IMPROVING MAIZE (*Zea mays* L.) GROWTH AND YIELD USING JATROPHA (*Jatropha curcas* L.) SEED CAKE UNDER ZIMBABWEAN SOIL CONDITIONS

BY

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ABSTRACT

A research study exploring the use of jatropha seed cake as a sole source of nutrients and used in combination with inorganic N fertilizer was conducted on station at Henderson Research Station on sandy and clayey soils during the rainy season of 2006/2007. Two experiments were conducted to determine the effect of jatropha seed cake on maize dry matter and grain yield and its effect on weed density and biomass.

Experiment 1 explored the use of jatropha seed cake rates ranging from 767kg/ha to 3835kg/ha in maize production. Included in the experiment were three other treatments viz extension recommendation for inorganic fertilizer, farmer's practice of applying cattle manure and a control. A Randomized Complete Block Design (RCBD) was used and a total of 8 treatments were assessed. Jatropha seed cake application rate and inorganic fertilizer had higher yields ($P \leq 0.05$) on maize dry matter yield at 4, 8 and 12wace on the sandy soil site. Application of 2301kg/ha of jatropha seed cake and the extension recommendation resulted in maize dry matter yields of 3059kg/ha and 3399kg/ha respectively at 12wace. There were no differences noted in maize dry matter yields on the clayey soil site. Weed densities of the following species *F exilis and Eragrostis spp* (sandy soil site) *and T. annua, C. rotundus, and L. martinicensis* (clayey soil site) were significantly reduced ($P<0.05$) where jatropha seed cake was applied. Weed biomass on the sandy soil site was reduced by 30% along the maize rows.

In experiment 2, three levels of jatropha seed cake were tested (0, 767kg/ha and 1534kg/ha) in combination with 3 levels of inorganic nitrogen levels (0, 25kg/ha and 50 kg/ha N) The N was applied as topdressing at 6wace. The other treatments included use of 200kg/ha Compound D (N: 7%, P:14% and K: 7%) as basal fertilizer in combination with the three inorganic N fertilizer rates. 12 treatments were tested in this experiment and it was laid out as a 3 x 3 factorial arranged in an RCBD design. The jatropha seed cake levels performed equally as well as the inorganic fertilizer treatment in terms of dry matter yield at 4 and 8 wace. The maize grain yield was significantly higher ($P<0.05$) were jatropha seed cake was applied (954kg/ha and 1036kg/ha) for the 767kg/ha and 1534kg/ha rates. The control had lower grain yield (538kg/ha). The interaction between the jatropha cake rate and inorganic N rate was not significant ($P>0.05$). The results from this study suggest that smallholder farmers can apply jatropha seed cake at a rate of 767kg/ha in maize production and 25kg/ha inorganic N can be used as a top dressing fertilizer.

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DEDICATION

To my husband, Passmore Chigwanda and my four daughters (Valerie, Takudzwa, Tanaka and Chantel Zanele Chigwanda) for being my pillars of strength and for the understanding and moral support they gave me through out the studies and to my mother, father, brothers, sisters and my late aunt, Mrs Doreen Sizi Mangoro, for always encouraging me to work hard.

CONTENTS

ABBREVIATIONS

ANOVA	Analysis of variance
HERS	Henderson Research Station
N	Nitrogen
P	Phosphorus
K	Potassium
Ha	Hectare
wace	weeks after crop emergence
Trt	treatment
Rep	replicate
Extn recom	Extension recommendation
Farmer prac	Farmers' practice

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CHAPTER 1

1.0 INTRODUCTION

Maize is the staple crop of Zimbabwe accounting for 60 % of the cropped area in Zimbabwe (Nyamangara, Bergström, Piha and Giller, 2003). Zimbabwe was often referred to as a success story in terms of food security and this status is probably because of expanded maize production as yield per unit area is characteristically low, averaging less than 700 kg/ha nationally in the smallholder sector (Agricultural Sector of Zimbabwe Bulletin, 2000).

Soil fertility is the major yield constraint as has been described by many authors (Grant, 1970, 1981, Mashiringwani, 1983, Mukurumbira and Dhliwayo, 1996 Nyamangara 2001). Most smallholder farmers grow maize on sandy soils derived from granite (Nyamapfene, 1991). These soils are characterized by deficiencies of N, P, K and S, relatively high acidity (Grant, 1981), low soil organic matter (often below 0.3 %) (Campbell, Bradley, and Carter, 1994) and low water holding capacity (Grant, 1981; Vogel, 1992). Nitrogen levels are particularly on the decline, Stoorvogel, Smaling and Janssen (1993) reported that it is estimated that more than 30 kg ha^{-1} is lost annually. Increased continuous mining of the soil by repeated crop production with little fertilizer or organic matter input has further depleted the soil nutrients (Waddington, 2003). However, most of these production constraints can be alleviated by the application of adequate and high quality organic amendments.

Some of the soil ameliorants used by farmers are inorganic fertilizers, cattle manure, and miombo leaf litter, of which miombo leaf litter tends to be of very low quality (1.2 % nitrogen (N)) with limited contribution to maize yields (Snapp, Mafongoya, and Waddington, 1998). Manure is of particular importance on sandy soils because it can improve both physical and chemical properties of the soil. The chemical composition of manure varies greatly from place to place. Manure samples collected and analysed by Mugwira and Mukurumbira (1984) had

N, phosphorus (P) and potassium (K) concentrations of 1.04, 0.16 and 0.96 % respectively compared to maize requirements of 5, 3 and 5 % N, P, and K (Zaidi and Singh, 2005) respectively during the early vegetative stages. The chemical composition of manure varies greatly and depends on factors such as age and condition of animals, nature and amount of litter, handling and storage of the manure before application and also the quality of the pasture.

Quantities of cattle manure available to farmers in Zimbabwe are however limited because of low livestock numbers per household (Nzuma, Murwira and Mpepereki, 1997) and hence use of manure is not widespread. The use of inorganic fertilizers is also severely limited because of unavailability and the inhibitive cost. Use of combinations of organic and inorganic fertilizers has thus become imperative (Hikwa, Murata, Tagwira, Chiduza, Murwira, Muza and Waddington, 1998) to increase yield levels, but this entails the need to find alternative supplementary sources of nutrients for soil fertility management under maize production.

Jatropha curcas L. (jatropha) seed cake (also known as jatropha press cake) an organic source of nutrients, has shown a lot of promise in countries such as Zambia where it has been used in maize production and also Zimbabwe in vegetable production (www.jatropha.org/binga.htm). Some of the uses of the seed cake that have been suggested include biogas production and fodder. The seed cake contains about 50 % protein but cursin, insoluble in the oil, remains in the seed cake rendering it toxic to animals (Wegmershaus and Oliver, 1980). The cake can therefore not be used as a stock feed without treatment; it can however alternatively be used as an organic fertilizer. The cake can be applied directly or it can be used in the production of compost to increase the value of the fertilizer (Gubitz, 1998). Heller (1996) reported that applications of high cake rates of 5t/ha showed phytotoxicity expressed as reduced germination in tomatoes. There is however limited information on the allelopathic effects of jatropha seed cake on weed species.

In Zimbabwe, Non Governmental Organisations (NGOs) such as Environment Africa, Biomass Users Network and international organizations such as the World Agroforestry Centre have been promoting the planting of *Jatropha curcas* L (jatropha) trees since 1996 (Kashyap, 1998). This has resulted in the planting of extensive live hedges in the country in areas such as Mutoko, Bindura, Chiweshe and Victoria Falls. In these communities, most farmers are extracting oil from the seeds for soap making. However, the seed cake residues derived from jatropha processing have not been systematically used in any meaningful way. This provides opportunities for using oilseed cake as an alternative source of organic manure. The amounts of seed cake residues will increase significantly in the future as the Zimbabwe Government has embarked on a National Bio diesel Programme.

It is expected that, by 2010, 10 % of the annual national diesel requirement will come from jatropha oil. This can be realized if at least 100,000ha of land would be put under jatropha. Most of the jatropha will be grown in the smallholder sector (Mushaka, Mavankeni, Madhovi and Pashapa, 2005). Huge amounts of the jatropha cake residue will remain after oil extraction. Working with a conservative yield level of 3t per hectare, 300 000t of Jatropha cake residue can be produced per year. It is therefore important that appropriate ways of disposal of the cake are developed to reduce environmental hazards. Using the jatropha seed cake as a fertilizer could result in increased maize yields thus, positively impacting on food security.

Harnessing the nutrient energy from biological and industrial waste is of prime importance for maximizing crop production. When these wastes are recycled as manure for crop production and are subjected to the degradation and assimilative capacity of soil, pollution of streams and/or rivers receiving these wastes is reduced to a large extent. (Balasubramaniyan and Palaniappan, 2003).

This study explores the possibility for using jatropha seed cake waste as an organic fertilizer to mitigate shortages of fertilizing material on maize in the smallholder-farming sector of Zimbabwe.

1.1 Objectives

1. To determine effects of varying levels of jatropha seed cake on maize growth, grain yield, weed density and biomass.
2. To determine the optimum rates of jatropha seed cake supplemented with inorganic N fertilizer on maize growth and grain yield

1.2 Hypotheses

1. Jatropha seed cake application rate has no effect on the growth rate, grain yield of maize and weed counts and biomass.
2. Varying levels of jatropha seed cake supplemented with inorganic N fertilizer have no effect on the yield of the maize crop.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 The jatropha Plant

The jatropha plant is a tropical shrub native to Mexico and Central America. It is widely distributed in wild and semi cultivated stands in Latin America (Paramathma, Partiban and Neelantan, 2004) The shrub is well adapted to arid and semi arid conditions. The plant has various uses. Jatropha is widely planted as a "living fence" in Zimbabwe (Mushaka, 1998) and hedgerows to protect food crops from damage by livestock and as a windbreak to prevent soil erosion and moisture depletion (www.jartropha.org) The bark is reported to yield tannin in commercially useable quantities. Jatropha is known as the physic or purging nut for its use as purgative/laxative, and is widely known as a source of medicine for treatment of a variety of ailments. The seeds and kernels also contain oil. Oil content in seeds range from 35-40 % oil and the kernels 55-60 % (www.jartropha.org). The oil has been exploited in the production of bio diesel or soap.

2.2 Jatropha Production and Utilisation in Zimbabwe

According to Mushaka (1998) jatropha production has traditionally been limited to the smallholder farming sector of Zimbabwe. From a combination of detailed sampling and transect studies it is estimated that Mutoko area alone has almost 8000ha under jatropha (Mushaka e*t. al*., 2005). The farmers in Binga (www.oregonstate.edu) and Mutoko (Mapako, 1998) use the jatropha seed for oil extraction and the oil is used for lighting purposes as well as for soap making.

2.3 Attributes of the jatropha seed cake

Jatropha seed cake is the waste product that is obtained when jatropha seed is either hand or machine crushed when extracting oil (Zimbabwe Biomass News, 1996). The method of extraction plays an important role in the residual oil that remains in the cake. When oil is extracted as a cottage industry the resulting cake is said to still contain approximately 11% oil (www.jartropha.org). The seed cake comprises of the husk and the other non-oil components of the seed (Zimbabwe Biomass News, 1996). The seed cake can be used for biogas production and fodder. It contains about 58-60 % crude protein (53-55 % true protein content), and the level of essential amino acids except lysine is higher than the FAO reference protein. A phytotoxin called curcin remains in the cake (www.jartropha.org). Curcin is a highly toxic protein that is similar to ricin, which is found in castor. It is insoluble in the oil thereby rendering the seed cake toxic and therefore unsuitable as an animal feed (www.jartropha.org). The cake does have potential as a fertilizer (Wegmershaus *et. al*. 1980). The cake can be applied directly or it can be used in the production of compost to increase the value of the fertilizer (Gubitz, 1998).

2.3.1 Phytotoxicity of jatropha cake

Heller (1996) reported that applications of high cake rates of 5t/ha showed phytotoxicity expressed as reduced germination in tomatoes. Work done by Chanyowedza and Chivinge (2004) also demonstrated the allelopathic effects of some organic amendments on the germination and emergence of the witch weed (*Striga asiatica*). Molisch (1937) coined the term allelopathy, which refers to all biochemical interactions (stimulatory or inhibitory) among plants including micro-organisms. The allelopathic effects of jatropha seed cake have not been reported. There is however limited information on the allelopathic effects of jatropha leaf extracts. Ourdia (1997) reported the allelopathic effect of jatropha leaf extracts on the germination of velvet bean (*Mucuna pruriens*) seeds.

