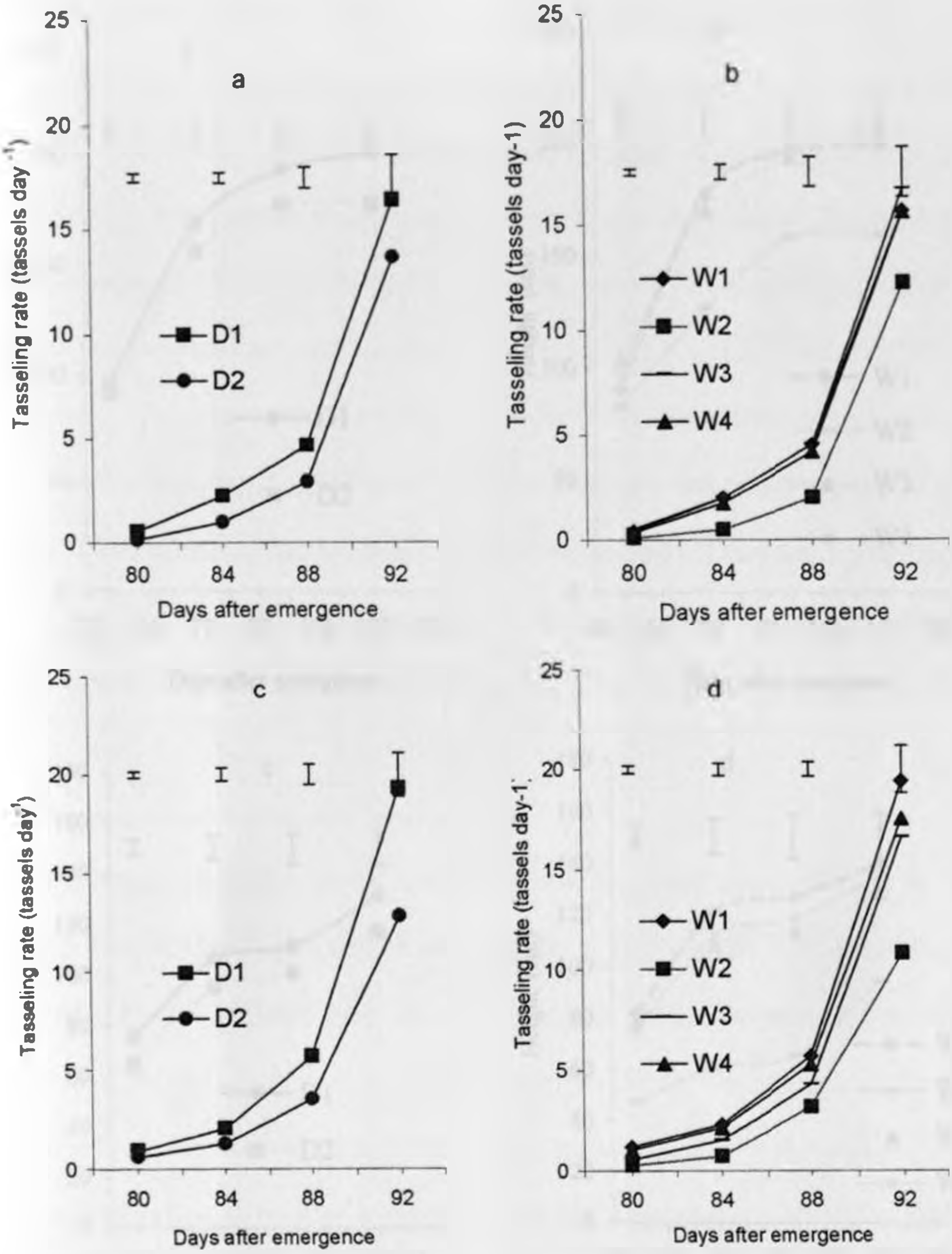


Figure 4. Effect of planting density and weeding regime on rate of tasseling over time in season one (a and b) and two (c and d) where; D1 – low density, D2 – high density, W1 – weed free. W2 – weedy regime. W3 – herbicide use, W4 – two times hand weeding. LSD bars indicated.

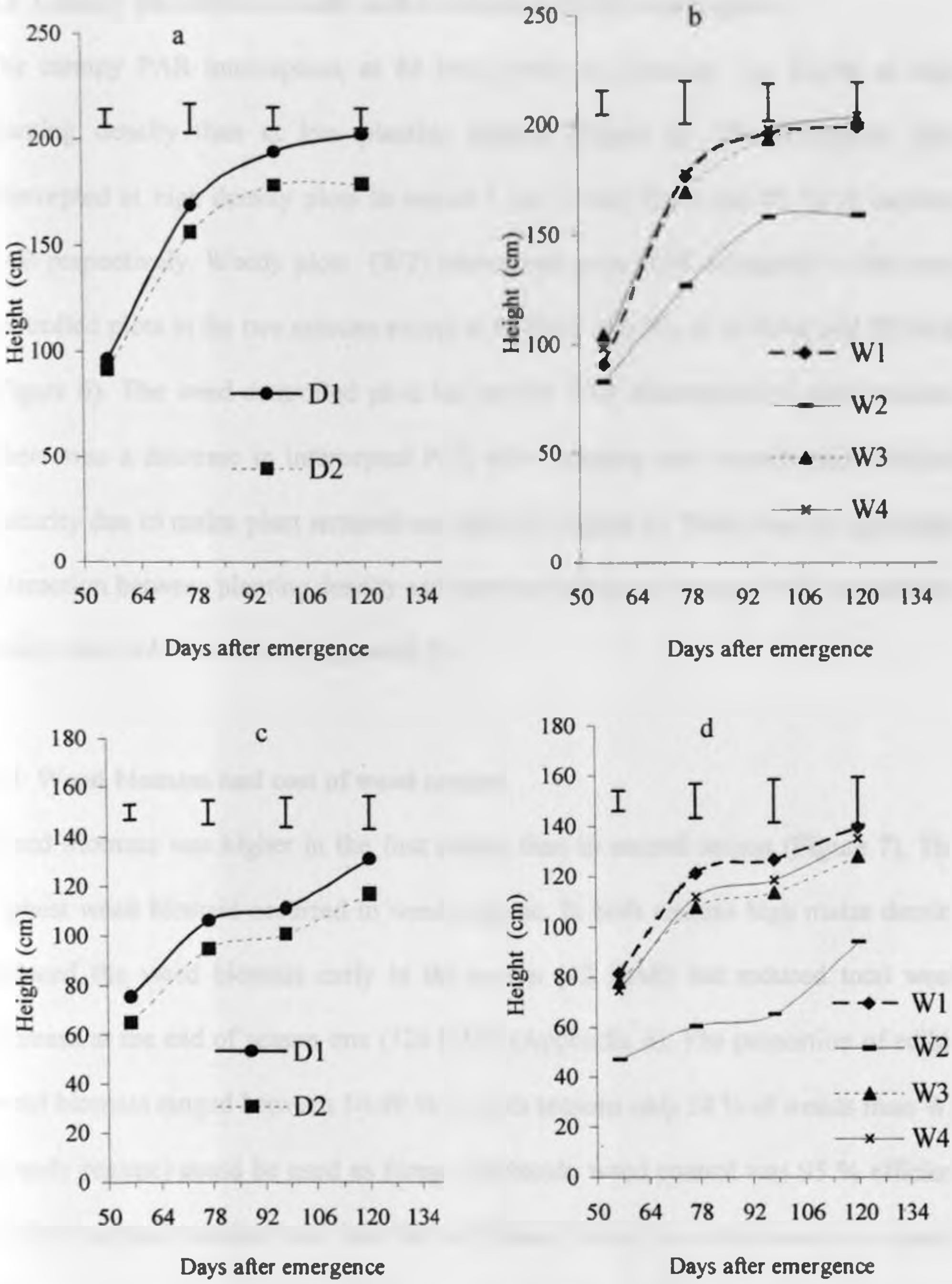


Figure 5. The effect of planting density and weeding regime on maize height in cm over season one (a and b) and two (c and d) where; D1 – low density, D2 – high density, W1 – weed free, W2 – weedy regime, W3 – herbicide use, W4 – two times hand weeding. LSD bars indicated.

4.3 Canopy photosynthetically active radiation (PAR) interception

The canopy PAR interception, at 84 DAE (prior to thinning) was higher at high planting density than at low planting density (Figure 6). The maximum light intercepted at high density plots in season 1 and 2 was 95 % and 82 % of incident PAR respectively. Weedy plots (W2) intercepted more PAR compared to the weed controlled plots in the two seasons except at 42 DAE and W1 at 56 DAE and 70 DAE (Figure 6). The weed controlled plots had similar PAR interception in both seasons. There was a decrease in intercepted PAR after thinning and towards physiological maturity due to maize plant removal and leaf fall (Figure 6). There was no significant interaction between planting density and weeding regime on canopy PAR interception at any time in both seasons (Appendix 5).

4.4 Weed biomass and cost of weed control

Weed biomass was higher in the first season than in second season (Figure 7). The highest weed biomass occurred in weedy regime. In both seasons high maize density reduced the weed biomass early in the season (42 DAE) but reduced total weed biomass at the end of season one (126 DAE) (Appendix 6). The proportion of edible weed biomass ranged between 50-90 %. In both seasons only 58 % of weeds from W2 (weedy regime) could be used as forage. Herbicide weed control was 95 % efficient while two hand weeding was over 80 % efficient. Failure to control weeds increased the weed biomass, while herbicide use controlled weeds better than twice hand weeding.

