EVALUATION OF NITRATE SOURCES AND IRRIGATION INTERVALS IN ONION PRODUCTION UNDER BIOMASS TRANSFER AND BASIN IRRIGATION

By

Amedeus Kasama

A dissertation submitted to the University of Zambia in partial fulfillment of the
requirements for the award of Master of Science in Integrated
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DECLARATION

I, Amedeus Kasama declare that this is my own work, that all the work of other scholars has been duly acknowledged and that this work has never been previously submitted at this university or any other institution for similar purposes.

....

CERTIFICATE OF APPROVAL

This dissertation of Amedeus Kasama has been approved as fulfilling the requirements or partial fulfillment of the requirements for the award of Master of Science in Integrated Soil Fertility Management by the University of Zambia.

Name of the examiner	Signature	Date
1)	....	....
2)	....	....
3)	....	....

ABSTRACT

Leguminous tree leaf litter has potential as a nutrient source for smallholder vegetable production systems. However, quality of the leaf litter influences yield responses by the crops grown. A field experiment was conducted at Msekera Research Station in Eastern Province of Zambia to assess the effect of biomass transfer on soil nitrate availability and water use in onion production under basin irrigation using fresh *Gliricidia sepium* biomass (3.7%N) and *Leucaena leucocephala* biomass (4.2%N). Results showed that residual soil nitrate after harvest was significantly different among the treatments [no fertilization, *Leucaena leucocephala* biomass, *Gliricidia sepium* biomass and inorganic fertilizer]. Treatments under inorganic fertilizer application had the highest residual soil nitrate accumulation. Among 3, 5 and 7 days irrigation intervals, '5 days irrigation interval' resulted in highest soil nitrate concentration and onion fresh yield. Inorganic fertilizer and *Gliricidia sepium* biomass resulted in highest onion fresh yield class with yields of 23.69 and 23.42 tons/ha, respectively. *Leucaena leucocephala* biomass provided a higher onion fresh yield of 21.13 tons/ha than control (no fertilization) which provided 17.53 tons/ha. The total seasonal amount of water irrigated to both main and sub-treatments was not significantly different. Five days irrigation interval was determined to be the optimal irrigation interval with water application rate of 213,843Litres/ha on loamy sand soil (FAO: Ferric Lixisols). There is need for further research to study optimal biomass decomposition periods for various Agroforestry trees before planting any crop and sensitize farmers on optimal water application intervals for onion production.

DEDICATION

I dedicate this research more especially to my wife, Astrida Mwansakombe Kasama and children, Peter and Daniel. I also extend my dedication to my extended family brothers, sisters, uncles and cousins.

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I thank my supervisor, Dr. E. Phiri who worked tirelessly on guiding me on how to set up a scientific project. He also taught me a lot of skills on how to analyze data which has been collected from a scientific project.

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CHAPTER ONE

1.0 INTRODUCTION

Diversification of crops produced by smallholder farmers in southern Africa has the potential of increasing employment and income, which in turn, permit people to purchase or otherwise acquire food to increase their food security (Dreschsel and Kunze, 2001). The production of onion and other leaf vegetables for local and export markets is one such profitable agricultural enterprise (Loehr et al., 1998; Kuntashula et al., 2004). Vegetables provide household nutritional security since they are rich in vitamins, minerals and roughage, which are essential for a balanced diet (Salunke and Kadam, 1998; Nyakudya et al., 2010).

Biomass transfer of leguminous tree leaf material to croplands has been shown to be a sustainable means of maintaining nutrient balances in maize and vegetable-based production systems (Mafongoya et al., 2008). These biomass transfer systems include the use of green mulch, dried prunings and litter as soil ameliorants (Constantinides and Fownes, 1994). Kuntashula et al. (2004) reported that amending soils with *Gliricidia sepium* and *Leucaena leucocephala* prunings was tenable for sustaining vegetable production in seasonal wetlands. In a related study, Kazombo-Phiri (2005) reported that the nitrogen availed following the application of 10 t ha^{-1} of *L. leucocephala* leafy biomass was comparable to the application of 100 kg ha^{-1} of mineral nitrogenous fertilizer. Biomass transfer refers to the cutting and carrying (transferring) nutrient-rich leaves of agroforestry tree species (usually planted in the upland) to fertilize fields for the production of high value crops and maize crop during the dry season (Matakala et al., 2006). In Zambia, Biomass transfer offers smallholder farmers the opportunity to supplement their incomes by growing crops that fetch high prices in urban markets. In this system, nitrogen fixing trees or shrubs are planted on a separate plot and leaves are regularly cut and used to fertilize neighbouring fields. It is normally practiced with basin irrigation which involves the use of sunken basins and irrigation using a watering can.