2.3.2 Nutrient value of the jatropha seed cake

Tigere (2002) reported the value of jatropha seed cake, chicken manure and cattle manures.

The results were as indicated in the table below:

Table 2.1: Fertilizer value of jatropha seed cake as percentage compared with chicken and cattle manure

	Content		
Nutrient	**Jatropha seed cake**	**Chicken**	**Cattle**
N	3.93	2.5	1.5
P_2O_5	2.93	2.6	0.65
K_2O	1.73	2.0	1.0

Adapted from Tigere, 2002)

According to Tigere (2002) the jatropha seed cake has a higher organic content (88 %) compared to chicken manure (15- 80 %) and cattle manure (20-70 %). The jatropha seed cake has been shown to be a valuable fertiliser when applied directly to the field. Compared to a commercial fertiliser the yield of maize and millets increased up to 179 % and 120 % respectively (Gubitz, 1998).

2.4 Manure application rate and time of application

Manure is not a balanced fertiliser, hence it is more economical to use a moderate quantity and supplement it with inorganic fertiliser. In a study conducted by Munguri (1996) in Chinyika, he found out that 50 % of the farmers who use manure supplemented it with ammonium nitrate as a top dressing. Gubitz (1998) reported that an application rate of 5t/ha of Jatropha seed cake resulted in a 79 % maize yield increase compared to a commercial fertilizer. The jatropha seed cake can be directly applied to the field (Gubitz, 1998) and should be incorporated into the soil before planting for quick decomposition (Balasubramaniyan *et. al*., 2003)

The advantages of direct application are low investment and maintenance costs. Composting of the seed cake represents an alternative to direct application (Gubitz, 1998). The use of compost leads to a long-term improvement of soils as nutrients are released slowly.

2.5 Method of manure application

Experiments carried out by Munguri (1996) in Chinyika and Domboshawa showed that the application of cattle manure at 4t/ha using the banding method increased grain yield by 36% over broadcasting at the application rate of 4t/ha. Tomer and Soper (1981) found that the superiority of banding over broadcasting with respect to grain yield was largely due to the reduced immobilisation of nitrogen in banding method. Monreal, Mcgill and Nyborg, (1986) suggested that banding results in a smaller portion of the soil being in contact with the manure. The low surface area: mass ratio reduces access by micro-organisms on the decomposing manure thereby minimising immobilisation (Mubonderi, 1999).

2.6 Interactions between manure and mineral fertilizer

Manure has been shown to be an unsatisfactory source of nitrogen because of its slow decomposition and inability to supply continuously large amounts of readily available nitrogen (Beauchamp, 1983; Mugwira 1985). Grant (1981) reported that manure alone is not adequate to sustain crop growth. Trials conducted by Rodel, Hopley and Boultwood, (1980) showed that manure is more effective on sandy soils when supplemented with inorganic fertilizer.

CHAPTER 3

3.0 GENERAL MATERIALS AND METHODS

3.1 The Experiments and Research Site

Two field experiments were conducted in Mazowe, at Henderson Research Station (HERS). Experiment 1 was conducted on sandy and clayey soil types whereas experiment 2 was carried out on a sandy soil site only.

HERS is about 30km from Harare. It is located in the Mazowe District in the Mashonaland Central Province of Zimbabwe. HERS lies at 30^{o} 38’ East and at 17^{o} 35’ South. The altitude at the HERS site is 1292 metres. There are two experimental blocks one sited on sandy and the other on clayey soil. The five year mean annual rainfall (for seasons 2001/02 to 2005/06) for the sandy and clayey experimental sites was 642.7mm and 709.1mm respectively. The soils are generally classified as deep well drained sandy soils derived from granite in the sandy experimental block and deep reddish brown clays in the clayey experimental block. HERS is in Natural Region (NR) II, which is an area of high agricultural potential. The mean annual temperature is 28 ^{o}C.

3.2 Maize Variety used in the Experiment

Maize variety SC513, a white dent early maturing three way hybrid was planted. The variety has very good tolerance to Grey Leaf Spot (GLS). It has a relatively high ear placement and is slightly susceptible to root lodging when planted at high plant populations. SC513 has a wide adaptability and good stress tolerance (Seed Co, 2004). The variety was chosen because of its tolerance to GLS, which is prevalent in high rainfall areas, and also its tolerance to stress as rainfall distribution is sometimes poor in NR II. The variety is commonly grown by smallholder farmers.

3.3 Source and treatment of jatropha seed cake

Jatropha seed cake that was used in the project was sourced from Harare Polytechnic College where it is a waste product of oil extraction. The seed cake samples were analysed for total nitrogen, total potassium, total phosphorus and lignin and dry matter.

3.4 Cattle manure used in the experiment

The cattle manure used in the study was obtained from a smallholder farmer in the Snake Park area of Harare. Cured cattle manure was used in this experiment.

3.5 Parameters measured

3.5.1 Plant heights

Plant heights were taken from a sample of ten maize plants selected at random from the net plot. The heights were taken at 4, 8 and 12 weeks after crop emergence.

3.5.2 Grain yield determination

A net plot of 3.6m long and 1.8m wide was sampled from the two middle rows. 2.4m comprising of 1.2m at either end of the plot were discarded. A total of 28 plants were harvested on a plot where plant survival was 100%. Grain yields were also determined after drying the samples. Grain weight was standardized to 12.5% moisture content.

3.5.3 Maize Dry Matter Determination

Random samples of two plants from the two boarder rows were cut at ground level at each sampling period i.e. at 4, 8 and 12 wace. The samples were weighed using a digital scale to determine fresh biomass yield and then they were dried at 60°C for four days and weighed for dry matter determination.

3.5.4 Weed Sampling

Weeds were harvested along and between the maize rows with a 30cm x 30cm quadrant. Sampling was done between 2nd and 3rd maize rows and along the 3rd and 4th rows. The sampling was done at random along and between maize rows. A total of 4 points were sampled per plot; two points were sampled along each row and 2 points between two maize rows. Sampling was done, just before weeding at 2 wace and 5 wace. The above ground weed biomass was harvested; weeds were separated into species and counted. All the weeds in each quadrant were weighed to determine the biomass yield. The weeds were dried at 60°C for 24 hours and weighed for dry matter determination.

3.5.5 Chemical Analysis Methods used on Samples

The jatropha seed cake total N was determined using the Kjedahl method (Hesse, 1971). Total K was determined using the flame photometry and the total P was measured calometrically after extraction with Mehlich 3 reagent. Lignin was quantified using the acid detergent fibre method by Van Soest and Wine as cited by Okalebo, Gathua and Woomer (2002).

3.5.6 Management of the Experiment

Land preparation for field trials at HERS was done using a tractor drawn disc plough. Maize was planted on the 22nd of December 2006 on the sandy soil site because the jatropha cake was not available in required quantities. Planting on the clayey soil site was done on 3 January 2007 because the site was dry in the third and fourth week of December 2006. Weeding was done twice at 2wace and 5wace in all field experiments. Rainfall was recorded and it was measured using standard rain gauges.

3.5.7 Standardization of Maize Grain Yield

Grain yield was standardized using the following formula;

Grain Yield (Y) = FWP x DM x S x F x M

Where Y = Grain Yield in Kgs/ha at 12.5% moisture content

FWP = Fresh grain weight per net plot in kg at harvesting

DM = Fraction of dry matter in sample (dry weight/fresh weight) in kg

S = Shelling percentage of maize expressed as a fraction

F = Conversion factor from kg/net plot to kg/ha

M = Moisture factor = 100/87.5 for 12.5 % moisture

3.5.8 Data Analysis

Randomisation of treatments was done using GENSTAT Statistical Package Version 8. Analysis of variance (ANOVA) for the data was done using Genstat statistical Package. F test for the comparison of means at 95% confidence level Least Significance Difference was used to compare the means where there were significantly different at alpha level 0.05. Data transformations were done on weed counts using log transformation method.

CHAPTER 4

EXPERIMENT 1

EVALUATING THE EFFECT OF VARYING LEVELS OF JATROPHA SEED CAKE ON MAIZE GROWTH, YIELD, WEED DENSITY AND BIOMASS UNDER RESEARCHER MANAGED CONDITIONS

4.0 Introduction

For a long time, crop production depended on organic resources for soil fertility replenishment, either by including long-term fallow periods, as was, for example, the case in sub-Saharan Africa (SSA), or by application of vast amounts of manures or other organic resources, e.g., sods of peat in northern Belgium (Dudal, 2001). The use of fertilizers started in western Europe only at the end of the 19th century in response to a higher demand for food. Other continents followed at a later stage (Van Lauwe, Palm, Murwira, and Merckx, 2002)

Manures from the smallholder farming sector of Zimbabwe have been the major source of nutrients in crop production systems in the country. They are now found in limited quantities that can not sustain maize production in the sector. The cattle manure from the same sector mineralise N slowly due to aerobic composting (Murwira and Kirchman, 1993). A study carried out by Murwira (1995) reported that manure from Chihota contained 57.4 % soil hence most of the aerobically composted manures in Zimbabwe are poor sources of N for crop production (Nyamangara, *et. al.* 2003). Given the limited quantities of available manure and the high cost of inorganic fertilizers, there is need to find alternative organic sources of nutrients for crop production.

Jatropha seed cake a waste product produced during the extraction of oil from jatropha seed has shown a lot of potential as an organic source of nutrients in vegetable production in

Zimbabwe (Kadzere personal communication), (www.jatropha.org/binga.htm). Its use in maize production has not been documented in Zimbabwe.

The aim of this study was to determine the effectiveness of varying levels of jatropha seed cake on maize growth, dry matter yield, grain yield, weed density and biomass yield over one cropping season.

4.1 Materials and Methods

4.1.1 Experimental Site

The field experiment was carried out at Henderson Research Station about 30km west of Harare during the 2006/2007 rainy season. Two contrasting soil types were used and these were the sandy soil site and the clayey soil sites.

4.1.2 Treatments

The experiment evaluated the performance of six jatropha seed cake application rates with the following levels (0, 767, 1534, 2301, 3068 and 3835kg/ha). Two sets of control plots were used and these consisted of the farmers' practice (farmer prac) that is application of 5000kg/ha cattle manure, and the extension recommendation in the smallholder sector of 200kg/ha Compound D (8 %N, 14 %P_2O_5. 7 % K_2O, 6.5 % S) and 150kg/ha Ammonium Nitrate (34.5%N).

4.1.3 Experimental design and lay out

The experiment was laid out as a 2 x 8 factorial experiment arranged in a RCBD with three replications. The factors were; 2 soil types viz sandy and clayey and the 8 treatment levels (6 cake levels plus the 2 controls). A total of eight treatments per replication were used.

4.1.4 Characterisation of the jatropha seed cake used in the experiment

Figure 4.1 Jatropha seed cake (press cake) just after oil extraction

A sample of the jatropha seed cake was analysed at the Chemistry & Soils Research Institute in the Department of Agricultural Research & Extension (Harare) in December 2006. The mineral nutrient concentrations are shown in Table 4.1

Table 4.1 Mineral nutrient content of jatropha seed cake

Mineral Nutrient	Content
Nitrogen (%)	3.26
Phosphorus (%)	0.504
Potassium (%)	2.25
Calcium (%)	0.58
Magnesium (%)	0.45
Manganese (p.p.m)	219
Zinc (p.p.m)	31
Boron (p.p.m)	38
Copper (p.p.m)	16

4.1.5 Lignin Content and dry matter of the jatropha seed cake

A sample of the same jatropha cake was also analysed for lignin and dry matter at the Department of Animal Science at the University of Zimbabwe and the results were as shown in Table 2.2 below:

Table 4.2 Lignin content and dry matter of jatropha seed cake

Parameter	**Quality**
% Lignin	13.34
% Dry matter	93.29

4.1.6 Management of the experiment

The experiment site had been under grass fallow the previous season and was ploughed using a tractor drawn disc plough. The gross plot was 5.4m x 6m, with six rows spaced at 90cm apart. The intra row spacing was 30cm, to give a plant population of 37 000 plants per hectare. The net plot was 1.8m x 3.6m. SC 513 maize variety was planted. Planting was done on the 22nd of December 2006 and 3rd of January 2007 on the sandy and clayey experimental blocks respectively.