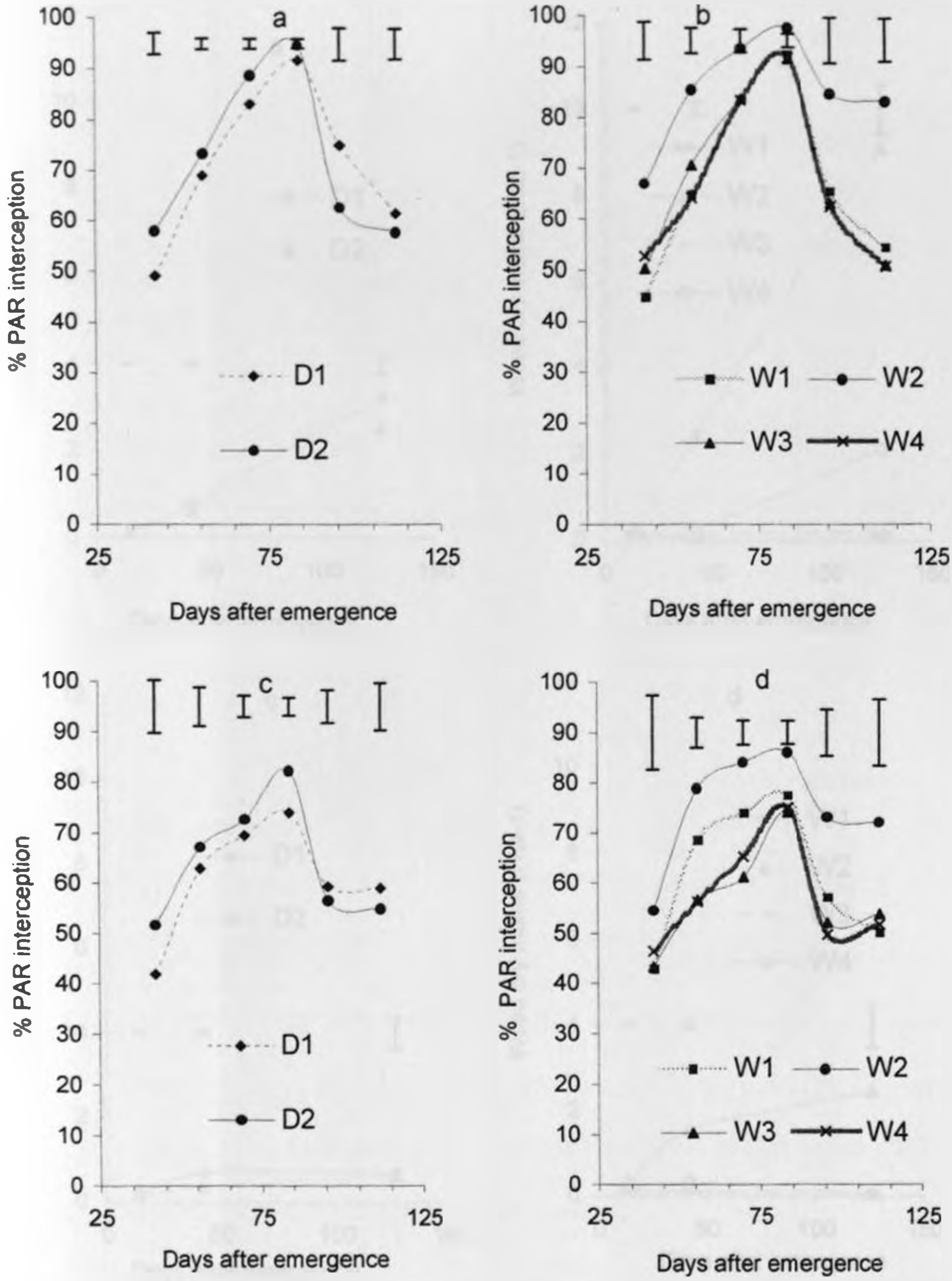


Figure 6. The effect of planting density and weeding regime on % PAR interception over time in season one (a and b) and two (c and d) where; D1 – low density, D2 – high density, W1 – weedfree, W2 – weedy regime, W3 – herbicide use, W4 – two times hand weeding. LSD bars indicated.

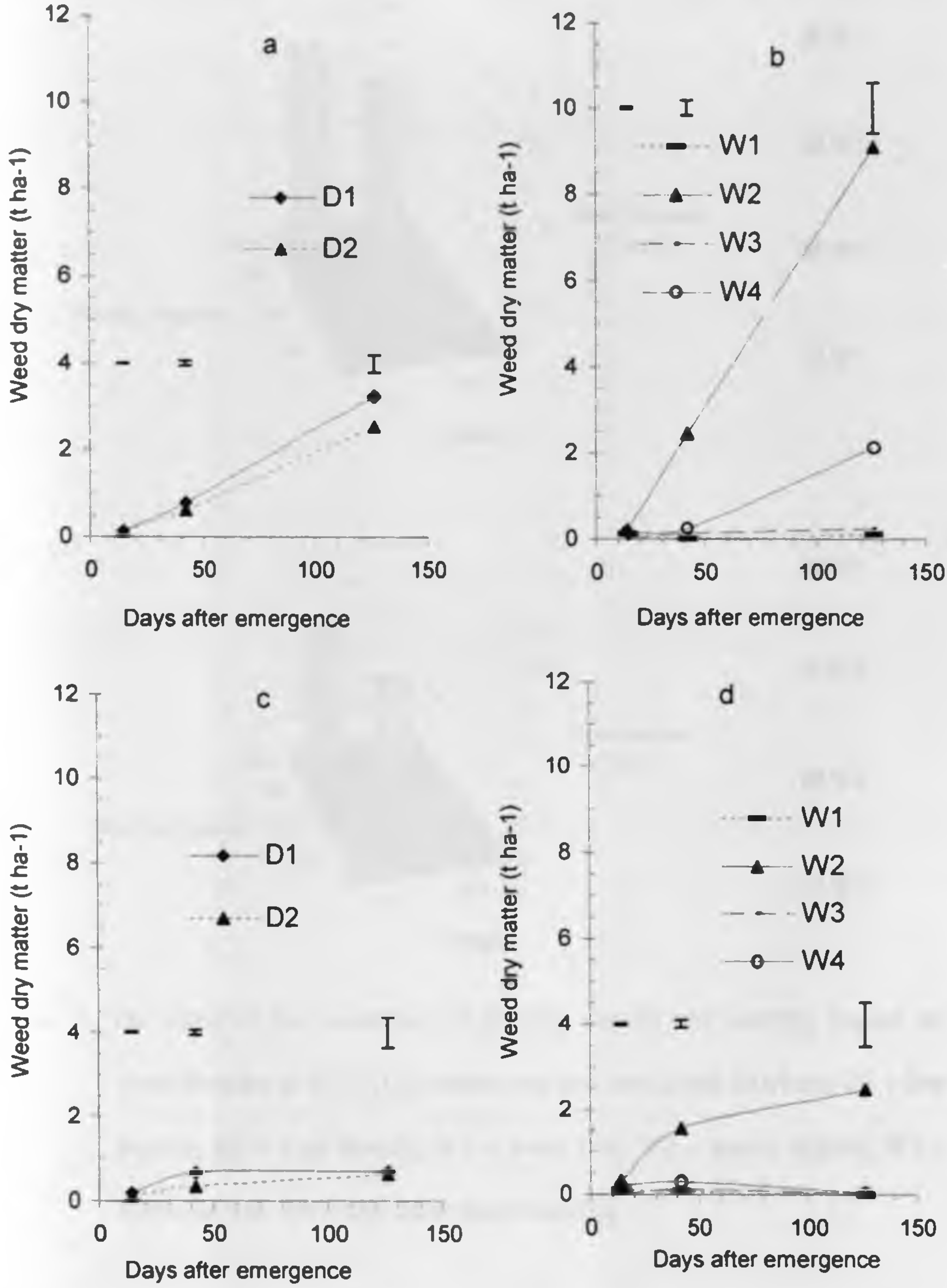


Figure 7. The effect of planting density and weeding regime on weed biomass in t ha^{-1} in season one (a and b) and two (c and d) where: D1 – low density, D2 – high density, W1 – weed free, W2 – weedy regime, W3 – herbicide use, W4 – two times hand weeding. LSD bars indicated.

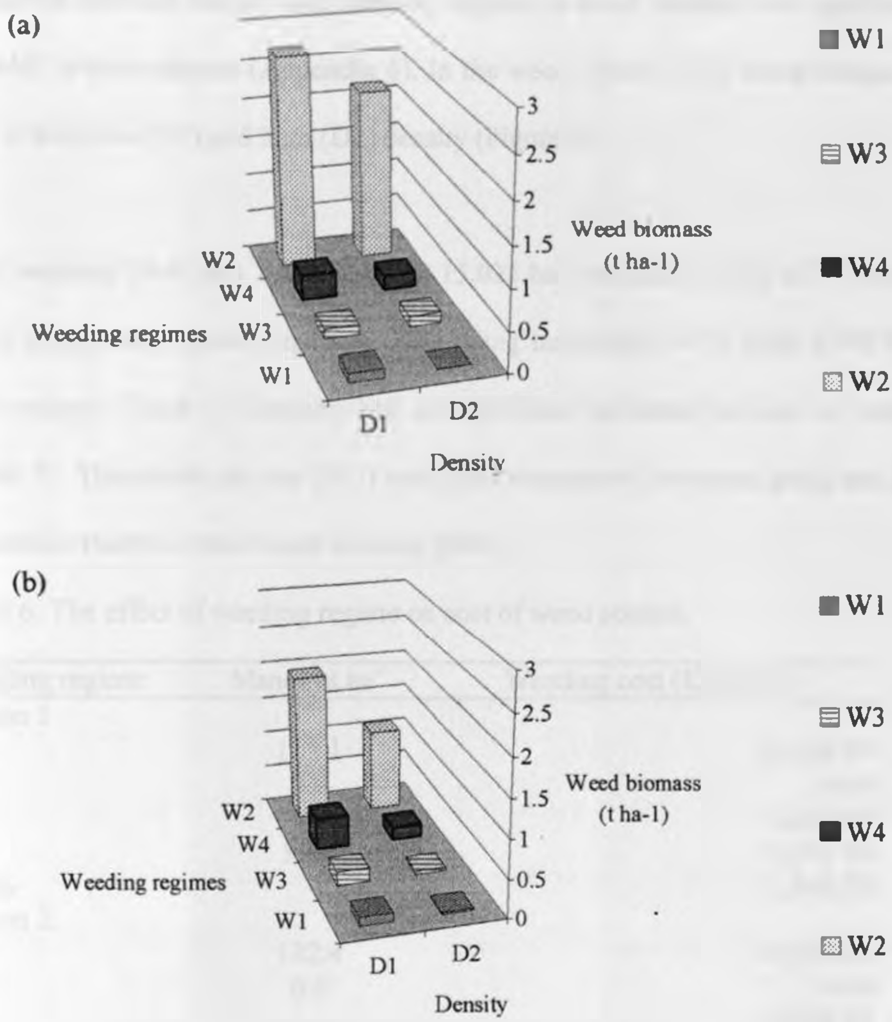


Figure 8. The effect of the interaction of planting density and weeding regime on weed biomass at 42 DAE in season one and two (a and b) where; D1 – low density, D2 – high density, W1 – weed free, W2 – weedy regime, W3 – herbicide use, W4 – two times hand weeding.