Nitrogen is the most important plant nutrient element because it is required in large quantity (Parmodh et al., 2012). Soil nitrogen in nitrate form is soluble and is easily lost from the plant root zone through leaching (Addscott., 1991). This problem becomes an issue when the soil receives excess water application. This is the case for most farmers who irrigate their crops in excess of leaching requirement and water not applied to field capacity. There is therefore need to determine an optimal irrigation interval and water application rate.

The water holding capacity of soils depends on texture, structure and organic matter content. The upper limit of plant available water is called "field capacity", while the lower limit is called the "permanent wilting point". Field capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement is negligible (Gary et al., 1988). This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and texture. The physical definition of field capacity (expressed symbolically as θfc) is the bulk water content retained in soil at 0.1 bar pressure for tropical soils. On the other hand, permanent wilting point (PWP) or wilting point (WP) is defined as the minimal point of soil moisture the plant requires not to wilt. If moisture decreases to this or any lower point, a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours. The physical definition of the wilting point (symbolically expressed as θwp) is defined as the water content at −15 bar of suction pressure (Gary et al., 1988).

Onion (*Allium cepa*) is a vegetable crop which is grown throughout Zambia. It is grown mainly for its bulb and its main use lies in flavouring a wide variety of dishes. Its popularity is due to its aromatic, volatile oil, the allyl-prophl sulphide which improves flavour to the food. In Zambia, onion is widely grown during the wet and the dry season. Onion yields are much higher during the dry season than wet season because of the fewer incidences of pests and diseases and due to an increase of irrigation (Sani and Jaliya, 2010).

1.1 Statement of the problem

Nitrogen is a plant element that exists in different forms. In nitrate-N form, soil Nitrogen is lost through leaching. The process of leaching has a great negative effect on the crop yield. This negative effect on crop yield was the reality in the study area because of inappropriate water application and lack of specific recommendations for water supply. Farmers in the study area had a number of irrigation methods namely drip irrigation, sprinkler irrigation, flood or furrow irrigation and stream recession irrigation. These irrigation methods lack site-specific recommendations for watering intervals and water application rates. The farmers, based on indigenous knowledge apply water twice in a day to their crops. This can lead to excess leaching of nitrates plus other plant nutrients.

1.2 Objectives

1.2.1 Main objective

The main objective of this study was to evaluate nitrate-Nitrogen sources and irrigation intervals in onion production under biomass transfer and basin irrigation.

1.2.2 Specific objectives

1. To evaluate the suitability of *Gliricidia sepium* and *Leucaena leucocephala* biomass as a source of soil Nitrate-Nitrogen levels on onion growth and yield.
2. To evaluate different irrigation intervals to determine optimal irrigation interval for onion production.

1.3 Research hypotheses

1. Nitrate-Nitrogen level from applied fresh biomass is the same as the applied inorganic fertilizer.
2. Onion yield from applied fresh biomass in the soil is same as the yield from applied inorganic fertilizer.
3. Irrigation intervals of 3, 5 and 7 days have same effect on onion plant growth and yield.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Leaching of nitrates