Weed sampling was done at 2 and 5wace and hand hoe weeding was then done immediately after sampling on the same day. Weeds were harvested along and between the maize rows with a 30cm x 30cm quadrant. Sampling was done between 2nd and 3rd maize rows and along the 3rd and 4th rows. The sampling was done at random along and between maize rows. A total of 4 points were sampled per plot; two points were sampled along each row and 2 points between two maize rows. Sampling was done, just before weeding at 2wace and 5wace. The above ground weed biomass was harvested; weeds were separated into species and counted. All the weeds in each quadrant were weighed to determine the biomass yield. The weeds were dried at 60^{o}C for 24 hours and weighed for dry matter determination.

The maize crop was harvested after attainment of physiological maturity. The moisture content of the maize grain was determined and was adjusted to 12.5%. The grain yield data was also standardized using formula on page 15.

4.1.7 Data Analysis

Plant height, maize dry matter, weed density and weed biomass data variables were analysed using the GENSTAT Statistical Package Version 8. Single site data analysis was done. Across site data analysis was also done to compare the effect of the jatropha seed cake on the contrasting soil types. ANOVA was performed after testing for normality of the data and homogeneity of variance using the Bartlett's Test. Mean separation was done, Least Significant Difference statistic was used to separate treatment means that were significantly different for plant height and dry matter, weed density and weed biomass variables. An alpha level of 0.05 was used. Weed density data was transformed using log transformation method.

4.2 Results

4.2.1 Rainfall received at HERS

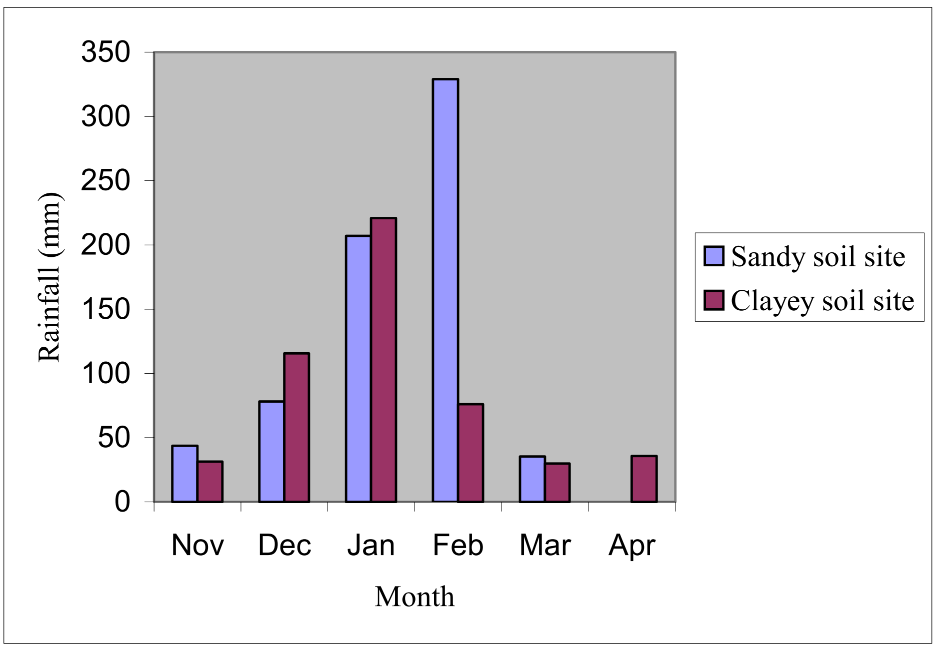

Figure 4.2 Rainfall received at HERS in the 2006/07 season

The amount of rainfall received and its distribution differed per site in the 2006/2007 season. The rainfall totals were 456mm and 509.7mm for the sandy and clayey soil sites respectively. Both sites received below the average potential of Natural Region II of 700mm. Rainfall distribution was better at the clayey soil site compared to the sandy site. The crop growing season prematurely ended at the sandy soil site when the rains ended in March. Results presented here are reported on a site basis.

4.2.2 Effect of jatropha seed cake rate on maize plant heights at HERS Sandy Soil Site

The jatropha cake level had a significant effect ($P \leq 0.05$) on the plant heights at 4, 8 and 12wace on the sandy soil site (Table 4.3). The following jatropha cake rates, 2301kg/ha, 3068kg/ha and 3835kg/ha had taller plants compared to extension recommendation inorganic fertilizer and the farmer practice treatments at 4 wace. All the jatropha cake levels out performed the control, which had the lowest plant height of 34cm at 4 weeks. However the control was not different ($P \leq 0.05$) from the farmer practice. There was no significant difference ($P \leq 0.05$) between maize plant heights from plots treated with jatropha cake levels of 2301kg/ha 3068kg/ha and 3835kg/ha and the extension recommendation treatment at 8 weeks. A similar trend was also noted at 12 wace at the sandy soil site (Table 4.3).

Table 4.3 Effect of jatropha seed cake rate on maize plant heights at 4, 8 and 12wace at HERS sandy soil site

	Plant height in cm		
Jatropha cake rate	**4wace**	**8wace**	**12wace**
Control	34^{c}	55^{c}	108^{bc}
767kg/ha	56^{ab}	86^{b}	136^{b}
1534kg/ha	54^{b}	92^{b}	134^{b}
2301kg/ha	65^{a}	117^{a}	166^{ab}
3068kg/ha	66^{a}	134^{a}	192^{a}
3835kg/ha	66^{a}	133^{a}	171^{a}
Extn recom	50^{b}	117^{a}	162^{a}
Farmer practice	35^{c}	57^{c}	114^{bc}
P value	0.000	0.000	0.001
$LSD_{0.05}$	9.62	24.62	34.07

Note: Means followed by different letters in the column are significantly different at $P \leq 0.05$

4.2.3 Effect of jatropha seed cake rate on maize plant heights at HERS Clayey Soil Site

Table 4.4 Effect of jatropha seed cake rate on maize plant heights at HERS Clayey Soil Site

	Plant height in cm		
Jatropha cake rate	**4wace**	**8wace**	**12wace**
Control	95	131	262
767kg/ha	98	138	266
1534kg/ha	99	142	267
2301kg/ha	99	139	276
3068kg/ha	102	145	270
3835kg/ha	101	144	266
Extn recom	99	137	267
Farmer prac	96	132	264
P Value	0.242	0.114	0.110
Significance	ns	ns	ns

Note: Means followed by different letters in the column are significantly different at P≤0.05

Jatropha seed cake application rate had no significant effect (P≤0.05) on plant heights at 4, 8 and 12wace on the clayey site.

4.2.4 Effect of soil type on maize dry matter at HERS

Table 4.5 The effect of soil type on maize dry matter at 4, 8 & 12wace at HERS

Soil Type	**Maize dry matter in kg/ha**		
	4wace	8wace	12wace
Sandy	271[b]	1470 [b] (442%)	2595 [b] (77%)
Clayey	1307[a]	6533 [a] (400%)	10225 [a] (57%)
P value	<.001	<.001	<.001
LSD $_{0.05}$	88.4	504.3	776.2

Note: Means followed by different letters in the column are significantly different at P≤0.05
Figures in brackets show percent increase in maize dry matter from 4wace to 8wace and from 8wace to 12wace respectively.

The clayey soil site had significantly higher ((P≤ 0.05) maize dry matter yields at 4, 8 and 12wace compared to the sandy soil site (Table 4.5). The rate of biomass accumulation was however higher on the sandy soil site by 42 % and 20 % from 4wace to 8wace and from 8wace to 12wace respectively.

4.2.5 Effect of jatropha seed cake rate on maize dry matter yield at 4, 8 and 12wace at HERS Sandy soil site

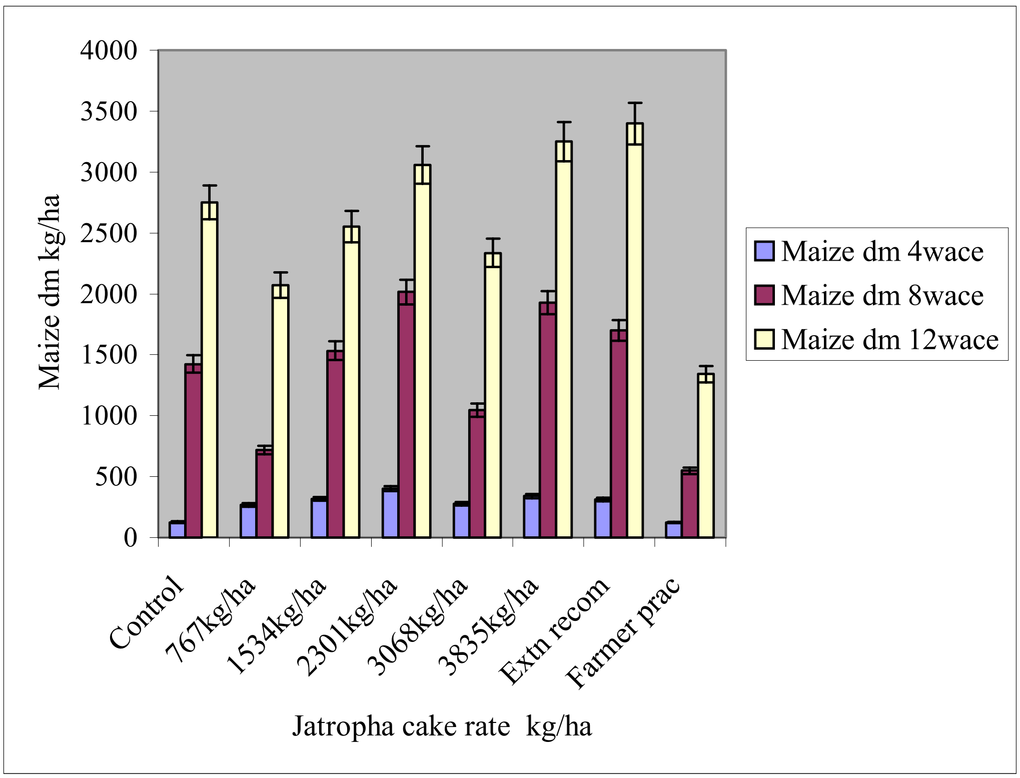

Figure 4.3 Effect of jatropha seed cake application rate on maize dry matter yield at 4, 8 and 12wace at HERS on sandy soil site. Error bars represent LSD $_{0.05}$

Figure 4.4 Effect of jatropha seed cake on maize growth at 4wace February 2007 HERS Sandy Site

Differences in plant height and growth could be seen visually in the field as illustrated by the above picture taken on the 4th of February 2007

Maize dry matter yield at 4wace was significantly different ($P \leq 0.05$) between the jatropha seed cake levels 2301kg/ha, 3068kg/ha, and 3835kg/ha and the farmer practice at 4wace, with the jatropha seed cake levels having higher yields compared with farmer practice and the control. The highest mean dry matter yield was 401kg/ha and it was attained by the jatropha cake rate of 2301kg/ha (Figure 4.3) The farmer practice and the control treatments performed equally and poorly and had lower ($P \leq 0.05$) maize dry matter yields of 125kg/ha and 126kg/ha respectively.

At 8wace, the following jatropha cake rates 2301kg/ha and 3835kg/ha had higher ($P \leq 0.05$) maize dry matter yields (2016kg/ha and 1928kg/ha respectively) compared to the extension recommendation inorganic fertilizer rate treatment, which gave a yield of 1700kg/ha. The jatropha cake rate of 767kg and the farmer practice had lower dry matter yields of 718kg/ha and 548kg/ha respectively.

At 12wace, the extension recommendation inorganic fertilizer treatment, jatropha cake rates of 2301kg/ha and 3835kg/ha attained higher ($P \leq 0.05$) maize dry matter yields of 3059kg/ha, 3235kg/ha respectively. The farmer practice had the lowest yield of 1341kg/ha (Figure 4.3).

4.2.6 Effect of jatropha seed cake rate on maize dry matter yield at 4, 8 and 12wace at HERS on the clayey soil site

Jatropha seed cake rate at 4wace, 8wace and 12 wace did not significantly affect maize dry matter ($P \leq 0.05$) on the clayey soil site (See Appendix 5, 6 and 7).

Grain yield was not obtained at both the sandy and clayey soil sites because the maize crop was damaged by baboons and wild pigs on both sites respectively.