Interaction between density and weeding regime on weed biomass was significant at 42 DAE in both seasons (Appendix 6). In the weedy plots (W2), weed biomass was high in both low (D1) and high (D2) density (Figure 8).

Hand weeding (W4) was 2-3 times (Ksh 15,025 ha^{-1} and Ksh 11,621 ha^{-1} in season 1 and 2 respectively) more expensive than using herbicides (W3) (Ksh 5,000 ha^{-1} in each season) (Table 6). Density had no significant influence on cost of weeding) (Table 7). Thus herbicide use (W3) was more economical in maize grain and forage production than two times hand weeding (W4).

Table 6. The effect of weeding regime on cost of weed control.

Weeding regime	Mandays ha^{-1}	Weeding cost (Ksh ha^{-1})
Season 1		
W1	115.1	18,188.00
W2	0.0	0.00
W3	-	5,000.00
W4	95.0	15,015.00
LSD_W	-	1,840.50
Season 2		
W1	132.4	20,923.00
W2	0.0	0.00
W3	-	5,000.00
W4	73.6	11,621.00
LSD_W	-	1,113.80

Table 7. The effect of planting density on cost of weed control.

Planting density	Mandays ha^{-1}	Weeding cost (Ksh ha^{-1})
D1	62	9,796.00
D2	65	10,270.00
LSD_D	-	1,301.40
Season 2		
D1	66	10,428.00
D2	62	9,796.00
LSD_D	-	786.60

The weeding labour efficiency in maize grain production was higher in low (D1) than high (D2) density but in production of thinnings it was lower in low (D2) than in high (D2) density) (Table 8). However weeding labour efficiency was not affected by density in production of stover, forage (stover + thinnings) and total biomass (forage + grain) (Table 8); Appendix 7). In the production of grain, thinnings, forage and total biomass (forage + grain) weeding labour efficiency was high on use of herbicides (W3) than use of two times hand weeding (W4) (Table 9; Appendix 7).

Percent loss of maize grain and total biomass due to weeds was 54 %, 39 % and 97 %, 78 % in the in the first and second season respectively as a result of uncontrolled weeds (Appendix 8).

Table 8. The effect of planting density on weeding labour efficiency on grain and forage production in kilograms per shilling used in weeding.

Planting density	Forage ($kg\ sh^{-1}$)	Grain ($kg\ sh^{-1}$)	Stover ($kg\ sh^{-1}$)	Thinnings ($kg\ sh^{-1}$)	Total biomass (forage +grains ($kg\ sh^{-1}$)
Season 1					
D1	2.5	0.4	1.7	0.8	2.9
D2	2.3	0.2	0.9	1.4	2.5
LSD_D	0.5	0.1	0.4	0.3	0.5
Season 2					
D1	1.0	0.1	0.7	0.4	1.1
D2	1.4	0.1	0.6	0.8	1.5
LSD_D	0.3	0.0	0.2	0.1	0.3

Table 9. The effect of weeding regime on weeding labour efficiency on grain and forage production in kilograms per shilling used in weeding.

Weeding regime	Forage ($kg\ sh^{-1}$)	Grain ($kg\ sh^{-1}$)	Stover ($kg\ sh^{-1}$)	Thinnings ($kg\ sh^{-1}$)	Total biomass (forage +grains ($kg\ sh^{-1}$)
Season 1					
W1	1.7	0.2	0.9	0.7	1.9
W2	0.0	0.0	0.0	0.0	0.0
W3	5.9	0.6	3.1	2.8	6.5
W4	2.2	0.3	1.3	0.9	2.5
LSD_W	0.7	0.1	0.5	0.5	0.7
Season 2					
W1	0.7	0.0	0.4	0.4	0.8
W2	0.0	0.0	0.0	0.0	0.0
W3	2.8	0.1	1.5	1.3	2.9
W4	1.3	0.1	0.7	0.6	1.4
LSD_W	0.5	0.0	0.3	0.2	0.5

4.5 Soil moisture

Soil neutron probe calibration upto 130 cm down the profile was done. Neutron relative count was linearly related to volumetric moisture content in the entire profile (Figure 9). Moisture content increased down the profile probably because water increased down the profile as well as H^{+} from other sources such as clay.

Volumetric soil water content was determined at 21, 49, 77, 105 and 132 DAE. Weeding regime caused significance difference of moisture content in both seasons but density only significantly influenced moisture content in the second season (Appendix 9). During the second season soil moisture was higher in D1 (low density) than in D2 (high density). Weedy regime (W2) had lower moisture content than the other weeding methods (W3 and W4), which had similar water content at all depths.

There was no significant difference of moisture content in W1 (weed free) and W2 (weedy regime)(Figure 9). In both treatments there was a progressive depletion of soil water through out the growing season down the soil profile (up to 130 cm depth) (Figure 10). Soil profile moisture changes in the first seasons were similar in both densities but in season 2, D1 had less moisture loss than D2 (Figure 10).

4.6 Maize biomass and yield

4.6.1 Maize forage and grain yields

High planting density (D2) increased thinnings but decreased grain yield in both seasons. Stover dry matter was low at high planting density in season one but was similar compared to that of D1 (low density) in season two (Figure 12). High density increased fodder (thinnings + stover) in season two but not in season one. Weed control (W1, W3, W4) increased thinnings, stover yield, grain yield and also the total forage in both seasons but failure to control weed (W2) decreased the yields. Hand weeding (W4), increased grain yield compared to herbicide use (W3) (Figure 12).

The treatment interaction (planting density x weeding regime) on thinnings, stover dry matter, grain yields and total forage was not significant in the first season while in second season interaction was only significant at thinnings quantity (Appendix 12).

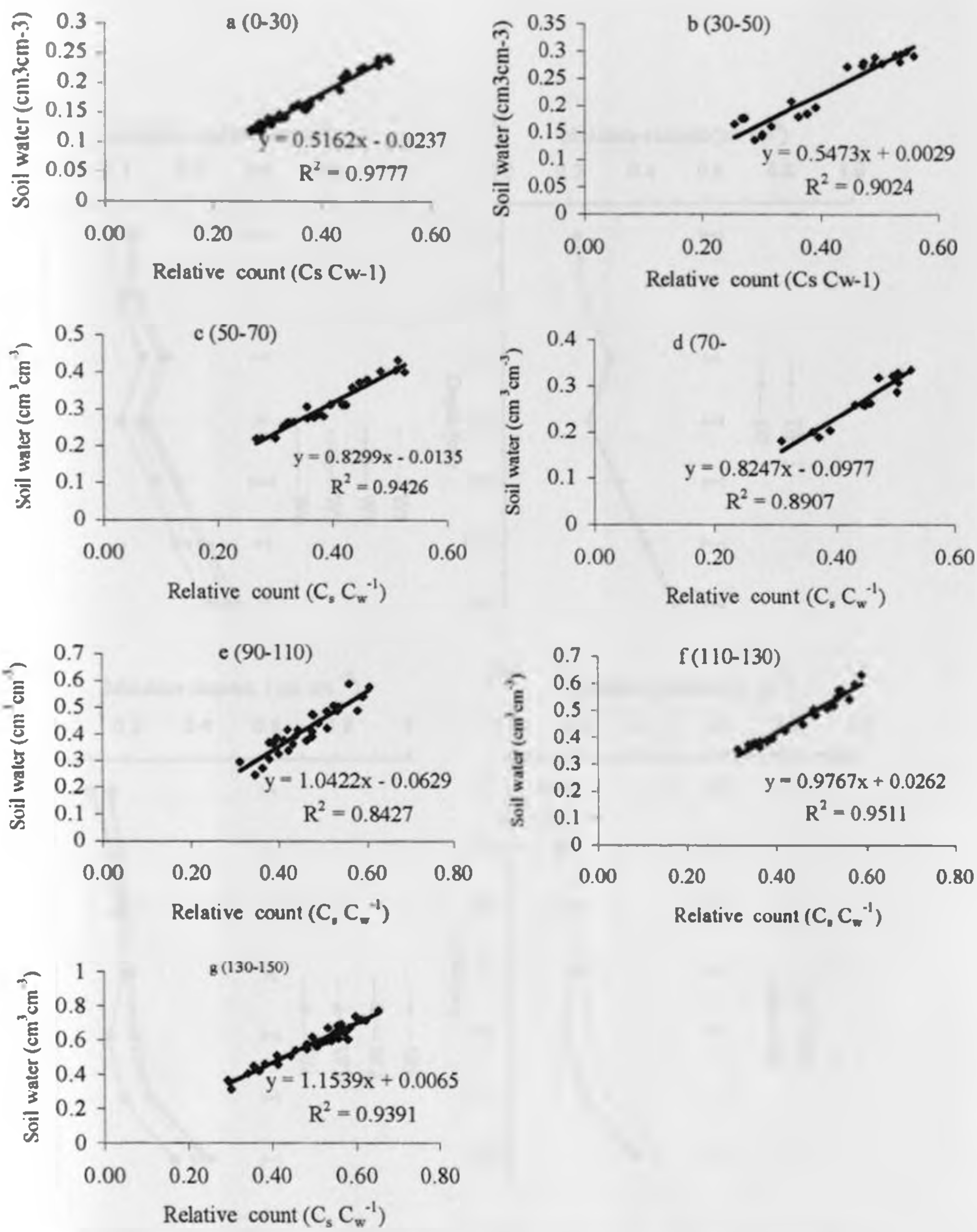


Figure 9. The neutron probe counts (counts sec^{-1}) calibration at the experimental site Muguga, where; C_s is probe count in soil, C_w is probe count in water and R^2 is regression coefficient.