Nitrate is one of the forms of Nitrogen that is available for plant uptake. It is highly soluble and easily lost to leaching as water moves through soil profile (Jones, 1995). Irrigated fields have the highest potential for leaching, especially on course soil. In dry conditions, nitrate leaching is insignificant because plant uptake of water usually exceeds precipitation preventing downward movement of water (Baunder et al., 1993). In all farming systems, organic matter can add soluble N to the soil, increasing the amount of soil nitrate available to be used by the plant and leached (Jones, 1995). Soil texture influences the ability of the soil to retain water. Sandy soils, soil with large pores and shallow soils have low water holding capacity (Chen and Neill, 2006). Cracks and other vertical channels that extend from soil surface to below root zone allow water to move unused nitrate downwards. Baunder (1993) stated that fallow fields have higher leaching potential because they may reach field capacity (the amount of water a particular soil can hold against drainage) the first fall. Additional precipitation or water irrigated can then run off or seep below the rooting zone taking nitrate with it. Higher seeding rate and row spacing affect N leaching (Chen and Neill, 2006). Optimal plant density increase crop yield and optimize resource use since N leaching is reduced.

2.2 The effect of nitrate deficiency on onion production

Nitrogen deficiency in the soil results in reduced onion plant growth and bulb production (Jones, 2011). Jones stated that without adequate amount of nitrogen which an onion plant takes in form of either nitrates or ammonium nitrogen, a onion plant is unable to properly build proteins and nucleic acid. Shock et al,. (2010), reported that old onion leaves turn pale green and eventually turn yellow and fall from the onion plant when nitrogen is deficient in the soil. New leaves are paler green than existing leaves and appear to be smaller than normal. Onion plants are also easily wilt under normal conditions.

2.3 Typical levels of soil Ammonium-N and Nitrate-N

Ammonium-N concentrations of 2-10 ppm are typical in most soils. However, soil Ammonium-N above 10 ppm may occur in cold or extremely wet soils or if the soil contains fertilizer residue (Marx et al., 1996).

According to Steven (Gaviola and Lipinski., 2008), soil nitrogen measurements are most useful for evaluating nitrogen management. Nitrate remaining in the soil after harvest can leach out and cause contamination of surface and groundwater. If residual nitrate levels are consistently high, it is recommended that Nitrogen fertilizer input is reduced in subsequent growing season. Table 1 shows the classification of soil-nitrate levels for nitrogen evaluation according to Horneck et al,. (2011) in USA.

Table 1: Residual soil nitrate-nitrogen for evaluating Nitrogen management

Description	**NO_3-N (ppm)**
Low	<10
Medium	10-20
High	20-30
Excessive	>30

Source: Horneck et al, 2011

Table 2 presents the interpretation of organic matter, total nitrogen and nitrate-N as applied for Zambian soils. Tables 1 and 2 show that the expressions of soil nitrate for USA and Zambia are within the same range.

Table 2: Interpretation of organic matter, total nitrogen and Nitrate-N

Ranking	**Organic matter %**	**Total nitrogen %**	**Mineral N (NO_3) (ppm)**
Very high	>7.6	0.3	-
High	4 - 6	0.2 - 0.3	>25
Medium	2 - 4	0.1 - 0.2	15 - 25
Low	1 - 2	<0.1	5 - 15
Very Low	<1	<0.1	-

Source: Soil and Plant Analysis Interpretative Guide, 2010.

2.4 Biomass transfer in Zambia

Farmer participatory experiments conducted in 2000 to 2004 by Kuntashula et al., (2004) have shown that biomass transfer using *Leucaena leucocephala* and *Gliricidia sepium* is tenable for sustaining vegetable production in Dambos. Increase of yields of vegetables such as cabbage, rape, onion, tomato and maize has been observed as a result of biomass transfer. Their studies suggested that biomass transfer has greatest potential when

(a) Biomass is of high quality and it rapidly releases nutrients.
(b) Opportunity costs of labour are low
(c) The value of the crop is high and
(d) The biomass does not have other valued uses apart from being a reliable source of nutrients.

2.5 Chemical composition of *Leucaena leucocephala* and *Gliricidia sepium* biomass

Karachi (2006), observed that nitrogen content in Leucaena species differed between species and between leaves and stems. The mineral content was higher in older leaves and stems than in young leaves and stems. Karachi reported that *Leucaena leucocephala* biomass had a higher proportion of nitrogen in the leaves compared to stems (51 to 59%) than other Leucaena species (45 to 48%). Tables 3 and 4, show the chemical composition of *Leucaena leucocephala* and *Gliricidia sepium* biomass.