4.3 Weed studies in a maize crop fertilized with jatropha seed cake

4.3.1 Ranked average weed counts per species at 2wace on the sandy soil site

Table 4.6 Ranked average weed counts per species at 2wace sandy soil site

Weed Species	Average weed counts
R. scabra	121
F. exilis	45
Gnaphalium spp	19
C. esculentus	10
A. hispidum	5
Digitaria spp	2

NB The average weed counts were based on the number of weed found in the whole sampled area (i.e. counts from the 12 quadrants from both positions i.e. along the maize rows where jatropha cake was applied and between maize rows).

The main weeds found on the experimental site were *Richardia scabra*, *Fimbrystilis exilis, Cyperus esculentus, Acanthospermum hispidum, Gnaphalium spp* and *Digitaria spp (comprising of D. ternate, D. tremula and D.viscose).* Other weeds that were present were *Eragrostis spp, Hibiscus meeuisei* and *Bidens pilosa.*

4.3.2 The effects of rate of jatropha application rate on weed species and counts at 2wace on the sandy soil site

Table 4.7 Effect of jatropha seed cake application rate on weed counts (plants/m^2) at 2wace Sandy soil

	Weed Species				
Jatropha rate	***R. scabra***	***C. esculentus***	***A. hispidum***	***F. exilis***	***Eragrostis spp***
Control	8.21	1.28	1.68	4.17	0.71[a]
767kg/ha	4.05	1.16	1.45	5.28	2.50[b]
1534kg/ha	4.25	2.13	2.02	5.27	1.00[a]
2301kg/ha	6.85	2.13	1.45	5.03	0.71[a]
3068kg/ha	6.16	2.67	1.29	4.18	1.93[b]
3835kg/ha	7.11	2.28	2.18	4.85	0.71[a]
Extn Recom	6.69	1.68	1.00	4.99	0.71[a]
Farmer prac	3.06	1.00	1.74	4.75	0.71[a]
P value	0.188	0.409	0.398	0.785	0.007
LSD	ns	ns	ns	ns	1.075

Means followed by different letters in the column are significantly different at P≤0.05

The jatropha seed cake application rate had significant effect (P≤0.05) on Eragrostis species. The lowest jatropha cake level of 767kg/ha had higher weed counts. There were however no differences (P≤0.05) between the control, 3825kg/ha jatropha cake, extension recommendation inorganic fertilizer and farmer practice treatments. There were no significant differences (P≤0.05) across all the jatropha cake application rates in all the other weed species that were found on the experimental site.

4.3.3 *Effects of sampling position on weed counts (plants/m^2) at 2wace on the sandy soil site*

Table 4.8 Effect of weed sampling position on weed counts(plants/m^2) at 2 wace sandy soil site

Weed Species

Sampling position	*Digitaria spp*	*F exilis*	*Gnaphalium spp*	*Eragrostis spp*
Between rows	0.707^{b}	5.62^{a}	0.71^{b}	1.42^{a}
Along rows	1.185^{a}	4.00^{b}	1.28^{a}	0.82^{b}
P value	0.016	<.001	0.048	0.03
LSD	0.3827	0.846	0.570	0.538

Means followed by different letters in the column are significantly different at P≤0.05

Weed sampling position had a positive effect on weed counts (P≤0.05) of the following weed species *Digitaria species, F. exilis, Gnaphalium spp. and Eragrostis spp*. had significantly lower weed counts (P≤0.05) along the maize rows. *Digitaria spp* and *Gnaphalium spp.* had lower weed counts (P≤0.05) when weeds were sampled between the maize rows. The interaction between position and seed cake level was not significant for all the weed species.

4.3.4 *Effects of weed sampling position on weed biomass (g/m^2) at 2wace sandy soil site*

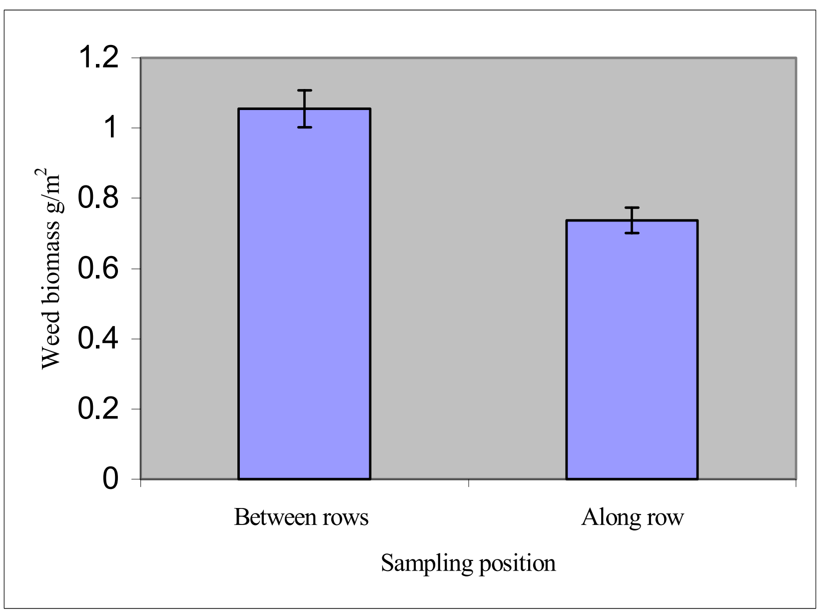

Figure 4.5 Effect of weed sampling position on weed biomass at 2wace at the sandy soil site

The sampling position had a positive effect (P≤0.05) on weed biomass. Weed biomass was lower along the maize row where jatropha cake was applied compared to the area between maize rows where jatropha cake was not applied. The different application levels of jatropha seed cake did not have any effect on weed biomass at 2wace (Appendix 24).

4.3.5 Ranked average weed counts per species at 5wace on the Sandy soil site

Table 4.9 Ranked average weed counts per species at 5wace sandy soil site

Weed species	Average weed counts
R. scabra	46
F. exilis	25
C. esculentus	5
A. hispidum	4
Gnaphaliun spp	1
Digitaria spp	1

Weeds species found during sampling at 5wace were *R. scabra, F. exilis, C. esculentus, A. hispidum, Gnaphalium spp and Digitaria spp.*

4.3.6 The effect of rate of jatropha application rate and sampling position on weed species and counts at 5wace on the sandy soil site

Table 4.10 Effect of jatropha seed cake application rate on weed counts (plants/m^{2}) at 5 wace at the sandy soil site

	Weed Species (plants/m^2)	
Cake rate	***R. scabra***	***F.** exilis*
Control	11.02 ^{b}	2.75 ^{ab}
767kg/ha	12.99 ^{b}	6.51 ^{bcd}
1534kg/ha	10.61 ^{b}	5.87 ^{abcd}
2301kg/ha	9.59 ^{ab}	2.63 ^{abc}
3068kg/ha	10.64 ^{b}	5.81 ^{abcd}
3835kg/ha	11.72 ^{b}	8.89 ^{d}
Extn recom	10.88 ^{b}	2.15 ^{abc}
Farmer practice	6.62 ^{a}	4.06 ^{abc}
P value	0.044	0.037
LSD	3.452	4.266

Means followed by the same letter within the column are not significantly different at $P \leq 0.05$

Two weed species viz *R. scabra* and *F. exilis'*s weed counts were affected ($P \leq 0.05$) by the jatropha seed cake application rate. The farmer practice had lower weed counts of *R. scabra* compared to the other treatments. Jatropha seed cake application rates of 767kg/ha and 3835kg/ha had higher weed counts of the weed species *F. exilis.* Weed sampling position and jatropha cake application level had no effect ($P \leq 0.05$) on the weed dry matter yield at 5 wace on the sandy soil site (Appendix 30).

4.3.7 *Ranked average weed counts per species at 2wace on the clayey soil site*

Table 4.11 Ranked average weed counts per species at 2wace clayey soil site

Weed Species	Average weed count
Panicum maximum	44
Bidens pilosa	20
Hibiscus meeuisei	18
Nicandra physaloides	16
Galinsoga parviflora	9

16 weed species were identified at the clay experimental site. Weeds species which had the highest weed counts were *Panicum maximum, Bidens pilosa, Hibiscus meeuisei, Nicandra physaloides and Galinsoga parviflora.* The other weed species found on the site were *Cyperus rotundus . Setaria pumula, Trumpheta annua, Commelina bengalensis, Cyperus esculentus, Melens repens, Setaria verticilata, Leucas martinicensis, Ipomeia plebeia, Tagetes minuta and Rottbolia.*

4.3.8 *Effect of jatropha application rate on weed species and weed counts at 2wace on the clayey soil site*

Table 4.12 Effect of rate of jatropha seed cake on weed counts/m^2 at 2 wace at the clayey soil site

	Weed Species				
Cake rate	***P. maximum***	***G. parviflora***	***N. physaloides***	***B. pilosa***	***C. rotundus***
Control	0.707	1.97	3.65	4.64	1.29
767kg/ha	0.707	1.29	4.10	4.10	1.48
1534kg/ha	0.707	3.82	3.28	3.34	0.71
2301kg/ha	0.999	2.59	4.26	3.27	0.71
3068kg/ha	0.999	2.13	4.09	4.76	0.71
3835kg/ha	1.157	2.51	2.74	5.12	1.96
Extension Recom	1.157	3.17	4.58	4.37	0.71
Farmer practice	0.707	3.02	3.60	4.37	1.00
P value	0.280	0.526	0.743	0.743	0.200
LSD	ns	ns	ns	ns	ns

The cake application rate had no significant effect ($P \leq 0.05$) on weed counts in all the weed species that were found on the clay soil experimental site at 2wace.

4.3.9 *Effect of weed sampling position on weed species and weed counts at 2wace on the clayey soil site*

Table 4.13 Effect of weed sampling position on weed counts /m² at 2 wace clayey soil site

	Weed Species (plants//m²)		
Cake rate	***T. annua***	***C. rotundus***	***L. martinicensis***
Between maize row	2.16 [a]	1.36 [a]	4.52 [a]
Along maize row	1.60 [b]	0.78 [b]	3.60 [b]
P value	0.045	0.04	0.036
LSD	0.554	0.548	0.853

Means followed by the same letter within the column are not significantly different at P≤0.05

The sampling position significantly affected the weed counts (P≤ 0.05) for the following weed species, *T. annua, C. rotundus* and *L. martinicensis.* Weed counts were lower when sampling was done along the maize row. The weed counts were (39), (6) and (3891) along the maize rows compared to (144), (23) and (33 113) for the weed species *T. annua,* C. *rotundus* and *L. martinicensis* respectively.

4.3.10 *Effects of jatropha seed cake application rate on weed biomass g/m² on clayey Soil Site at 2wace*

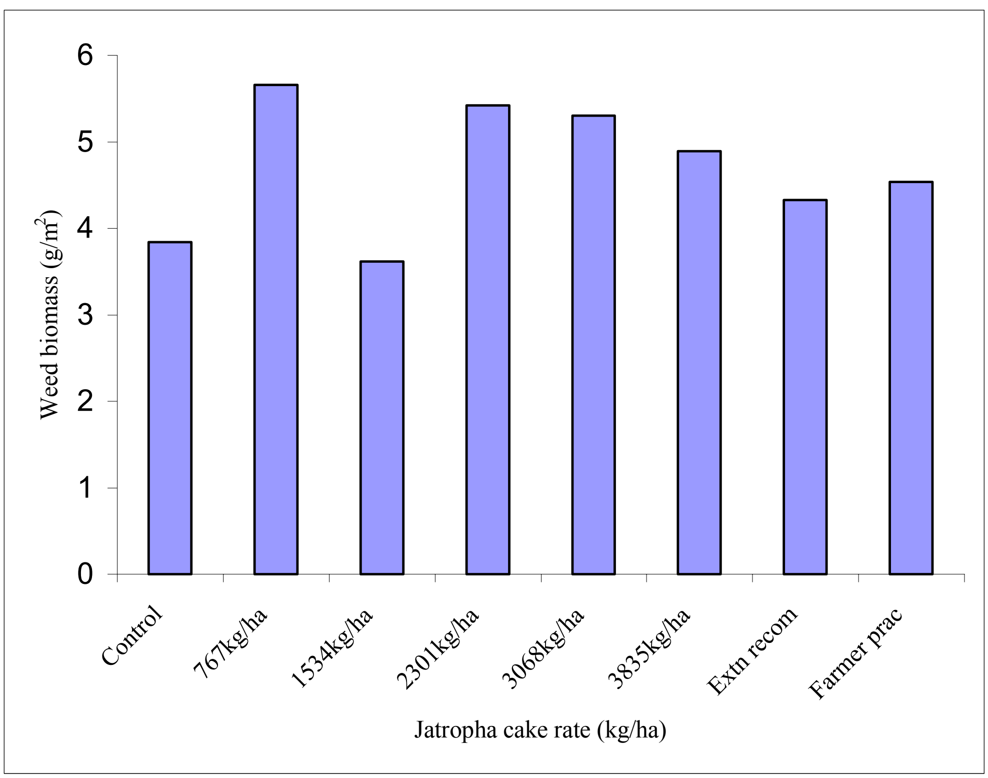

Figure 4.6 Effect of jatropha seed cake application rate on weed biomass (g/m²) on clayey soil site at 2wace

There were no differences ($P \leq 0.05$) between the jatropha seed cake application rates, extension recommendation, farmer practice and the control with respect to weed biomass (g/m^2) on the clayey soil site at 2wace (Figure 4.6).