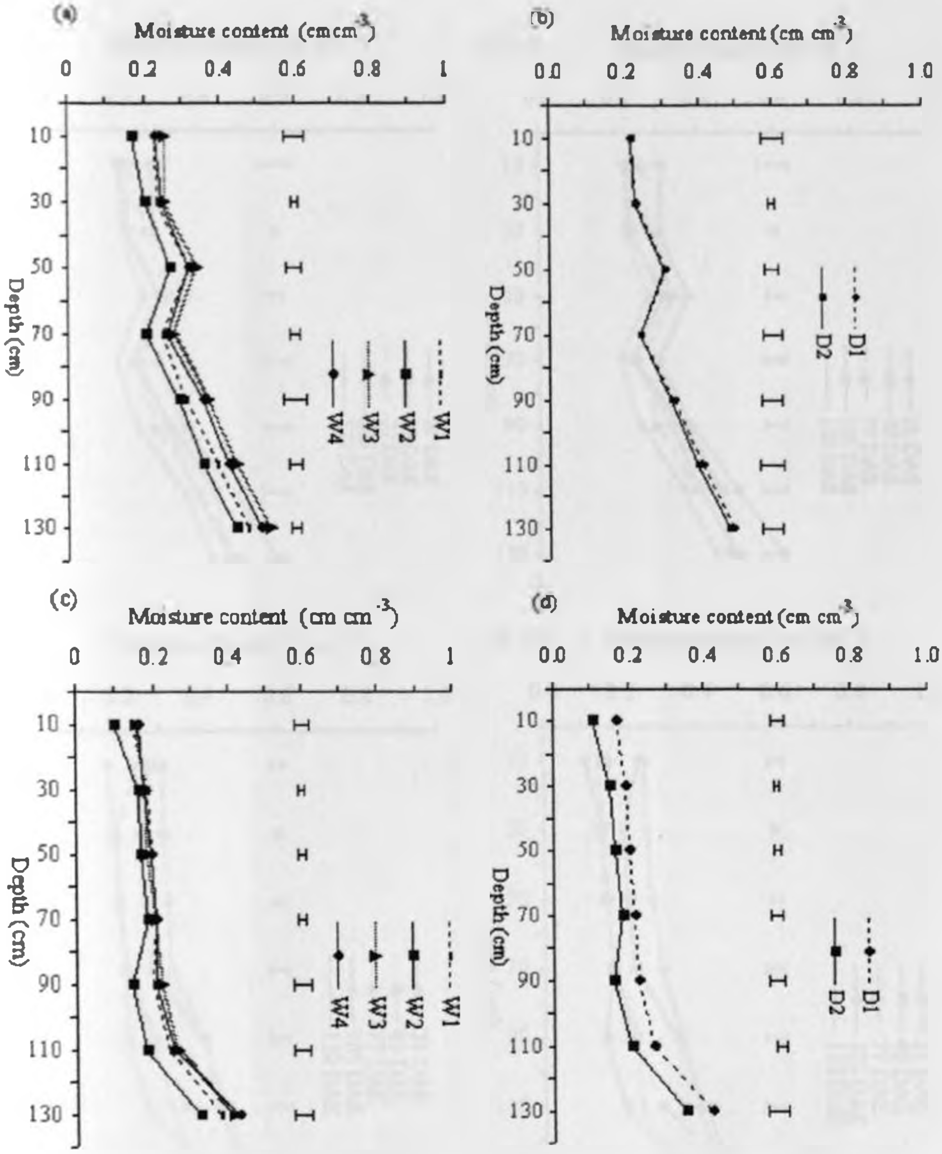


Figure 10. The effect of planting density and weeding regime on soil moisture content at 105 DAE ($cm^3\ cm^{-3}$) during season one (a and b) and two (c and d) where; D1 – low density, D2 – high density, W1 – weedfree, W2 – weedy W3 – herbicide use, W4 – two times hand weeding

LSD bars indicated

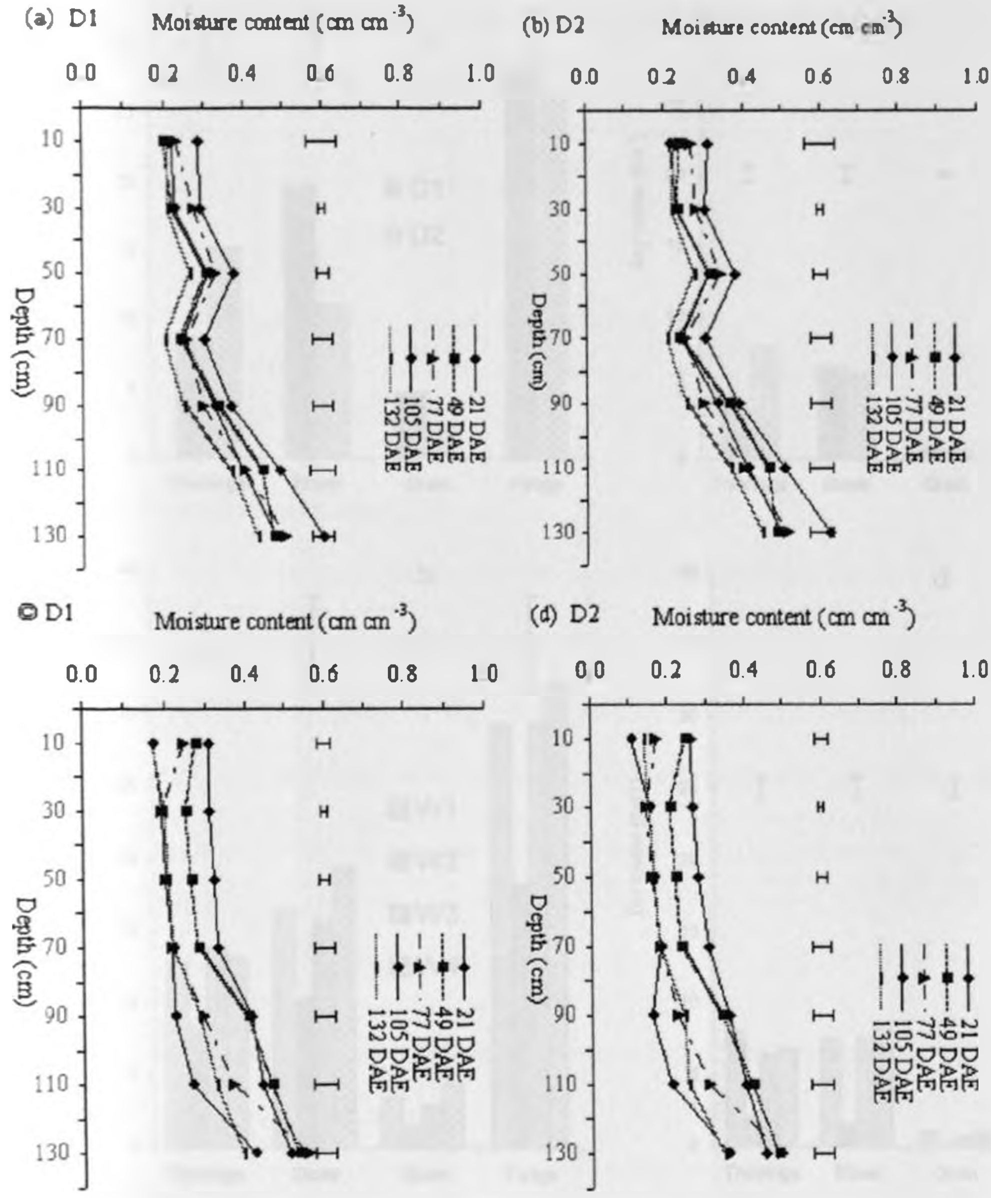


Figure 11. The effect of density on moisture content in the profile over time during season one (a - D1 and b - D2) and two (c - D1 and d - D2) where, D1 - low density, D2 high density. LSD bars indicated.

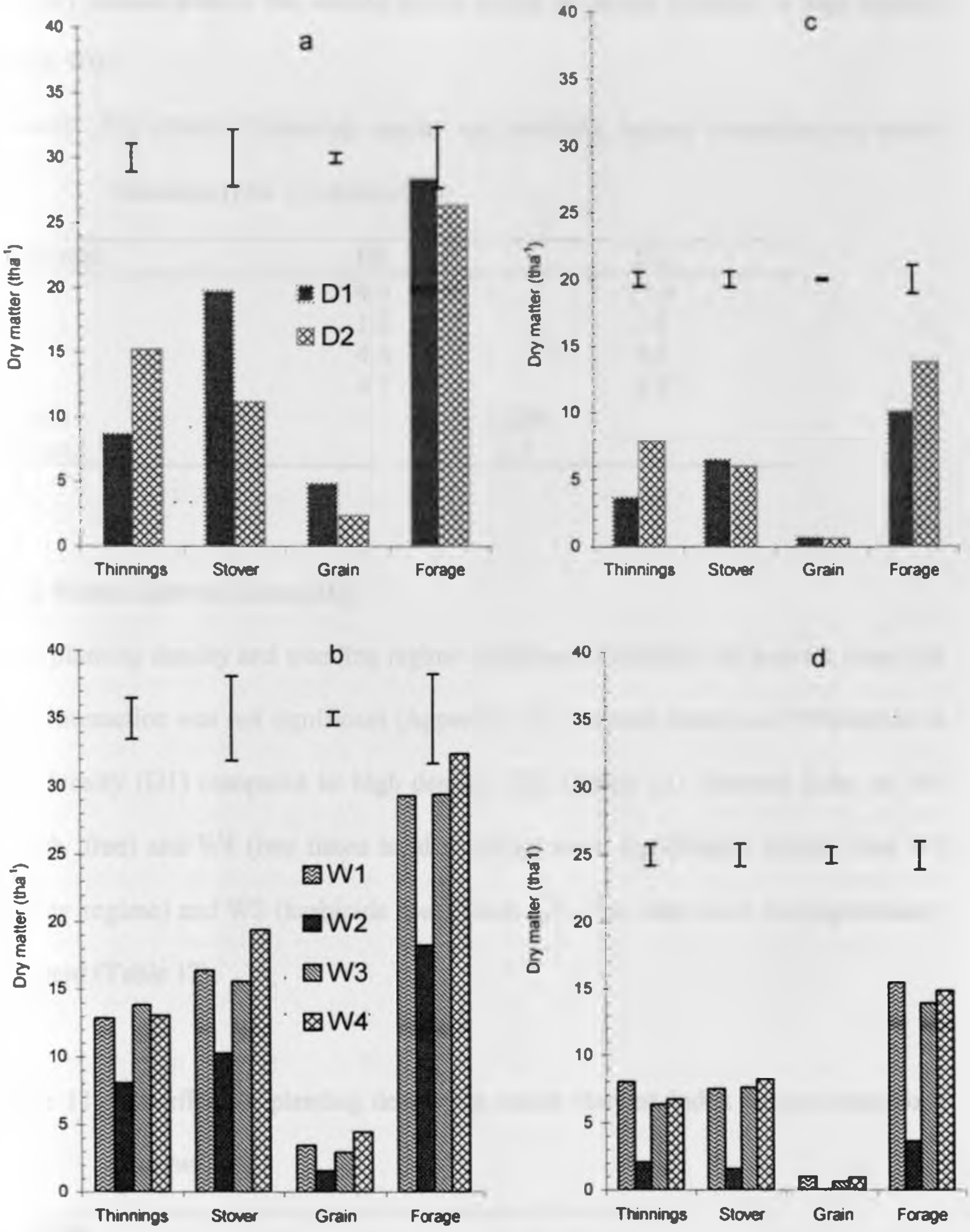


Figure 12. The effect of planting density and weeding regime on maize forage and grain yields in tha^{-1}, in season one (a and b) and two (c and d) where; D1 – low density, D2 – high density, W1 – weedfree, W2 – weedy regime, W3 – herbicide use, W4 – two times hand weeding. LSD bars indicated.