Table 3: Chemical Composition of air-dried *Leucaena leucocephala* and *Gliricidia sepium* biomass

Parameter	*Leucaena leucocephala*	*Gliricidia sepium*
Dry matter (%)	90.3	86.37
Crude protein (%)	25.27	21.92
Calcium (%)	1.48	0.74
Sodium (%)	2.66	6.23
Potassium (%)	1.06	2.49
Phosphorous (%)	0.28	0.43
Magnesium (%)	0.23	0.44
Manganese (g.kgDM^{-1})	55.16	46.31
Iron (mg.kgDM^{-1})	187.58	231.56
Copper (mg.kgDM^{-1})	22.07	11.58
Zinc (mg.kgDM^{-1})	308.95	393.66
Oxalate (mg.kgDM^{-1})	0.882	0.909
Phytin (mg.kgDM^{-1})	10.27	16.18
Phytin -P (mg.kgDM^{-1})	2.89	4.55

Source: Aletor and Omodara, 2008

Table 4: Chemical Composition of air-dried *Leucaena leucocephala's* leaf and stem

Sample	%N	%P	%K	%Ca	%Mg
Leaf					
Mean	4	0.22	1.6	0.9	0.4
Maximum	4.2	0.25	1.7	1.2	0.5
Minimum	3.4	0.21	1.5	0.7	0.2
Stem					
Mean	2.1	0.2	1.8	0.5	0.3
Maximum	2.5	0.21	2.1	0.6	0.4
Minimum	1.9	0.18	1.6	0.4	0.2

Source: Karachi, 2006

In a different experiment which was carried out by Pandey and Rai (2007), on 'Nitrogen Cycling in *Gliricidia sepium* under alley cropping in human tropics', it was found that the total concentration of nitrogen in the leaves (biomass) of *Gliricidia sepium* was found to be 3%. The result from this study indicated that the percentage of total nitrogen in *Gliricidia sepium* leaves was almost the same as that of *Leucaena leucocephala*.

2.6 The use of *Leucaena leucocephala* biomass in soil improvement

Leucaena leucocephala can provide as much as 160 kg N, 150 kg K and 15 kg P per hectare in alley cropping systems (Dalland et al., 1993). When applied to soil, every tonne of *Leucaena leucocephala* leaves produces the same increase in soil nitrogen as 10 kg or more of chemical nitrogen fertilizer. At the same time *Leucaena leucocephala* leaves greatly increase the efficiency of chemical fertilizer use. For instance, by combining *Leucaena leucocephala* leaves with 40 kg N fertilizer alone (Harrison, 1989), it is estimated that yield advantages of alley cropping with *Leucaena leucocephala* build up with time as the organic content of the soil increases.

2.7 The use of *Gliricidia sepium* biomass in soil improvement

Mafongoya et al., (2006) reported yield increase of onion by 40t/ha (183%) and 51t/ha (143%), respectively when 8 and 12t/ha fresh biomass of *Gliricidia sepium* was applied. Similarly, the yields of cabbage increased by 6t/ha (145%) and 9t/ha (145%) respectively for garlic and 7t/ha for green maize when 8t/ha *Gliricidia sepium* biomass was used. Recently, Kuntashula et al., (2004, 2006) compared the effect of *Gliricidia sepium* biomass with full rate inorganic fertilizers on vegetable yields on fields in eastern province of Zambia. *Gliricidia sepium* biomass applied at 8 and 12t/ha gave a comparable cabbage, onion and maize yields with those from full rate inorganic fertilizer application.