4.4 Discussion

4.4.1 Effects of jatropha seed cake, cattle manure and inorganic fertilizer on biomass accumulation on sandy soil

The findings from this study indicate that biomass accumulation in plots at the sandy soil site that received manure was low. This trend has been reported by other researchers such as Mugwira and Murwira (1997) who noted nitrogen deficiency in maize fertilized with cattle manure during early plant growth (up to 6weeks) after planting. Tester (1990) also noted that only one third of the total nitrogen in manure is released during the first year of application.

In contrast, application of jatropha seed cake in the sandy soils resulted in high biomass accumulation compared with cattle manure during the earlier part of the crop growth. This could be an indication that the cake decomposed quickly leading to the release of nitrogen and possibly other nutrients early. Saunder and Grant (1962) reported higher N mineralization rates in sandy soils (2-4% of total N per annum) compared to clay soils (2-3 %) under field conditions in Zimbabwe. The nutrient mineralization pattern of the jatropha seed cake was not part of the study in this experiment and hence was not quantified.

The jatropha seed cake that was used in the study had relatively high nitrogen (3.26 %), phosphorus (0.504 %) and potassium (2.25 %) content (Chemistry & Soils Research Unit Analysis Report 2006) compared to other organic sources of nutrients such as cattle manure Mubonderi (1999) reported average nutrient content levels as follows nitrogen (1.18%), phosphorus (0.223 %) and potassium (0.95 %) for cattle manure samples taken from Chinyika a smallholder farming area.

The rapid biomass accumulation by the jatropha cake treatments at the sandy soil site might be an indication that there is little immobilisation of N from the time of application. This is supported by a recommendation made by Van Lauwe, Palm, Murwira and Merckx (2002) that organic materials with an N content of greater than 2.5 % and a lignin content of less than 15% are good quality organic sources of nutrients. It is recommended that such organic material be directly applied to the soil as they are expected to release a substantial amount of N in a short time (Van Lauwe *et. al.,* 2002).

Cattle manure application however resulted in stunted growth. This observation is supported by work done by Nyamangara *et al,* (2003). The stunted growth may be explained by the fact that there was nitrogen immobilisation and this was worsened by the low rate of manure applied. Singh, Singh, Maskina and Meelu, (2004) reported that the addition of cattle manure resulted in a period of net N immobilization lasting up to 4 weeks. Mubonderi, (1999) recommended a rate of 10t/ha of manure. The reduced growth rate might have also been confounded by the premature end of the rain season. The maize crop was also showing symptoms of nitrogen deficiency, which were manifested, in the typical yellowing and premature senescence of the older lower leaves

.

Basal fertilizer application rate of 200kg of Compound D (8 %N, 14 %P_2O_5. 7 % K_2O, 6.5 % S) did not result in very high biomass accumulation. The nutrients released from the inorganic fertilizer might also have been lost during the first four weeks of the maize crop's life as more than 75 % of the rains were received then. Nyamangara *et al,* (2003) reported that nitrogen in mineral fertilizer is immediately available for plant uptake but it is susceptible to loss in gaseous forms or by leaching. Leaching of nitrogen in sandy soils occurs at a rate of 5cm per cm of rainfall received (Mubonderi, 1999).

The increase in maize dry matter yield in jatropha seed cake treated plots could also be due the high organic matter content of the cake. Tigere (2002) reported that jatropha seed cake has an organic matter content of 88 % compared to cattle manure, which has an organic matter content ranging from 20-70 %. In a study done by Mubonderi (1999) it was reported that high cattle manure rates increased the water holding capacity of the soil and reduced leaching of mobile nutrients such as nitrogen. It was also observed in this study that during periods of moisture stress plots that received jatropha cake took longer periods to show signs of wilting. However after 12 weeks of growth the maize crop was showing symptoms of nitrogen deficiency.

4.4.2 Effect of jatropha seed cake, cattle manure and inorganic fertilizer on biomass accumulation on clayey soil

Contrary to the results observed on the sandy soil site, the clayey soil site did not register any major differences in terms of plant heights or maize dry matter yield across the treatments. This is possibly because the site had higher clay content and nutrient content compared to the sandy site. Mugwira, Mukurumbira, Butai and Mandiringana (1992) reported that the red clay soils found in Zimbabwe have higher organic matter contents (1.5-2.5 % C, 0.11-0.18 %N) compared to granitic sandy soils (0.4-0.8 % C, 0.03-0.06 %N). The rainfall received at the clayey soil site was also more evenly distributed across the season compared to the sandy soil site.

4.4.3 Effect of jatropha seed cake application rate on weed density and biomass

This study was carried out against a background where information on the effect of jatropha seed cake on weeds was scarce. The jatropha application rate had a significant effect on some weed species such as *Eragrostis spp* at 2wace and *R. scabra* and *F. exilis* at 5wace. For example the jatropha cake rate rates of 767kg/ha, 1534kg/ha and 3068kg/ha had significantly higher weed densities of *Eragrostis spp* at 2wace on the sandy soil site. *R.scabra* and *F. exilis* responded to the application of jatropha seed cake at 5wace. Although differences were noted there was however no definable trend from the results.

4.4.4 Effects of sampling position on weed density and biomass

Sampling along the maize row position resulted in lower weed densities of the following weeds, *F. Exilis* and *Eragrostis* spp on the sandy soil site and *T. annua*, *L.* martinicensis *C. rotundus* on the clayey soil site. The reduction of weed density of *C. rotundus* is of particular interest as this is a most difficult weed to control. The weed can produce underground rhizomes that are about 2m long. The findings of this study seem to suggest that the use of jatropha seed cake can help to reduce the weed numbers of this weed species. This would benefit the farmers tremendously and result in the reduction of time and cost required to manage this weed.

Application of jatropha cake along the maize rows resulted in the reduction of weed counts when sampling was done along the maize rows at 2wace. Weed biomass was also affected by the sampling position with the weed biomass from along the maize row being lower than that sampled between maize rows. Heller (1996) reported that applications of jatropha seed cake resulted in phytotoxicity in tomatoes and this was expressed as reduced germination. The reduction in weed numbers could possibly be explained by way of allelopathic effects of the jatropha seed cake manifested as inhibitory effect (Ourdia, 1997) especially in the case of weed seed germination and growth. This observation confirms the hypothesis advanced by Ashraf and Sen (1978) that the same allelochemicals act differently on different crops and plant species. This can explain why some weed species such as *Digitaria spp* and *Gnaphalium spp* had higher weed densities along the maize rows where jatropha seed cake was applied compared to the others such as *F. exilis* and *Eragrostis spp,* which had lower densities. There were however no differences at 5wace possibly due to possibly to the fact that the allelochemicals found in the jatropha seed cake work for a short period possibly 2 weeks to 3 weeks.

4.5 Conclusion

The results of this study highlight the potential of jatropha seed cake as a sole source of nutrients in maize production on granitic sandy soils. The jatropha seed cake rate of 2301kg/ha constantly gave higher maize dry matter yields in this experiment, beyond which dry matter was not stable. Better growth of the maize crop was noted mainly from 4wace to 8wace across the jatropha application levels this could be an indication that the nutrient supplying power of the cake weakened there after. Application of jatropha seed cake resulted in the reduction of weed densities of some weed species and the total weed biomass. This suggests that farmers can make a saving on labour costs since they will spend less time weeding a maize crop fertilized with jatropha seed cake. It is therefore a recommendation of this study that jatropha seed cake be applied in maize production systems to reduce weed density and biomass, improve maize biomass accumulation and reduce the drudgery associated with smallholder farming.

There is however need to repeat the work in different seasons and also to undertake detailed weed studies for example in pot experiments so as to confirm the positive and or negative effects of jatropha seed cake on some weed species.

CHAPTER 5

EXPERIMENT 2

THE EFFECT OF JATROPHA SEED CAKE SUPPLEMENTED WITH INORGANIC N FERTILIZER ON MAIZE GROWTH AND GRAIN YIELD

5.0 Introduction

Organic amendments used in crop production do not provide all nutrients required by crops in required quantities. For a farmer to get all nutrients required he has to use inorganic fertilisers. These fertilizers are expensive and at times unavailable on the market, hence it is more economical to use a moderate quantity of organic amendment and supplement it with inorganic fertiliser.

Nitrogen is of major importance in crop production as it is the most limiting plant nutrient in most soils in Zimbabwe (Grant, 1981). Maize as the staple crop receives most of the N fertilizer (Nyamangara *et. al,* 2003). Despite this nitrogen deficiency has been widely reported in maize during the early plant growth (up to six weeks after planting) when manure is used as the sole N source (Mugwira and Murwira, 1997). The use of combinations of organic and inorganic fertilizers becomes necessary to increase crop yield levels.

The concept of integrated nutrient management utilizing available organic and inorganic nutrient resources has become a dominant paradigm for research in the smallholder agricultural systems of Sub Saharan Africa (Van Lauwe, Wendt and Diels, 2001) A number of studies have been carried out that examined the effect of combining cattle manure and inorganic N fertilizer in maize production (Munguri, 1996; Mubonderi, 1999 and Nyamangara *et al,* 2003). Rate of cattle manure recommended when supplementing with inorganic nitrogen vary widely from 4.5t/ha plus 90kg nitrogen (Rodel *et al,* 1980). According to Whingwiri and Mataruka (1987) the rate of 8t/ha of manure plus 122kg of inorganic nitrogen used as top dressing is recommended in the smallholder sector. Given the limited quantities of organic resources available in the smallholder sector and the limited quantities of inorganic fertilizer available to smallholder farmers (Nyamangara *et. al,* 2003) there is the possibility of increasing the effectiveness of the two nutrient sources when applied in combination. The combination of locally available organic manures and inorganic fertilizers may be an appropriate way to reduce cost of inorganic fertilizer and to reduce decline in soil fertility in smallholder cropping systems in Zimbabwe.

The objective of this study was to evaluate the effectiveness of combining jatropha seed cake and inorganic N fertilizer on maize growth, biomass accumulation and grain yield.

5.1 Materials and Methods

5.1.1 Experimental Site

The field experiment was conducted at HERS in Mazoe on a sandy soil site during the 2006/2007 rainy season.

5.1.2 Experimental Treatments

The experiment evaluated the performance of three jatropha seed cake levels (0, 767, 1534kg/ha) supplemented with three levels of inorganic nitrogen fertilizer (0, 50, 100kg N/ha). Three other treatments were included in the study; these were the application of 200kg/ha Compound D (8 %N, 14 %P_2O_5. 7 % K_2O, 6.5 % S) at planting supplemented with the three rates of inorganic nitrogen viz (0, 50, 100kg N/ha). A total of 12 treatments were used in the experiment.

5.1.3 Experimental Design and lay out

The experiment was laid out as a 3 x 3 factorial experiment arranged in an RCBD with three replicates. The factors were the three jatropha seed cake rates and the 3 inorganic nitrogen rates. An inorganic fertilizer rate of 200kg/ha Compound D was also included as a control supplemented with the three levels of inorganic N fertilizer. This made up a total of 12 treatments within a replicate.