In a dry season even a few weeds would reduce thinnings biomass at high density (Table 10).

Table10. The effect of planting density and weeding regime interaction on maize thinnings (t ha^{-1}) in season two.

Treatment	D1		D2
W1	4.6		11.4
W2	1.2		2.9
W3	4.3		8.4
W4	4.7		8.7
F value		0.028	
LSD_{W*D}		2.2	

4.6.2 Maize Harvest Index (HI)

Both planting density and weeding regime significantly affected the harvest index but their interaction was not significant (Appendix 10). Harvest Index was 57% higher in low density (D1) compared to high density (D2) (Table 11). Harvest index in W1 (weedy free) and W4 (two times hand weeding) were significantly higher than W2 (weedy regime) and W3 (herbicide use) (Table 12). The latter were not significantly different (Table 12).

Table 11. The effect of planting density on maize Harvest Index during season one and two.

Planting density	Season 1	Season 2
D1	0.14	0.16
D2	0.08	0.09
LSD_D	0.02	0.03

Table 12. The effect of weeding regime on maize Harvest Index during season one and two.

Weeding Regime	Season 1	Season 2
W1	0.12	0.14
W2	0.08	0.09
W3	0.10	0.12
W4	0.13	0.15
LSD_W	0.03	0.04

4.6.3 Evapotranspiration (ET) and Water Use Efficiency (WUE)

During the first season weedy regime (W2) had lower ET crop while the two methods of weed control W3 and W4 had similar ET crop. However in the second season weeding regime did not significantly influence cumulative ET crop (Appendix 11). In both seasons density did not influence cumulative ET . Density and weeding influenced WUE in both seasons (Appendix 11). Low density (D1) increased water use efficiency in grain (maize and beans, WUE_G) in both seasons but increased total biomass; grain (maize and beans) + forage (maize and beans) (WUE_T) only in the second season (Table 13). Weedy regime reduced WUE in grains and total biomass in both seasons but W1, W3 and W4 were similar during season one while in second season W1 and W4 were similar but W3 was lower than W4 (Table 14).

Table 13. The effect of planting density on Cumulative Evapo-transpiration and water use efficiency on maize grain (WUE_G) and total biomass (WUE_T) in kg ha^{-1}.

Planting density	Cum. ET (mm)	WUE_T (kg ha^{-1} mm^{-1})	WUE_G (kg ha^{-1} mm^{-1})
Season 1			
D1	623	47.1	6.0
D2	610	41.6	2.9
LSD_D	29.93	7.55	1.04
Season 2			
D1	362	27	1.8
D2	349	37.1	1.5
LSD_D	18.04	5.88	0.29

Table 14. The effect of weeding regime on Cumulative Evapo-transpiration and water use efficiency on maize grain (WUE_G) and total biomass (WUE_T) in kg ha^{-1}.

Weeding regime	Cum. ET (mm)	WUE_T (kg ha^{-1} mm^{-1})	WUE_G (kg ha^{-1} mm^{-1})
Season 1			
W1	611	48.5	5.0
W2	578	31.1	2.5
W3	638	45.9	4.1
W4	640	51.8	6.2
LSD_W	42.33	10.68	1.47
Season 2			
W1	366	40.6	2.4
W2	347	9.6	0.1
W3	356	37.6	1.7
W4	353	40.4	2.4
LSD_W	25.51	8.32	0.41

4.7 Forage quality analysis

4.7.1 Weeds

In the first season composite samples of maize forage were analysed while in the second season experiment samples from each plot were analysed and an ANOVA done (appendix 13). Some of the weeds that appeared in the first season (*Amaranthus spp*, *Emex australis*, *Erlangea cordifolia*, *Galinsoga parviflora*, Bidens *pilosa*, and Leonotis *mollissima*) were absent in the second season (Table 15).

DM digestibility of the edible weeds during the first and second season experiment was 65 % and 64 % respectively but the crude protein 19.2 % and 8.2 % in the first and the second season respectively. *Amaranthus spp* had the lowest crude protein and also was the least digestible. In the second experiment *Erucastrum arabicum* had the least crude protein and least digestible (44 %). On the other hand couch grass (*Digitaria abyssinica*) had the highest digestibility (74) and crude protein content of 16.9 %. In the second season, *Commellina bengalensis* had the highest digestibility (73.5%) and crude protein content of 6.8 %. Thus digestibility increased with increase of % crude protein to a point and then started decreasing (Table 15)

4.7.2 Maize

Maize forage DMD and CP were high in the thinnings (98 DAE) and low in the stover (132 DAE). Planting density did not influence the dry matter digestibility of maize forage on the leaves and stems of thinnings and stover significantly (Table 16).

Table 15. Percent dry matter digestibility (DMD) and % crude protein (CP) composition of edible weeds at 126 DAE.

Weed type	Season one		Season two	
	DMD (%)	CP (%)	DMD (%)	CP (%)
Amaranthus spp	52	8.5	-	-
Emex australis	55	27.9	-	-
Erlangea cordifolia,	65	16.4	-	-
Galinsoga parviflora	64	19.7	-	-
Ageratum conyzoides	66	17.7	68.5	12.3
Erucastrum arabicum	66	32.1	44.4	5.3
Comellina bengalensis	68	13.0	73.5	6.8
Bidens pilosa	68	16.5	-	-
Sonchus oleraceus	73	27.1	72.5	8.5
Leonotis mollissima	68	22.7	-	-
Digitaria abyssinica (couch grass)	74	16.9	61.6	8.2
Mean	65	19.2	64	8.2

However stover components had lower digestibility (DMD) and CP than thinnings counter parts in both seasons (Appendix 13, Table 16 and 17). Weeding regime significantly influenced digestibility (DMD) of the stems and leaves of stover and thinnings (Appendix 13). The weedy regime increased digestibility (DMD) but increased crude protein (% CP) only on stover during first season compared to weed controlled treatments (W3, W4 and W1), which had similar crude protein and digestibility on all the components (Table 17).

Table 16. The effect of planting density on percent dry matter digestibility (% DMD) and percent crude protein (% CP) of maize forage components.

Forage	Season one				Season two			
	% DMD		% CP		% DMD		% CP	
	D1	D2	D1	D2	D1	D2	D1	D2
Stover leaves	59	61	5	4	53	53	4	4
Stover stems	63	66	3	4	71	72	4	4
Stover mean	61	64	4	4	62	63	4	4
Thinnings leaves	76	76	9	7	72	72	8	8
Thinnings stems	77	77	6	6	79	78	7	7
Thinning mean	77	77	8	7	76	75	7	7

Table 17. The effect of weeding regime on percent dry matter digestibility (% DMD) and percent crude protein (% CP) of maize forage components.

Forage	% DMD				(% CP)			
Season one	W1	W2	W3	W4	W1	W2	W3	W4
Stover stems	67	67	62	62	4	4	3	3
Stover leaves	59	63	59	60	5	6	4	4
Stover mean	63	65	61	61	4	5	4	3
Thinning stems	76	77	76	76	6	6	6	6
Thinning leaves	76	78	75	75	10	8	8	7
Thinning mean	76	78	76	76	8	7	7	7
Season two								
Stover stems	70	77	69	69	4	4	4	4
Stover leaves	54	63	55	53	4	4	4	4
Stover mean	62	70	62	61	4	4	4	4
Thinning stems	77	82	78	77	6	8	6	7
Thinning leaves	70	76	71	70	8	6	8	8
Thinning mean	73	79	74	73	7	7	7	8

4.7.3 Forage quantity: Maize and weeds

Maize density did not influence the quantity of CP on weeds and forage however low density decreased CP in thinnings but increased in stover during season one. However in season two high density increased CP on total forage and thinnings but did not influence CP on weeds and stover (Appendix 14; Table 18). Weedy regime reduced

CP in stover thinnings and total forage but increased CP in edible weeds. Weed controlled treatments (W3, W4 and W1) had same CP in both seasons (Table 19). Density did not influence the quantity of DMD on forage however low density decreased DMD in thinnings but increased in stover during season one. In season two high density increased DMD on total forage thinnings but did not influence DMD on stover. Weedy regime reduced DMD in stover, thinnings and total forage but increased DMD in edible weeds (Table 19). The rest of the regimes had same DMD in both seasons (Appendix 14). Density did not influence the quantity of DMD on weeds (Appendix 14). Weedy regime increased DMD in edible weeds (Table 19).

Table 18. The effect of planting density on quantity of digestible dry matter (DMD) and crude protein (CP) on maize and edible weeds forage in kg ha^{-1}.

Planting density	CP				DMD			
Season 1	Stover	Thinnings	Weeds	Forage (stover + thinnings	Stover	Thinnings	Weeds	Stover
D1	788	609	361	1397	12415	6698	1223	19113
D2	445	1064	283	1508	7001	11703	957	18704
LSD_D	176.7	150.4	87.6	217.4	2782.8	1654.3	296.5	3056.9
Season 2								
D1	247	273	30.3	520	3958	2719	236	6678
D2	241	559	30	799	3722	5789	234	9511
LSD_D	71.3	110.2	35.44	149.2	644.9	796.9	276.6	1286.7

Table 19. The effect of weeding regimes on quantity of digestible dry matter (DMD) and crude protein (CP) on maize and edible weeds forage in kg ha^{-1}.