2.8 Onion production

Onion (*Allium cepa*) can grow under a wide range of climates from temperate to tropical areas. According to FAOSTAT (2001), the present world production is about 46.7 million tons of bulbs from 2.7 million hectare under cultivation. Under normal conditions, onion forms a bulb in the first season of growth and flowers in the second season. The production of the onion bulbs is controlled by daylength. The critical daylength varies from 11 to 16 hours of sunshine depending on variety. The crop flourishes in mild climates without extremes in temperature and without excessive rainfall. For the initial growth period, cool weather and adequate water is advantageous for proper crop establishment, whereas during ripening, warm, dry weather is beneficial for high yield of good quality. The optimum mean daily temperature varies between 15 and 20°C (FAO, 2000). Proper crop variety selection is essential, particularly in relation to the daylength requirements. For example, a long day temperate variety in tropical zones with short days will produce vegetative growth only without forming the bulb. The length of the growing period varies with climate but in general 130 to 175 days are required from sowing to harvest (FAO, 2001).

Onion is often sown on the nursery and transplanted after 30 to 35 days. Nevertheless, direct seeding in the field is also practiced. The crop is usually planted in rows or on raised beds, with two or more rows in a bed, with spacing of 0.3 to 0.5 x 0.05 to 0.1 m. Optinum soil temperature for germination is 15 to 25°C. For bulb production the plant should not flower since flowering adversely affects yields. Bulbs are harvested when the tops fall. For initiation of flowering, low temperatures (lower than 14 to 16°C) and low humidity are required. Flowering is, however, little affected by daylength (FAO, 2000).

FAO (2001) stated that onion is sensitive to water deficit. For high yield, soil water depletion should not exceed 25 percent of available soil water. When the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Irrigation should be discontinued as the crop approaches maturity to allow the tops to desiccate and also to prevent a second flush of root growth. For high yield of good quality the crop needs a controlled and frequent supply of water throughout the total growing period. Over-irrigation leads to reduced growth of onion (Shock et al., 2010). Table

5, shows the general growth stages of onion according to Colorando Onion Association, Arkansas and Shippers Association.

Table 5: Growth stages of onion

Stage	Days After seeding	Description
1	10 – 30	radicle & flag leaf emergence
2	30 – 50	1 - 2 true leaves
3	50 - 70	3 - 4 leaves
4	70 - 90	5 - 7 leaves
5	90 - 110	8 - 12 leaves, bulb initiation
6	110 - 130	bulb diameter of 2.5–3.8 cm
7	130 - 150	bulb diameter of 3.8 - 7.6 cm
8	150 - 170	bulb enlargement complete, 50% + topped
9	170 +	dry down from pre-harvest to harvest Days After

Source: Colorando Onion Association & Arkansas & Shippers Association - 1998

2.8 Onion water uptake

Onion has a shallow root system with roots concentrated in the upper 0.3 m soil depth (Shock et al., 2010). In general 100 percent of the water uptake occurs in the first 0.3 to 0.5 m soil depth. To make sure that crop water requirements are met, the soil must be kept relatively moist, under an evapotranspiration rate of 5 to 6 mm/day. The rate of water uptake starts to reduce when about 25 percent of the total available soil water has been depleted. According to FAO (2001), Onion requires frequent, light irrigations which are timed when about 25 percent of available water in the first 0.3 m soil depth has been depleted by the crop. From previous studies, it has been observed that irrigation application every 2 to 4 days is commonly practiced. Over-irrigation sometimes causes spreading of diseases such as mildew and white rot. Irrigation can be discontinued 15 to 25 days before harvest. Most common irrigation methods are furrow and basin irrigation,

2.9 Onion yield

In general, there are various factors that determine onion yield. Some of those factors include onion variety, period on the ground, climatic condition, soil type, incorporation of soil amendments and fertilizers and an irrigation system used to grow onion on the ground. In most cases, onion has the tendency of cracking at harvest. In order to prevent that cracking of the bulb, irrigation is required (Jensen et al., 2010). Also adequate water supply is essential for a high quality crop. Jensen also indicated that in general a good bulb yield under irrigation with recommended period on the ground is 35 to 45 ton/ha and water utilization efficient for harvested yield for bulbs containing 85 to 90 percent moisture is 8 to 10 kg/m^3.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Experimental site

3.1.1 Study area description

Msekera Research Station is located on the eastern plateau of Zambia. It is situated 12 km west of Chipata and 2 km off Great East Road. The station falls under agro-ecological region II with medium rainfall that ranges from 800 to 1,000 mm per annum. This trial was conducted on 32^{o}33.126’E and 13^{o}38.390’S. The annual mean temperature for Msekera ranges from 15 to 30 degrees Celsius.