5.1.4 Characterisation of the jatropha cake used in the experiment

The jatropha cake used in this experiment was the same as the one used in Experiment 1. The nutrient content was as shown in the table below:

Table 5.1 Mineral nutrient content of jatropha seed cake

Mineral Nutrient	Content
Nitrogen (%)	3.26
Phosphorus (%)	0.504

Potassium (%)	2.25
Calcium (%)	0.58
Magnesium (%)	0.45
Manganese (p.p.m)	219
Zinc (p.p.m)	31
Boron (p.p.m)	38
Copper (p.p.m)	16

5.1.5 Lignin and dry matter of the jatropha seed cake

A sample of the same jatropha cake was also analysed for lignin and dry matter at the Department of Animal Science at the University of Zimbabwe and the results were as shown in Table 5.2.

Table 5.2 Lignin content and dry matter of jatropha seed cake

Parameter	Quality
% Lignin	13.34
% Dry matter	93.29

5.1.6 Management of the experiment

The land was ploughed using a tractor drawn disc plough. The gross plot was be 5.4m x 6m. The inter row and intra row spacing was 90cm x 30cm. The net plot was 1.8m x 3.6m. Maize variety SC 513 was used in the experiment. The jatropha seed cake was applied in its raw state in furrows about 5 to 10cm deep. A thin layer of soil of about 2cm was applied to cover the cake. Planting of maize was done on the same day the jatropha seed cake was applied. Both operations were done on the 22nd of December 2006. The gross plot size was 611m long and 5.4m wide and the net plot was 3.6m long and 1.8m wide.

Hoe weeding was done at 2 and 5wace. Foliar sampling was done at 4, 8 and 12 wace. The samples were oven dried at 60^{o}C for 4 days for dry matter determination and were then stored pending analysis.

The maize crop was harvested at physiological maturity. The moisture content of the maize grain was determined and was adjusted to 12.5%. Standardization of grain data was also done.

5.1.7 Data Analysis

The data were analysed using the GENSTAT Statistical Package Version 8. ANOVA was performed to determine overall treatment effects for the dry matter and grain yield variables, after testing for normality of the data and homogeneity of variance. Maize dry matter yield data at 4wace was transformed using the Box cox method. Mean separation was done using the LSD to separate treatment means that were significantly different for plant height and dry matter and grain yield parameters. Alpha level 0.05 was used.

5.2 Results

5.2.1 Rainfall distribution at Henderson Research Station

A total of 456mm was received. The amount received translates to about 65% of the average potential of the Mazowe area of 700mm. The rains were spread over the months of November 2006 to March 2007 with less than 100mm being received per month in November, December and March.

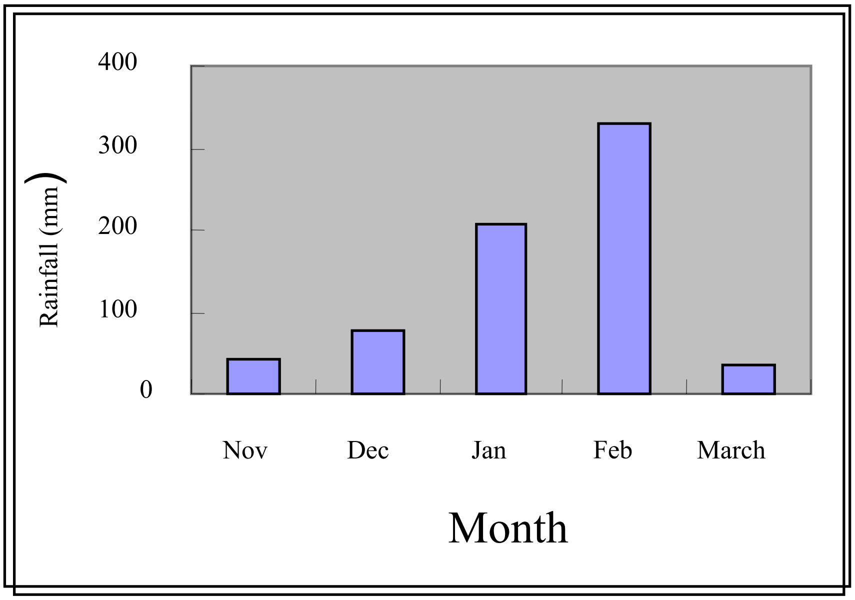

Figure 5.1 Rainfall graph for the HERS Sandy Soil Site (2006/2007 season)

5.2.2 Effects of jatropha cake rate on maize dry matter yield at 4, 8 and 12wace

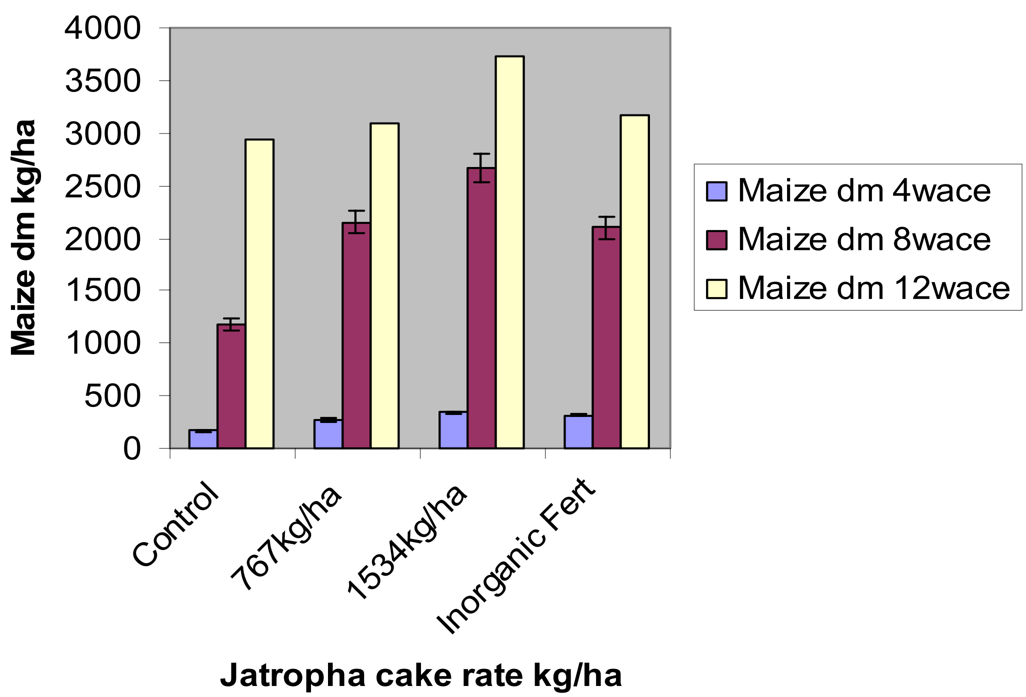

Figure 5.2 Effects of jatropha cake application rate on maize dry matter yield at 4, 8 and 12wace HERS Site

At 4wace the jatropha seed cake application rate of 1534kg/ha and the extension recommendation inorganic fertilizer treatment had significantly ($P \leq 0.05$) higher maize dry matter yields. There was no significant difference ($P \leq 0.05$) between the lower jatropha seed cake rate of 767kg/ha and the extension recommendation inorganic fertilizer treatment. (Figure 5.2) The control had the lowest yield of (172kg/ha).

At 8wace the jatropha seed cake levels (767kg/ha and 1534kg/ha) and the extension recommendation inorganic fertilizer treatment had similar yield levels but were all significantly different from the control. The mean maize dry matter yield at 8wace was 2021kg/ha. There were no significant differences ($P \leq 0.05$) noted at 12wace.

Figure 5.3 Effects of jatropha seed cake on maize growth at 4wace

Maize plants that received jatropha seed cake grew at a faster rate and were greener than the maize plants that did not receive jatropha seed cake.

5.2.3 Effect of Inorganic nitrogen fertilizer on maize dry matter yield at 8 and 12wace

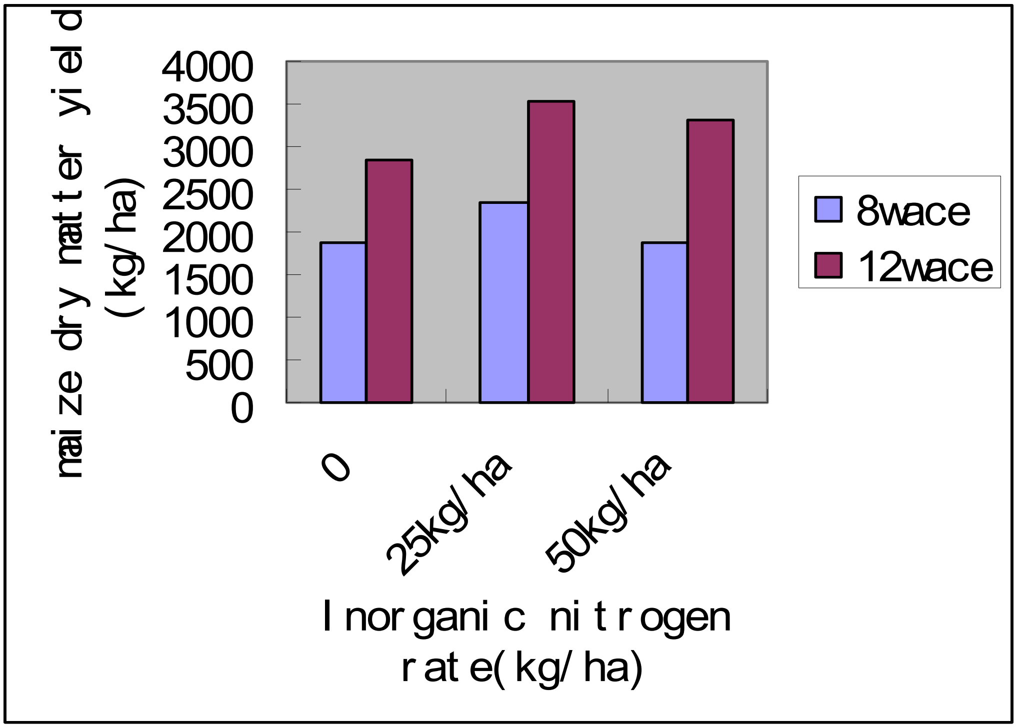

Figure 5.4 Effects of inorganic nitrogen fertilizer on maize dry matter yield at 8 and 12wace

No significant differences ($P \leq 0.05$) were noted due to the addition of in inorganic nitrogen fertilizer at 8 and 12wace (see Figure 5.4).

5.2.4 Effects of jatropha cake application rate x inorganic nitrogen interaction on maize grain yield

Table 5.3 Effect of jatropha cake application rate, inorganic nitrogen and the interaction on maize grain yield

Jatropha cake rate	Inorganic N rate			Means
	0	25	50	
0kg	622	653	339	538 [b]
767kg/ha	621	853	1389	954 [a]
1534kg/ha	641	1244	1222	1036 [a]
Inorganic fertilizer	536	1139	1182	952 [a]
Means	605[b]	972[a]		1033[a]
	P Value		LSD	
Effect of jatropha	0.017		319.2	
Effect of Inorganic N	0.009		276.4	
Jatropha X N interaction	0.103		ns	

Means followed by the same letter within the column are not significantly different at P≤0.05

5.2.5 Effects of jatropha cake application rate on maize grain yield

The use of jatropha seed cake and inorganic fertilizer resulted in significantly higher (P≤0.05) grain yield. Statistically there were no differences (P≤0.05) between the two jatropha cake levels (767kg/ha and 1534kg/ha) and the inorganic fertilizer treatment. The control had a significantly lower (P≤0.05) yield of 538kg/ha compared to the jatropha seed cake and inorganic fertilizer treatments.

5.2.6 Effects of inorganic nitrogen fertilizer on maize grain yield

Grain yield increased with the addition of inorganic nitrogen fertilizer from 605kg/ha to 1033kg/ha. There was no significant difference (P≤0.05) between the two inorganic nitrogen application level of 25kg/ha N and 50kg/ha N.

5.2.7 Effect of jatropha cake application rate x inorganic nitrogen interaction on maize grain yield

The interaction between the jatropha seed cake application level and the inorganic nitrogen fertiliser was not significant ($P \leq 0.05$) (Table 5.3). These results show that addition of inorganic nitrogen to jatropha treated plots did not result in any added benefits.