Weeding regimes	CP				DMD			
Season 1	Stover	Thinnings	Weeds	Forage (stover + thinnings	Stover	Thinnings	Weeds	Forage (stover + thinnings
W1	657	900	19	1556	10341	9896	55	20238
W2	410	564	798	974	6458	6200	3254	12658
W3	624	968	21	1592	9834	10644	149	20478
W4	775	915	293	1689	12199	10060	902	22259
LSD_W	249.9	212.7	123.9	307.5	3935.5	2339.6	419.3	4323.1
Season 2								
W1	286	561	0	847	4607	5837	0	10443
W2	59	145	118.5	204	1115	1619	925	2734
W3	286	441	0.7	727	4650	4682	5	9331
W4	345	515	1.3	861	4989	4879	10	9868
LSD_W	100.9	155.8	50.11	211	912.1	1126.9	391.1	1819.7

CHAPTER 5

DISCUSSION

5.0 Bean grain and dry matter yield

The recommended beans spacing is 45 to 60cm x 15 cm (depending on the variety) resulting to a population of 110,000 to 145,000 plants ha^{-1} which yields 220 to 1,100 kg ha^{-1} (Acland, 1971). In this experiment beans were sown at a spacing of 75cm x 30 cm two seeds per hill resulting to a population of 88,000 plants ha^{-1} and their yields ranged 61 to 144 kg ha^{-1}, a very poor performance relative to national bean yield average of 600 to 800 kg ha^{-1} (Muigai and Ndegwa, 1991). Thus less population contributed to the low yields of beans in this experiment. At 0 to 42 DAE approximately over 40 % of the PAR was transmitted through the maize canopy, however low light (20% of the total PAR) may have had severely limited photosynthesis during the reproductive phase (45 to 90 DAE). Probably weeds competition for plant nutrients and poor rainfall might have contributed to low beans yield.

Low light supply may have reduced nitrogen fixation because of low assimilate supply to the N fixing bacteria. Application of fertiliser along the maize rows and failure to apply fertilizer along the bean rows also may have increased maize competitiveness that may have resulted to the poor bean yields. It may be prudent not to intercrop beans at high maize densities or to use wider maize row spacing to increase bean yields.

5.1 Maize phenological development

Maize reproductive phase was much shorter in season two (Table 5) probably because of drought (Figure 2) hastening maturity (Kramer, 1983). This led to the tasseling, grain filling, physiological maturity and dead maturity occurring a week earlier in season two than in season one (Table 5). Thermal units over the developmental stages were lower in season two than in season one (Table 5) because temperature was lower in season two than season one (Figure 3).

5.2 PAR interception

High density increased PAR interception prior to thinning (Figure 6) possibly because of increased competition for light. Fractional PAR interception is directly related to LAI hence PAR intercepted is an indication of LAI (Squire 1990). PAR interception increased to maximum at full vegetative growth (thinning time at 100 % tasseling) when the leaf area was highest (Figure 6). Thinning reduced leaf area index hence PAR interception. However weedy treatment (W2) had higher leaf area index and thus intercepted more PAR compared to the other weeding regimes (Figure 6) because weeds contributed much to the leaf area surface (above 50 % of the weeds height were similar or taller compared to the height of the maize). However PAR interception in D1 after thinning was higher than in D2 because plants in the higher density were smaller probably because of intraplant competition for plant nutrients prior to thinning. PAR interception decreased late in the season (after 85 DAE) (Figure 6) due to leaf fall and senescence (Masri and Boote, 1988).

5.3 Weed biomass and cost of weeding

A combination of high maize density and weed control led to suppression of late emerging weeds primarily through low light availability. Maize easily smothers weeds that germinate 3 to 4 weeks after its emergence (Maina, 1997). Weeds and crops in unweeded field can take up to four times as much nutrient (N, P, K and Mg) taken up by corresponding weed free crops three weeks after sowing (Bhushaan *et al.*, 1984). Grain and fodder yields were low in the unweeded plots relative to where weeds were controlled (Figure 12) possibly because of competition for soil moisture (Figure 10) and nutrients.

Weeds biomass was highest in the unweeded control (Figure 8). W3 (herbicide use) had above 95 % weed control efficiency while W4 (two times hand weeding) had above 80 % in both seasons (Figure 7). This was possibly because of early and effective herbicide weed control (Maina, 1997). W4 was more expensive than W3 because manual weeding required more labour than use of W3. The expenses in W3 were mainly the herbicide cost which was low relative to the cost of labour for hand weeding (Table 6). The results are similar to those of Maina (1997). Herbicidal weed control was 60 to 70 % less compared to the cost of hand weeding in both seasons and this is comparable to (Maina, *et al.*, 2001). Soil moisture stress in second season reduced weed biomass relative to season one (Figure 2) similarly the crop was stressed more in second season compared to first season reducing forage and grain yield (Figure 12).

5.4 Soil moisture, ET and Water Use Efficiency

5.4.1 Soil moisture

Increased plant densities and failure to control weeds (W2) probably increased root density and leaf area index mid season thus increasing transpiration which significantly reduced soil moisture content in high density treatment (D2) in season two. Soil moisture increased down the soil profile indicating that water was lost through evapotranspiration and probably being replenished from deeper parts of the soil profile because of high plant uptake and evaporation losses in the top 30 cm of the soil. Rainfall and irrigation also replenished water loss in the soil.

Increasing rate of drying of the soil down the profile indicates water uptake by roots (MC Gowan and Williams, 1989) (Figure 10 and 11). In season one the largest fluctuation in soil water occurred in the top 70 cm indicating the bulk of maize roots concentrated at 70 cm depth. In season two water extraction occurred up to 110 cm indicating deeper root penetration due to reduced water supply (Figure 10 and 11). Uncontrolled weeds and high density planting increased leaf area index and probably root density that increased transpiration reducing soil moisture.

5.4.2 Evapotranspiration (ET) and water use efficiency (WUE)

Cumulative maize ET ranged from 578 to 640 mm ha^{-1} and 347 to 366 mm ha^{-1} during season one and two respectively (Table 13 and 14). The cumulative ET values are similar to those reported in Kenya (Lenga, 1979) and elsewhere (Fernandez *et al.*, 1996). Low ET values in season two was attributable to limited water supply. Soil water supply limit surface evapotranspiration (Yunusa *et al.*, 1993). Pilbeam *et al.*, (1995), found that in the semi arid parts of Kenya at least 70 % of the rainfall in the bean plots was lost through direct evaporation from the soil surface and water transpired decreased with season with low rainfall. In maize bean intercrop total water loss attributed to transpiration was as little as 15 % in seasons with 150 mm rainfall rising to 40 % for seasons with 400 to 500 mm rainfall in Kenya (Pilbeam *et al.*, 1995). Hence ET and water use efficiency was low in season two because moisture availability (Figure 2) was high during season one than season two.

During the first season failure to control weeds reduced ET of the crop (Table 14), because weeds competed for water, light and nutrients reducing the maize canopy, and transpiration reducing the WUE of the crop but probably increasing the water use efficiency of the weeds. This led to high weed biomass, low maize forage/grain yields and reduced WUE of the maize in the weedy treatment (Figure 8). Water use efficiency was low at high density due to competition between individual maize plants and the weeds for water, light and probably plant nutrients leading to low dry matter conversion per unit plant and reduced WUE in D2 than in D1. WUE_G in the weeded plots (Table 14) were comparable to those obtained at Kabete (7.22 to 9.5 kg $ha^{-1}mm^{-1}$) (Lenga, 1979).

5.5 Maize forage and grain yield

5.5.1 Maize forage and grain yield

Maize stover, thinnings and total forage yields were lower in weedy plots possibly because of competition for light (Figure 6), soil moisture (Figure 10) and nutrients within the root zone. The rate of dry matter production involves reduction of atmospheric CO_2 absorbed through stomata under light and water. Maize does not exhibit light saturation in even at full sunlight thus with sufficient moisture, PAR interception is directly proportional to maize biomass production (Hesketh and Moss, 1963; Louwerse, 1980). Soil moisture stress in weedy plots may have reduced the rate of CO_2 uptake and fixation in maize hence reduced dry matter yield (Macharia, 1990).

The potential transpiration and photosynthesis are attained under ample soil water supply (de Vries *et al.,* 1989). Irrigation in season one increased the maize biomass production almost twice relative to season two (not irrigated because farmers in central Kenya do not irrigate maize) probably because of increased water supply, that resulted in increased leaf area growth, light interception, photosynthesis and biomass production. Stewart, (1983) reported that yields of maize and beans increased linearly with application of irrigation and reported yields in maize/bean intercrop were 4.98 and 0.7 t ha^{-1} respectively at 438 mm water. In this experiment season one had 581 mm rainfall while season 2 had 201 mm of rainfall. Thus in season two grain yield and maize biomass decreased probably due to moisture stress.

Thinnings were higher in D2 than in D1 in both seasons (Figure 12) because three plants were thinned in D2 while only one was thinned in D1. However under drought conditions, thinning at once at the two densities did not affect the stover yield probably because moisture stress occurred before and after thinning (Figure 12). However Methu et *al.*, (2001) found no effect on dense planting and thinning for green forage for the dairy if gradual thinning was done. This indicated that the competition due to increased density had insignificant effect on stover but significantly increased total forage yields if gradual thinning was done under inadequate moisture content as was the case in season two. However with irrigation maize planted at low density D1 had higher total yield than in D2.

Weedy plots intercepted most of the light that led to high weed biomass (Figure 9) but reduced maize and forage yields as a result of light competition. Weeds reduced maize biomass by 39 % and 77 % in first and second season respectively (Appendix 8). This compares with the findings of Parker and Frier, (1975) of yield reductions of up to 40 to 53 % due to weed interference. Also agrees with findings of Maina, (1997), Ngesa, (1993) and Sebuliba-Mutumba *et al.*, (1997) who found out that weeds reduced yields by 15 to 90 %.

5.5.2 Maize harvest index

5.5.2 Maize harvest index

Plant population density influences the partitioning of dry matter in plants (Squire, 1990). The HI of maize at densities of 2.3 m^{-2}, 3.5 m^{-2}, 4.8 m^{-2}, 6.1 m^{-2} and 7.4 m^{-2} were 0.5, 0.4, 0.35, 0.35 and 0.3 respectively in Zimbabwe (Squire, 1990). The results reflected a reduction of HI with increase in maize density. This is because the additional higher population relative to the recommended plant density intercepts little more solar radiation however lower in quality (Squire, 1990). Also total dry matter accrued after grain began filling decreased with increase of maize population because denser maize stands senenced slightly more rapidly (Squire, 1990). The HI was significantly higher at D1 (density 9 m^{-2}) than at D2 (density 18 m^{-2}) and was also higher in two times hand weeding (W4) than where no weeding was done (W2) (Table 11 and 12). This was probably due to effect of high competition for intercepted light and moisture due to high density and weeds that led to reduced quantity of unit PAR intercepted per plant and reduced amount of moisture available per unit plant. This probably led to poor leaf area development which probably reduced photo assimilates production leading to poor ear development and thus reduced grain mass.

With increased leaf area index, evaporation losses from the soil surface are often small while transpiration losses are commensurately greater (Pilbeam, *et al.*, 1995). Thus biomass production increases with increased transpiration with sufficient light interception and sufficient CO_2 concentration. However in this experiment high density resulted to reduced biomass compared to low density probably because of inter and intra plant competition for plant resources, higher in high density (D2) compared to low density (D1). Increasing plant density consistently causes water stress especially during flowering reducing grain yield and thus harvest index (Berzsenyi, 1988). Thus both high density and weeds increased the moisture and light competition (Figure 6, 10 and 11) reducing the grain yield and HI (Table 11 and 12).

5.6 Forage quality

Percentage digestibility and crude protein were lower in the stover than in thinnings because the crop was investing its resources on the chlorophyll to maximise photosynthesis by time of thinning (98 DAE) (Figure 6). This was possibly also due to assimilate redistribution from stem to grain resulting to structural material i.e. cellulose in the stover. This led to reduction of CP in stover in the experiment. Low crude protein (CP) of maize stover has also been reported (Little and Said, 1987; Methu, 1998). Stover in unweeded crop had higher % CP and % digestibility (Table 17) possibly due to the crop was out competed by weeds for resources and invested very little on seed production hence assimilates were retained in the stems. Probably also in the unweeded crop, there was little or no N retranslocation to reproductive parts and thus accumulated N mainly in the stems and leaves. This is evident in the experiment since grain yields were very low in W2. Weeds (at 126 DAE) had higher % CP in both seasons than maize while % digestibility was similar to stover (Table

15). This may be because most of the edible weed species were leguminous and broad leafed (Table 15) thus conversion rate of photosynthates to protein was higher than in maize. However digestibility was same to the maize stover probably because fibre content was same. Edible weed harvested from two times hand weeding (W4), in the first season, had 0.9 t ha^{-1} digestible DM and 0.3 t ha^{-1} Crude Protein while in season two weeds digestible DM and Crude Protein was negligible because weed biomass was negligible due to drought (Table 19).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Maize biomass and grain yield was increased by higher rainfall but greatly reduced by weeds. Herbicide use was more economical than weeding twice by hand. Harvesting edible weeds would contribute to dairy animal forage since edible weeds formed above 50 % of available weeds at any one time. Increased maize density would significantly decrease maize grain yields and weeds biomass, increase quality of maize forage by increasing thinnings and also increase total maize forage (depending on rainfall conditions).

The specific conclusions and recommendations were;

- Failure to control weeds and dense planting of maize in maize bean intercrop increased the competition for soil moisture and light, which reduced bean yields. Thus it is prudent not to intercrop beans with maize at high densities but incase of intercropping then wider row spacing should be used.

- High maize density increased PAR interception thus reducing the amount of light available to weeds in the understorey. Although weedy treatment intercepted higher PAR the weeds biomass produced was low because most of the weeds were C3 plants and had lower biomass because of lower conversion efficiency than maize.

- High density (D2) increases quality of maize forage through thinnings but it is only beneficial with sufficient rainfall.

- The digestibility of maize and crude protein was high in thinnings and lower in the stover. Therefore it is advisable for smallholder dairy farmers whose priority is not high maize grain yield, to plant at high density then thin later for the green forage (thinnings). Weed control increased the quantity of crude protein and digestible dry matter per ha.

- Under high planting density hand weeding once and probably later roguing the weeds that grow later is adequate. The weeds had a higher % CP but similar digestibility compared to maize and more than half the weeds that were edible to dairy animals and could be selected to feed the animals. Weeds should be rogued before they flower to avoid building the soil weed seed bank. However farmers should not leave the crop unweeded anticipating to harvest some weeds for animal feed for weeds reduced maize biomass by 39 to 77 %.

- It is more efficient and more economical to use herbicide to control weeds than using two times hand weeding. On the basis of the findings of this work it is advisable for farmers with shortage of labour but with capital to buy the herbicides to control the weeds. However the cost of labour compared to that of chemicals and their application at any given time and place will determine farmer's choice.

- Farmers who use the maize stover, thinnings and edible weeds to feed the animals should make an attempt to return the animal manure to the farm to prevent nutrient mining from the soil.

Further research areas

- Intercropping with beans at higher maize densities and wider row spacing.
- Determine herbicide residue levels in maize and weeds forage to be fed to the animals.
- Determining the viability of edible weed seeds after under going the rumen digestion and manure decomposition would verify the extent of weed dissemination through manure after feeding the cattle with seeded weed forage.
- Gradual maize thinning could be experimented to establish the point in time to start thinning and the frequency of thinning that would give optimal grain yield.
- The effect of not weeding on soil weed seed bank in subsequent season.

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APPENDICES

Appendix 1. Soil profile physical and chemical characteristics.

Depth (cm)	Horizon	Structure	Bulk density	Sand	Silt	Clay	% organic C	% N
0-20	A11	Crumb	1.1	20.5	23.8	46.4	4.6	0.6
20-35	A12	Crumb	1.1	20.9	28.9	47	1.6	0.2
35-58	B11	Sub angular blocky	1.1	16.8	26.4	55.4	0.7	0.1
58-78	B12	Sub angular blocky	1.1	16.8	24.7	57.6	0.5	0.09
78-95	B21	Sub angular blocky	1.2	16.1	20.7	62.1	0.4	0.08
95-105	B22	Sub angular blocky	1.2	26.4	16.9	56.3	0.2	0.06
105-125+	B22	Sub angular blocky	1.3	18.1	10.4	71.1	0.2	0.01

Chemical analysis results at start of experiment (depth 0-20cm)	
% organic C	3.2
% N	0.3
Avail. P (mg P kg^{-1})	8.6
K (mg K kg^{-1})	1128.5
pH water	5.9
Adequate ranges	
% organic C	0.5 - 3
% N	0.05 - 0.25
Avail. P (mg P kg^{-1})	150 - 500
K (mg K kg^{-1})	50 -175
pH water	5.5 - 7.0

Source: Tekalign, 1991, East Africa Forest Research Organisation, 1975.

In view of the above the soil was deficient in phosphorous.

Appendix 2. The sum of mean squares of the effect of weeding regimes and maize planting density on bean dry matter and grain yield where * or ** indicates significance at $P<0.05$.or $P<0.01$ respectively, (this applies to all sum of squares appendices).

Source of variation	df	Season 1		Season 2	
		Dry matter	Beans	Dry matter	Beans
Blocks	3	2767	1498	940	57
Density	1	7243*	5336	940	180
Weeding regime	3	38796**	13548**	6857**	4705**
Interaction DxW	3	2763	3201	745	383
Residual	21	1533	1666	717	545
Total	31	5562	3067	1343	873

Appendix 3. The sum of mean squares of effect weeding regime and planting density on the percent tasseling of maize.

Source of variation	df	80 DAE	84 DAE	88 DAE	92 DAE
Season one					
Blocks	3	0.914	16.34	43.89	216.3
Density	1	22.05**	169.2**	387.18**	940.53**
Weeding regime	3	4.77*	55.09**	190.58**	485.25**
Interaction (DxW)	3	1.91	30.85	68.96	70.9
Residual	21	1.50	10.7	30.08	97.92
Total	31	2.47	22.6	62.19	171.4
Season two					
Blocks	3	2.189	1.642	17.35	40.6
Density	1	10.64*	72.64**	590.8**	5379**
Weeding regime	3	23.62**	65.89**	163.2**	1763**
Interaction (DxW)	3	3.252	15.08	10.53	114.8
Residual	21	2.14	5.61	8.807	69.72
Total	31	4.61	14.13	43.52	406.4

Appendix 4. The sum of mean squares of effects of weeding regime and planting density on the height of maize at various times during the growth period in cm.

Source of variation	df	DAE 56	77	98	120
Season one					
Blocks	3	67.3	721.3	834	1229
Density	1	176.8	1298	1960.1*	4298.7**
Weeding regime	3	694**	4663.2*	2864	3610.1*
Interaction (DxW)	3	97.2	268.2	533.4	272.1
Residual	21	123.7	348.4	275.1	323.5
Total	31	230.9	824.9	659.2	852.5
Season two					
Blocks	3	130.5	112.5	191	150.4
Density	1	883.2**	1067.0*	919.7	1546.3*
Weeding regime	3	2013**	5947**	6139**	3392**
Interaction (DxW)	3	112.4	27.9	87.1	260.8
Residual	21	62.15	172	265	326.3
Total	31	288.9	740	830.2	638.9

Appendix 5. The sum of mean squares of effects of weeding regime and planting density on the percent PAR interception in maize at various times during the growing period.

Source of variation	df	42DAE	56DAE	70DAE	84DAE	96DAE	112DAE
Season one							
Blocks	3	48.3	136.7	38.6	9.5	403.8	64.4
Density	1	629.6**	153.8*	263.1**	68.1**	1244.7**	116.5
Weeding regime	3	704.7**	777.6**	199.3**	64.8**	893.0**	1952.9**
Interaction (DxW)	3	22.8	60.4	63.6*	12.1	96.4	35.7
Residual	21	51.5	24.1	19.9	6.3	73.9	66.2
Total	31	130.3	115.6	51.0	14.8	225.1	247.3
Season two							
Blocks	3	1321	1238.2	196.1	183.3	10.6	56.3
Density	1	727.2	145	76.6	557.0**	132.1	82.5
Weeding regime	3	232.4	952.8**	823.2**	244.2*	825.9**	1137.3**
Interaction (DxW)	3	109.5	94.5	96.6	85.7	69.5	125.4
Residual	21	202.6	109	72.1	57.4	163.2	112.6
Total	31	321.6	299.7	159.3	106.5	202.5	206.6

Appendix 6. The sum of mean squares of effect of planting density and weeding regimes on weeds biomass (in t/ha) at various times during growth of maize.