5.3 Discussion

5.3.1 Effect of jatropha seed cake application rate and inorganic fertilizer on maize dry matter yield

Maize dry matter yield responded positively to the application of jatropha seed cake. Use of the jatropha seed cake resulted in higher yield increase probably due to the availability of nitrogen and other nutrients such as potassium and zinc released from the jatropha seed cake. The dry matter accumulation rate was lower in the control possibly because of the low inherent nutrient content of the soil as well as the low pH.

The rapid biomass accumulation by the jatropha cake treatments at the sandy soil site might be an indication that there is little immobilisation of N from the time of application as highlighted in Experiment 1. This is supported by a recommendation made by Van Lauwe, Palm, Murwira and Merckx (2002) that organic materials with an N content of greater than 2.5 % and a lignin content of less than 15% are good quality organic sources of nutrients. The jatropha seed cake used in this experiment falls within the good quality category as it contained 3.26% N and 13% lignin.

Even though there were no differences in dry matter yield between the jatropha cake rates and inorganic fertilizer treatment the rate of accumulation was lower in the fertilizer treatment possibly due to leaching. The high dry matter accumulation can also be possibly attributed to the release of other nutrients such as potassium and possibly micro nutrients such as zinc by the jatropha seed cake.

The maize plants however showed acute phosphorus deficiency in the control plots and all the jatropha seed cake treatments. The low phosphorus content of the cake (0.504 %) can explain this. This meant that at the application rate of 767kg/ha of jatropha seed cake 3.87kg/ha of phosphorus was effectively applied. This amount was much lower compared to the amount of phosphorus supplied by the Compound D inorganic fertilizer which amounted to 28kg/ha.

5.3.2 Effects of inorganic N fertilizer on maize dry matter yield at 8wace and 12wace

Application of inorganic nitrogen did not significantly affect maize dry matter yield. This was probably due to leaching as the inorganic nitrogen fertilizer was applied in February. About 75% of the rains were received in the months of January and February. The low maize dry matter yield achieved by the control plots on the sandy soil site might also be explained by the low pH of the soil which was reported to be acidic (pH 4.8) (Mangosho pers comm.).

5.3.3 Effects of jatropha seed cake application rate on maize grain yield

Maize grain yield responded positively to the application of the jatropha seed cake. Maize grain yields were higher where the jatropha seed cake and the Compound D fertilizer were applied compared to the control plot. The increase in grain yield could be attributed possibly to the nitrogen released by the seed cake and the other nutrients supplied by the cake as highlighted in Experiment 1. The seed cake has about 88 % organic matter content (Tigere,

2002) this might have improved the physical characteristics of the soil leading to improved water and nutrient holding capacity which probably aided crop growth and grain yield.

5.3.4 Effects of inorganic nitrogen application rate on maize grain yield

Application of inorganic nitrogen fertilizer as topdressing fertilizer resulted in significantly higher yield grain yields compared with the control. The pH of the soil was low (4.8) and this explains the low grain yield from the control plot. The lower inorganic nitrogen fertilizer rate (25kg/ha) gave comparable grain yield with the higher rate (50kg/ha N). This is contrary to the findings by other researchers who have reported a linear response to an increase in nitrogen rate (O'Leary and Remlin, 1990). The nitrogen was possibly lost due to leaching. The lower grain yield could also be attributed to the poor distribution of rainfall and the premature end of the rain season. The results of this study imply that farmers can however use a lower rate (25kg/ha) of inorganic nitrogen when growing maize under similar rainfall and soil conditions and still get reasonable yields in terms of grain yield.

The interaction between the cake application level and the inorganic N fertiliser was not significant. Mubonderi (1999) also found similar results in the work done using cattle manure.

5.4 Conclusion

Maize dry matter and grain yield were similar at the jatropha seed cake application rates of 767kg/ha and 1534kg/ha in Experiment 2. Farmers can use the low jatropha seed cake rate application rate of 767kg/ha and spread the jatropha seed cake they have over a bigger hectarage. Use of a higher inorganic nitrogen rate did not result in higher grain yields, therefore farmers can use the lower rate of 25kg/ha N and still get reasonable yields. This will result in a cost saving for farmers as inorganic nitrogen fertiliser accounts for a greater portion of the fertilizer costs. The farmers are encouraged to grow their own jatropha plants so that each farmer can grow his own organic fertilizer at his farm. This poses a challenge to the Zimbabwe national jatropha programme to ensure that the hectarage under jatropha is increased so that more farmers can benefit from the jatropha seed cake in the near future.

It is also recommended that the experiments be repeated in the next two seasons to evaluate the effect of the jatropha seed cake rates on maize dry matter and grain yield under different seasons. There is also need to undertake studies on the residual effect of the jatropha seed cake to assess if the following maize crop will benefit.

CHAPTER 6

6.0 GENERAL CONCLUSION AND RECOMMENDATIONS

This study explored the potential of jatropha seed cake as a sole source of nutrients and also its use in combination with inorganic nitrogen fertilizer for maize production on granitic sandy soils and clayey soils. In the smallholder farming sector of Zimbabwe low soil fertility and in particular nitrogen deficiency is one of the major constraints to maize production.

6.1 CONCLUSIONS

6.1.1 Effect of soil type on maize dry matter yield

The clayey soil site had better maize dry matter yields compared to the sandy soil site. The rate of biomass accumulation was however higher on the sandy soil site by 42 % and 20 %. It would be therefore more beneficial to use the jatropha seed cake on sandy soils.

6.1.2 Effect of jatropha seed cake application rate on maize dry matter yield

Maize dry matter yield of 3tonnes was attained higher where the jatropha seed cake rate of 2301kg/ha was applied in Experiment 1 on the sandy soil site. On the clayey soil site no benefits were noted from the application of jatropha seed cake. In the second experiment however a lower seed cake rate of 767kg/ha also gave better yields. The response to jatropha seed cake rates of 767kg/ha and 2301kg/ha in Experiment 1 and 2 respectively could be attributed to different nutrient levels of the two experimental sandy soil sites. Depending on the nutrient status of the soils being cultivated, a jatropha seed cake application rate ranging from 767kg/ha to 2301kg/ha could be used in the sandy soils.

The high maize dry matter yields are of particular importance in the smallholder sector where maize stover is used as livestock feed during the dry season and bedding for livestock among other uses. The livestock and crop production systems are closely linked and hence farmers will benefit from the use of jatropha seed cake.

6.1.3 Effect of jatropha seed cake application rate on maize grain yield

The jatropha application rate of 767kg/ha gave higher maize yields in Experiment 2. It performed comparably with the inorganic fertilizer treatment. This seems to suggest that the use of a low jatropha seed cake rate can result in improved maize yields that are comparable with the use of inorganic fertilizer in the sandy soils in the smallholder sector. Currently in Zimbabwe the national jatropha programme is still in its infancy and hence there is very little jatropha seed cake. The smallholder farmers can utilize the limited quantities available for maize production. A jatropha seed cake application rate of 767kg/ha is recommended based on the results of this preliminary study. Use of jatropha seed cake can be used as a strategy to improve the soil fertility status of the granitic sandy soils of Zimbabwe and specifically the nitrogen levels.

6.1.4 Effect of the interaction of jatropha seed cake and inorganic nitrogen fertilizer

The interaction between jatropha seed cake rate and inorganic nitrogen fertilizer was not significant. This study has shown that maize dry matter yield was not affected by the addition of inorganic nitrogen fertilizer. These preliminary results suggest that jatropha seed cake can be used as a sole source of nutrients. There is however need to manage the phosphorus as the jatropha treated plots showed phosphorus deficiency. This can be achieved through composting jatropha seed cake with rock phosphate or applying single super phosphate to the maize field at planting

Figure 6.1 Maize plant showing phosphorus deficiency

All treatments also showed phosphorus deficiency and this was more pronounced in the jatropha seed cake treated plots and the control plots which did nor receive any inorganic fertilizer or jatropha seed cake.

6.2 Recommendations

This study highlighted the potential of jatropha in maize production. These findings strongly suggest that jatropha cake can be effectively used in sandy soils. Jatropha seed cake application rate ranging from 767kg/ha to 2301kg/ha is recommended. Application of jatropha seed cake rates higher than 2301kg/ha did not result in significantly higher maize dry matter yields. Jatropha seed cake performs just as well as inorganic fertilizer in as far as maize dry matter accumulation and grain yield is concerned.

Further evaluations of jatropha seed cake application levels ranging from 767kg/ha to 2301kg/ha in increments of 50kg.

There is need to undertake studies to establish the nutrient release pattern of the cake during the period between 6 and 12 weeks after germination and there after as nitrogen deficiency was observed in all the experimental plots and particularly the jatropha seed cake treated plots. It was also observed that during periods of moisture stress plots that received jatropha cake took longer periods to show signs of wilting. It would be beneficial to assess the effect of the cake on soil properties to see if the cake improves the structure of the soil.

There is also the need to undertake studies on the management of phosphorus when using jatropha seed cake in maize production. The effect of the residual nitrogen in the jatropha cake treatments also need to be assessed to see if the following maize crop will benefit as well. It is recommended that these two experiments be repeated in different seasons to confirm these findings on the performance of jatropha seed cake.

Further studies on the effect of jatropha seed cake on weeds using known quantities of weed seeds are recommended. Pot experiments are recommended because they offer more control over non-treatment variables than when an experiment is carried out in the field. For example it is possible to ensure a uniform distribution of *F.exilis* weed seeds in a limited pot environment than is the case under field experiments. This type of work will validate this study’s findings.

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APPENDICES

Appendix 1 Characteristics of Natural Farming Region II

Characteristics

- Intensive crop and livestock production
- Intensive crop and livestock production
- Rainfall is reliable and is in the range of 700 – 1000mm per annum
- In some years, crop performance and yields is affected by relatively short rainy seasons and or dry spells during the season

Appendix 2 Experiment 1: ANOVA for maize plant heights 4wace HERS Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	359.92	179.96	5.96	
Rep.*Units* stratum					
Trt	7	3579.66	511.38	16.95	<.001
Residual	14	422.47	30.18		
Total	23	4362.05			

Appendix 3 Experiment 1: ANOVA for maize plant heights at 8 wace HERS Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2319.2	1159.6	5.42	
Rep.*Units* stratum					
Trt	7	21150.7	3021.5	14.12	<.001
Residual	14	2996.1	214.0		
Total	23	26466.0			

Appendix 4 **Experiment 1: ANOVA for maize plant height at 12wace HERS Sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2178.6	1089.3	2.88	
Rep.*Units* stratum					
Trt	7	18285.3	2612.2	6.90	0.001
Residual	14	5298.1	378.4		
Total	23	25762.0			

Appendix 5 **Experiment 1: ANOVA for maize plant heights at 4wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	131.250	65.625	6.85	
Rep.*Units* stratum					
Trt	7	101.167	14.452	1.51	0.242
Residual	14	134.083	9.577		
Total	23	366.500			

Appendix 6 **Experiment 1: ANOVA for maize plant heights at 8wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	887.58	443.79	11.98	
Rep.*Units* stratum					
Trt	7	541.83	77.40	2.09	0.114
Residual	14	518.42	37.03		
Total	23	1947.83			

Appendix 7 **Experiment 1: ANOVA for maize plant heights at 12wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	652.75	326.38	13.77	
Rep.*Units* stratum					
Trt	7	351.96	50.28	2.12	0.110
Residual	14	331.92	23.71		
Total	23	1336.62			

Appendix 8 **Experiment 1: ANOVA for effect of soil type on maize dry matter yield at 4wace**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	28585.	14293.	0.64	
Rep.*Units* stratum					
Soil type	1.	12885302.	573.54	<.001	
Cake level	7	427931.	61133.	2.72	0.026
Soil type. Cake level	14	819.	21117.	0.94	0.491
Residual	30	673990.0	22466.		
Total	47	14163627			

Appendix 9 **Experiment 1: ANOVA for effect of soil type on maize dry matter yield at 8wace**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1223014.	611507.	0.84	
Rep.*Units* stratum					
Soil type	1	307699782.	307699782.	420.58	<.001
Cake level	7	13331570.	1904510.	2.60	0.032
Soil type. Cake level	7	4280889.	611556.	0.84	0.566
Residual	30	21948240.	731608.		
Total	47	348483495			

Appendix 10 **Experiment 1: ANOVA for effect of soil type on maize dry matter yield at 12wace**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5521636.	2760818.	1.61	
Rep.*Units* stratum					
Soil type	1	698408249.	698408249.	406.70	<.001
Cake level	7	8817609.	1259658.	0.73	0.645
Soil type. Cake level	7	22147272.	3163896.	1.84	0.115
Residual	30	51517165.	1717239.		
Total	47	786411931.			

Appendix 11 **Experiment 1: ANOVA for maize dry matter yield at 4wace HERS Sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	65835.	32918.	4.55	
Rep.*Units* stratum					
Trt	7	203314.	29045.	4.01	0.013
Residual	14	101311.	7236.		
Total	23	370460.			

Appendix 12 **Experiment 1: ANOVA for maize dry matter yield at 8wace HERS Sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2758728.	1379364.	0.32	
Rep.*Units* stratum					
Trt	7	42391007.	6055858.	1.41	0.275
Residual	14	60024819.	4287487.		
Total	23	105174554.			

Appendix 13 **Experiment 1: ANOVA for maize dry matter yield at 12wace HERS Sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2261182.	1130591.	1.11	
Rep.*Units* stratum					
Trt	7	9694459.	1384923.	1.36	0.295
Residual	14	14249355.	1017811.		
Total	23	26204996.			

Appendix 14 **Experiment 1: ANOVA for maize dry matter at 4wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2732.	1366.	0.04	
Rep.*Units* stratum					
Trt	7	372435.	53205.	1.40	0.280
Residual	14	532698.	38050.		
Total	23	907865.			

Appendix 15 **Experiment 1: ANOVA for maize dry matter at 8wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1835467.	917734.	1.13	
Rep.*Units* stratum					
Trt	7	7893855.	1127694.	1.39	0.283
Residual	14	11352333.	810881.		
Total	23	21081655.			

Appendix 16 **Experiment 1: ANOVA for maize dry matter at 12wace HERS Clayey soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12576633.	6288317.	2.84	
Rep.*Units* stratum					
Trt	7	18220925.	2602989.	1.18	0.376
Residual	14	31001128.	2214366.		
Total	23	61798686.			

Appendix 17 **Experiment 1: ANOVA for Richardia *scabra* 2wace Sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	23.30	11.65	0.94	
Rep.*Units* stratum					
Position	1	45.00	45.00	3.61	0.067
Trt no	7	135.30	19.33	1.55	0.188
Position.Trt no	7	34.21	4.89	0.39	0.899
Residual	30	373.44	12.45		
Total	47	611.24			

Appendix 18 **Experiment 1:ANOVA for *Cyperus esculentus* 2wace Sandy Soil Site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	11.870	5.935	2.91	
Rep.*Units* stratum					
Position	1	4.596	4.596	2.25	0.144
Trt no	7	15.236	2.177	1.07	0.409
Position.Trt no	7	16.200	2.314	1.13	0.369
Residual	30	61.269	2.042		
Total	47	109.171			

Appendix 19 **Experiment 1: ANOVA for *Acanthospermum hispidum***

2wace Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	33.4967	16.7484	20.33	
Rep.*Units* stratum					
Position	1	0.0258	0.0258	0.03	0.861
Trt no	7	6.2491	0.8927	1.08	0.398
Position.Trt no	7	8.6639	1.2377	1.50	0.204
Residual	30	24.7184	0.8239		
Total	47	73.1540			

Appendix 20 Experiment 1: ANOVA for *F. exilis* 2wace Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.752	0.876	0.43	
Rep.*Units* stratum					
Position	1	31.443	31.443	15.27	<.001
Trt no	7	8.011	1.144	0.56	0.785
Position.Trt no	7	14.106	2.015	0.98	0.465
Residual	30	61.778	2.059		
Total	47	117.089			

Appendix 21 Experiment 1: ANOVA for *Digitaria spp* 2wace Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.4218	0.2109	0.50	
Rep.*Units* stratum					
Position	1	2.7403	2.7403	6.50	0.016
Trt no	7	2.0631	0.2947	0.70	0.672
Position.Trt no	7	2.0631	0.2947	0.70	0.672
Residual	30	12.6409	0.4214		
Total	47	19.9291			

Appendix 22 Experiment 1:ANOVA for: *Gnaphalium spp* 2wace Sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.4273	1.7137	1.84	
Rep.*Units* stratum					
Position	1	3.9714	3.9714	4.26	0.048
Trt no	7	3.8854	0.5551	0.59	0.755
Position.Trt no	7	3.8854	0.5551	0.59	0.755
Residual	30	28.0000	0.9333		
Total	47	43.1695			

Appendix 23 Experiment 1: *Eragrostis spp* 2wace sandy soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.1771	2.0885	2.51	
Rep.*Units* stratum					
Position	1	4.3266	4.3266	5.20	0.030
Trt no	7	20.4939	2.9277	3.52	0.007
Position.Trt no	7	9.8583	1.4083	1.69	0.149
Residual	30	24.9488	0.8316		
Total	47	63.8046			

Appendix 24 Experiment 1: ANOVA for Weed biomass 2wace sandy soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.9800	0.9900	9.60	
Rep.*Units* stratum					
Position	1	1.2094	1.2094	11.73	0.002
Trt no	7	0.7433	0.1062	1.03	0.431
Position.Trt no	7	1.0405	0.1486	1.44	0.226
Residual	30	3.0936	0.1031		
Total	47	8.0669			

Appendix 25 Experiment 1: ANOVA for *Richardia scabra* 5wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	91.161	45.580	5.32	
Rep.*Units* stratum					
Position	1	0.003	0.003	0.00	0.984
Trt no	7	144.268	20.610	2.41	0.044
Position.Trt no	7	58.106	8.301	0.97	0.471
Residual	30	257.081	8.569		
Total	47	550.620			

Appendix 26 Experiment 1: ANOVA for *F. exilis* 5wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	416.43	208.21	15.91	
Rep.*Units* stratum					
Position	1	17.47	17.47	1.34	0.257
Trt no	7	229.64	32.81	2.51	0.037
Position.Trt no	7	17.78	2.54	0.19	0.984
Residual	30	392.61	13.09		
Total	47	1073.93			

Appendix 27 Experiment 1: ANOVA for *C. esculentus* 5wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.401	3.700	0.89	
Rep.*Units* stratum					
Position	1	6.117	6.117	1.46	0.236
Trt no	7	40.630	5.804	1.39	0.246
Position.Trt no	7	18.071	2.582	0.62	0.737
Residual	30	125.275	4.176		
Total	47	197.495			

Appendix 28 **Experiment 1: ANOVA for *Digitaria spp* 5wace**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.212	2.606	2.05	
Rep.*Units* stratum					
Position	1	0.104	0.104	0.08	0.777
Trt no	7	10.112	1.445	1.14	0.366
Position.Trt no	7	2.346	0.335	0.26	0.963
Residual	30	38.070	1.269		
Total	47	55.845			

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Appendix 29 **Experiment 1: ANOVA for *A. hispidum* 5wace**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	39.696	19.848	9.66	
Rep.*Units* stratum					
Position	1	0.299	0.299	0.15	0.706
Trt no	7	31.477	4.497	2.19	0.064
Position.Trt no	7	11.417	1.631	0.79	0.598
Residual	30	61.631	2.054		
Total	47	144.521			

Appendix 30 **Experiment 1: ANOVA for Weed biomass 5wace sandy soil site**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.9777	0.4888	2.35	
Rep.*Units* stratum					
Position	1	0.2771	0.2771	1.33	0.257
Trt no	7	2.3456	0.3351	1.61	0.170
Position.Trt no	7	0.4143	0.0592	0.28	0.955
Residual	30	6.2376	0.2079		
Total	47	10.2522			

Appendix 31 Experiment 1: ANOVA for *P. maximum* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.3065	1.6532	4.72	
Rep.*Units* stratum					
Position	1	0.2563	0.2563	0.73	0.399
Trt no	7	1.8026	0.2575	0.73	0.644
Position.Trt no	7	3.1996	0.4571	1.30	0.282
Residual	30	10.5170	0.3506		
Total	47	19.0820			

Appendix 32 Experiment 1: ANOVA for *G. parviflora* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	44.250	22.125	7.85	
Rep.*Units* stratum					
Position	1	1.694	1.694	0.60	0.444
Trt no	7	25.844	3.692	1.31	0.280
Position.Trt no	7	2.704	0.386	0.14	0.994
Residual	30	84.589	2.820		
Total	47	159.081			

Appendix 33 Experiment 1: ANOVA for *N. physaloides* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.713	1.356	0.57	
Rep.*Units* stratum					
Position	1	7.747	7.747	3.28	0.080
Trt no	7	14.714	2.102	0.89	0.526
Position.Trt no	7	16.398	2.343	0.99	0.455
Residual	30	70.789	2.360		
Total	47	112.361			

Appendix 34 Experiment 1: ANOVA for B. *pilosa* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.682	6.341	1.60	
Rep.*Units* stratum					
Position	1	6.179	6.179	1.56	0.222
Trt no	7	16.935	2.419	0.61	0.743
Position.Trt no	7	21.166	3.024	0.76	0.623
Residual	30	119.087	3.970		
Total	47	176.050			

Appendix 35 Experiment 1: ANOVA for *C. rotundus* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.9146	1.9573	2.26	
Rep.*Units* stratum					
Position	1	4.0021	4.0021	4.62	0.040
Trt no	7	9.1864	1.3123	1.52	0.200
Position.Trt no	7	9.4179	1.3454	1.55	0.187
Residual	30	25.9669	0.8656		
Total	47	52.4880			

Appendix 36 Experiment 1: ANOVA for *T annua* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	22.3936	11.1968	12.67	
Rep.*Units* stratum					
Position	1	3.8717	3.8717	4.38	0.045
Trt no	7	13.1576	1.8797	2.13	0.071
Position.Trt no	7	10.7118	1.5303	1.73	0.139
Residual	30	26.5073	0.8836		
Total	47	76.6421			

Appendix 37 Experiment 1: ANOVA for *L martinicensis* 2wace

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.602	0.301	0.14	
Rep.*Units* stratum					
Position	1	10.116	10.116	4.83	0.036
Trt no	7	11.296	1.614	0.77	0.616
Position.Trt no	7	32.376	4.625	2.21	0.062
Residual	30	62.839	2.095		
Total	47	117.230			

Appendix 38 Experiment 1: ANOVA for Weed biomass 2wace clayey soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	49.619	24.810	10.62	
Rep.*Units* stratum					
Position	1	1.179	1.179	0.50	0.483
Trt no	7	23.308	3.330	1.43	0.232
Position.Trt no	7	12.951	1.850	0.79	0.600
Residual	30	70.098	2.337		
Total	47	157.155			

Appendix 39 Experiment 1: ANOVA for weed biomass at 5wace Clayey soil site

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.033	2.016	0.96	
Rep.*Units* stratum					
Position	1	0.715	0.715	0.34	0.564
Trt no	7	13.470	1.924	0.92	0.506
Position.Trt no	7	3.791	0.542	0.26	0.965
Residual	30	62.857	2.095		
Total	47	84.865			

Appendix 40 Experiment 2: ANOVA for maize dry matter yield at 4wace HERS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	65835.	32918.	4.55	
Rep.*Units* stratum					
Trt	7	203314.	29045.	4.01	0.013
Residual	14	101311.	7236.		
Total	23	370460.			

Appendix 41 Experiment 2: ANOVA for maize dry matter yield at 8wace HERS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	570536.	285268.	0.56	
Rep.*Units* stratum					
Cake level	3	10580170.	3526723.	6.94	0.002
N Level	2	1708984.	854492.	1.68	0.209
Cake level. N Level	6	5096439.	849406.	1.67	0.175
Residual	22	11174603.	507937.		
Total	35	29130732.			

Appendix 42 Experiment 2: ANOVA for maize dry matter yield at 12wace HERS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	241200.	120600.	0.19	
Rep.*Units* stratum					
Cake level	3	3151773.	1050591.	1.63	0.211
N Level	2	3167977.	1583988.	2.46	0.109
Cake level. N Level	6	1869646.	311608.	0.48	0.813
Residual	22	14176391.	644381.		
Total	35	22606987.			

Appendix 43 Experiment 2: ANOVA for maize grain yield HERS

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		361425.	180712.	1.71	
Rep.*Units* stratum						
Cake level	3		1365699.	455233.	4.32	0.017
N Level	2		1285464.	642732.	6.10	0.009
Cake level. N Level	6		1307138.	217856.	2.07	0.103
Residual	20	(2)	2107610.	105380.		
Total	33	(2)	6391824.			