Source of variation	df	14DAE	42DAE	126DAE	% Edible
Season one					
Blocks	3	0.002	0.016	0.147	107.9
Density	1	0.002	0.218**	4.041**	561.17*
Weeding regime	3	0.056**	10.78**	143.3**	2202.35**
Interaction (DxW)	3	0.001	0.129*	1.83**	377.24*
Residual	21	0.0008	0.026	0.313	79.12
Total	31	0.006	1.082	14.4	331.8
Season two					
Blocks	3	0.001	0.052	1.982	2.03
Density	1	0.032**	0.876**	0.036	2289.4*
Weeding regime	3	0.135**	3.84**	13.56**	76.8
Interaction (DxW)	3	0.006	0.257**	0.04	133.9
Residual	21	0.002	0.029	0.956	467
Total	31	0.016	0.449	2.156	502.4

Appendix 7. The sum of mean squares of effect of planting density and weeding regime on the forage and grain production rate in kgs per shilling used in weeding.

Treatment	d.f	Forage	Grain	Stover	Total biomass (forage +grains	Thinnings
Season 1						
Blocks	3	2.77	0.00	1.10	2.85	0.54
Density	1	0.33	0.24**	5.26**	1.13	2.96**
Weeding regime	3	49.31**	0.48**	13.73**	59.35**	11.05**
Interaction DxW	3	0.72	0.06**	2.55**	1.08**	0.66**
Residual	21	0.45	0.01	0.27	0.47	0.22
Total	31	5.42	0.06	2.03	6.48	1.43
Season 2						
Blocks	3	0.34	0.00	0.13	0.39	0.05
Density	1	1.03*	0.00	0.00	0.95*	1.15**
Weeding regime	3	11.12**	0.02**	3.39**	12.18**	2.24**
Interaction DxW	3	0.25	0.00	0.00	0.25	0.23**
Residual	21	0.19	0.00	0.07	0.20	0.04
Total	31	1.29	0.00	0.39	1.41	0.30

Appendix 8. The percent loss of maize grain and forage yields due to weeds.

Component	Weed free(W1) regime yields (kg ha^{-1})	Weedy (W2) regime yields (kg ha^{-1})	% loss due to weeds
Season *1*			
Grain	3.4	1.6	54
Thinnings	12.9	8.1	37
Stover	16.4	10.2	38
Forage (Thinnings+ Stover)	29.3	18.3	38
Total biomass (Thinnings + Stover +grain)	32.7	19.9	39
Season 2			
Grain	1.0	0.03	97
Thinnings	8.0	2.1	74
Stover	7.5	1.6	79
Forage (Thinnings + Stover)	15.5	3.6	77
Total biomass (Thinnings + Stover +grain)	16.5	3.7	78

Appendix 9. The sum of mean squares of effect of planting density and weeding regimes on volumetric moisture content down the soil profile at 105 DAE on maize bean intercrop.

Source of variation	df	Soil depth in cm 10	30	50	70	90	110	130
Season one								
Blocks	3	36.7	3.9	30.0	34.2	97.0	58.8	35.7
Density	1	3.5	2.7	0.4	0.3	7.7	15.7	21.0
Weeding regime	3	103.2*	48.0**	66.8**	83.2**	107.6**	136.0**	127.2**
Interaction (DxW)	3	34.5	0.8	5.0	14.2	36.5	39.6	44.3
Residual	21	27.6	1.8	5.9	10.7	12.6	17.7	14.4
Total	31	35.7	6.4	13.9	20.0	32.1	35.2	30.5
Season two								
Blocks	3	4.8	6.0	13.1	35.8	167.6	113.5	62.1
Density	1	322.6**	125.2**	93.3**	98.4**	308.3**	268.6**	415.7**
Weeding regime	3	61.7**	6.3**	10.7*	11.1	99.5**	115.6**	185.5**
Interaction (DxW)	3	15.8	2.2	1.9	6.1	14.5	5.7	19.8
Residual	149	5.6	0.7	3.3	9.6	12.8	14.5	12.8
Total	159	22.2	5.9	7.7	14.8	45.9	41.2	47.9

Appendix 10. The sum of mean squares of the effect of weeding regimes and planting density on maize grain harvest index.

Source of variation	df	Season 1	Season 2
Blocks	3	0.002	0.003
Density	1	0.025**	0.041**
Weeding regime	3	0.003*	0.005*
Interaction (DxW)	3	0.001	0.002
Residual	21	0.001	0.001
Total	31	0.002	0.003

Appendix 11. The sum of mean squares of effect of planting density and weeding regime on Cumulative Evapotranspiration (ET) in mm and Water Use Efficiency (WUE) on maize forage and grain in kg ha^{-1} mm^{-1}.

Treatment	df	Cumulative ET	WUE total biomass	WUE of grains
Season 1				
Blocks	3	2984	414.5	0.9
Density	1	1496	239.8	77.8**
Weeding regime	3	6657*	669.3**	20.4**
Interaction DxW	3	1608	60.9	2.8
Residual	21	1657	105.5	2.0
Total	31	2259	189.9	6.2
Season 2				
Blocks	3	346	144.2	1.3
Density	1	1467	826.3**	1.1*
Weeding regime	3	510	1809.1**	10.1**
Interaction DxW	3	328	40.2	0.3
Residual	21	602	64.1	0.2
Total	31	570	263.0	1.3

Appendix 12. The sum of mean squares of the effect of weeding regimes and planting density on maize forage and grain yields in t ha^{-1}.

Source of variation	df	Thinnings	Stover	Grain	Fodder
Season one					
Blocks	3	26.3	91.7	0.37	188.4
Density	1	337.9**	590.7**	38.4**	35.1
Weeding regime	3	55.4**	115.5*	11.1**	308.4**
Interaction (DxW)	3	4.0	35.8	1.40	48.6
Residual	21	8.5	36.1	1.03	40.3
Total	31	24.9	67.0	3.18	81.2
Season two					
Blocks	3	5.6	6.0	0.21	21.3
Density	1	139**	2.1	0.22**	107.1**
Weeding regime	3	52.7**	77.1 **	1.6**	250.2**
Interaction (DxW)	3	8.6*	0.75	0.05	6.2
Residual	21	2.3	2.6	0.02	7.9
Total	31	12.7	9.9	0.21	35.6

Appendix 13. The sum of mean squares of effects of weeding regime and planting density on the quality of maize forage in season two.

Source of variation		DMD				CP			
		Thinnings		Stover		Thinnings		Stover	
	df	leaves	stems	leaves	stems	leaves	stems	leaves	stems
Blocks	3	7.9	15.6	139.5	10.7	2.1	1.3	1.8	1.5
Density	1	0.1	8.2	1.3	4.7	0.4	1.6	0.2	1.1
Weeding regime	3	74.9**	38.9**	167.9**	125.5**	5.4	5.8*	0.7	0.3
Interaction DxW	3	1.1	2.5	6.1	8.3	2.0	3.2	0.3	0.7
Residual	21	5.6	5.1	9.9	11.0	1.3	2.2	1.9	2.4
Total	31	11.9	9.2	37.2	21.6	1.8	2.5	1.6	1.9

Appendix 14. The sum of mean squares of effect of planting density and weeding regime on quantity of crude protein (CP) and degradable dry matter (DMD) on maize and edible weeds forage in kg ha^{-1} (Figures in 000').

Treatment		CP				DMD			
	df	Stover	Thinnings	Weeds	Forage	Stover	Thinnings	Weeds	Forage
Season 1									
Blocks	3	147	129	15	473	36410	15600	174	86150
Density	1	945**	1656**	49	99	234400**	200400**	566	1337
Weeding regime	3	185*	271**	1552**	841**	45840*	32820**	17793**	145400**
Interaction DxW	3	57	20	58**	102	14200	2382	666**	20870
Residual	21	58	42	14	87	14320	5063	163	17290
Total	31	11	122	169	59	462	3429	1932	36194
Season 2									
Blocks	3	3	69	5	64	937	2504	299	5699
Density	1	0	654**	0	625**	446	75360**	0	64210**
Weeding regime	3	128**	281**	28**	768**	26640**	26720**	1692**	103800**
Interaction DxW	3	7	53	0	41	504	4288*	0	3664
Residual	21	9	22	2	41	769	1175	142	3063
Total	31	20	75	5	133	3252	6471	289	15097

List of abbreviations

ADF	Acid Detergent Fibre
AEZ's	Agro Ecological Zone's
CBS	Central Bureau Statistics
CIMMYT	International Maize and Wheat Improvement Centre
CP	Crude Protein
D F value	Density analysis of variance F statistic
D1	Low density of planting of 9 plants per m^2
D2	High density of planting and 18 plants per m^2
DAE	Days After Emergence
DAP	Days After Planting
DFID	Department for international development
DMD	Dry matter digestibility
DMI	Dry Matter Intake
DxW F	Density and weeding regime interaction F statistic
EU	Eropean Union
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Statistics
GIT	Gastro intestinal track.
IFPRI	International Food Policy Research Institute
KARI	Kenya Agricultural Research Institute
LERs	Land Equivalent Ratios
LSD	Least significant difference
masl.	Meters above sea level
MSV	Maize Streak Virus

N	Nitrogen
NARCM	National Agricultural Research Center, Muguga
NDDP	National Dairy Development Programme
ODA	Overseas Development Agency
P	Phosphorous
PAR	Photosynthetically Active Radiation
RPT	Reading Pressure Technique
SOM	Soil Organic Matter
SSA	Sub Saharan Africa
ET	Evapotranspiration
WUE	Water Use Effeciency
USDA	United States Department for Agriculture
VFAs	Volatile Fatty Acids
W1	Weed free
W2	Weedy
W3	Herbicide use
W4	Hand weeding