3.1.2 Soil Characterization

During land preparation, 40 soil samples were collected from the study area for the determination and analysis of soil bulk density, pH, organic matter, total Nitrogen, nitrate Nitrogen, Phosphorous, Potassium and Zinc. Table 6 shows the average soil characterization from the study area.

Table 6: Average soil characterization from study area

Replicates = 5	Bulk Density	pH	OM	N	NO_3^-	P	K	Zn
Unit	g/cm^3		%		mg/kg		cmol/kg	
Soil depth (cm)	0 - 5		5 - 20					
Mean	1.33	6.5	1.5	0.1	12.5	3.0	0.15	0.4
Critical value	1.3	5.0	4.0	0.2	25.0	10	0.22	0.5

Table 6 shows the average fertility status of the site. Organic Matter, Nitrates, Phosphorous, Potassium and Zinc needed fertilization.

3.1.2.1 Parameters determined before planting and after onion harvest

This trial consisted of 36 plots. From all the plots, soil samples were collected after land preparation and onion harvest. Analysis of chemical and physical properties was done on those soil samples. The specific soil properties that were determined included;

(i) Soil bulk density

(ii) Soil pH

(iii) Total Nitrogen and

(iv) Available Nitrogen.

3.1.2.2 Determination of soil bulk density

The bulk density of soil depends greatly on the mineral make up normally vary from between 1.0 and 1.6 g/cm³ for mineral soils. Bulk density was determined from 36 soil samples that were collected using core rings. Samples were weighed before and after subjected to temperature of 105° for 48 hours. This was according to soil bulk density determination method by Garretson (1999).

3.1.2.3 Determination of soil pH

Soil pH was determined by adding 0.01M calcium chloride solution to the soil samples. That mixture was then stirred and later suspensions in the mixture were allowed to settle and thereafter soil pH was measured using the soil pH meter, (Karla et al, 1991).

3.1.2.3 Determination of Total Nitrogen in soil and biomass samples

Total Nitrogen in the soil and biomass samples was determined by the use of 'micro-Kjeldahl digestion' method followed by distillation and titration (Anderson and Ingram, 1993). Before determination of total Nitrogen in biomass, biomass was oven dried and the oven dried samples followed the same process as soil samples of adding sulphuric acid to it plus a catalyst and thereafter the process of digestion followed. For both soil and biomass samples, the mixtures were exposed to the temperature of 410^{o}C for about 45 minutes and thereafter distillation and titration followed after the sample mixtures were cooled.

Table 7: Total nitrogen percentages in Gliricidia and Leucaena biomass

Sample	**Total Nitrogen**
	%
Gliricidia sepium	3.7
Leucaena leucocephala	4.2

3.1.2.4 Determination of soil available Nitrogen

Soil available nitrogen was determined using Kjeldahl method. This method involved adding the soil samples to 2M Potassium chloride. The soil sample mixtures were then shaken and filtered. The filtrate was distilled into boric acid after addition of two catalysts (MgO and Devarda's alloy). These distillates were then titrated with 0.25 M Hydrochloric acid to change colour from green to purple.

3.1.3 Soil profile description

According to ICRAF, (1989), the soil classification for the study area was Ferric Lixisols (FAO). This is a moderate fertile soil that requires fertilization in order for farmer to have good crop yield. The study area had a slope of 3 to 5%. The texture for the soil was loamy sand in the upper 30 cm of the soil profile. The top surface consisted of the gravel or stones. The colour of this layer was dark brown with the presence of a number of roots since the area was covered with grass and it had not been cultivated for a number of years. The second layer which was 50 cm consisted of soil with colour that ranged from light brown to yellow. This layer consisted of red spots which was an indicator of mottling. Roots and a few small stones were also present in this layer. The third layer observed had a thickness of 20cm. This layer was light brown, no stones and it was limited by a huge rock below it.

3.1.4 Rainfall

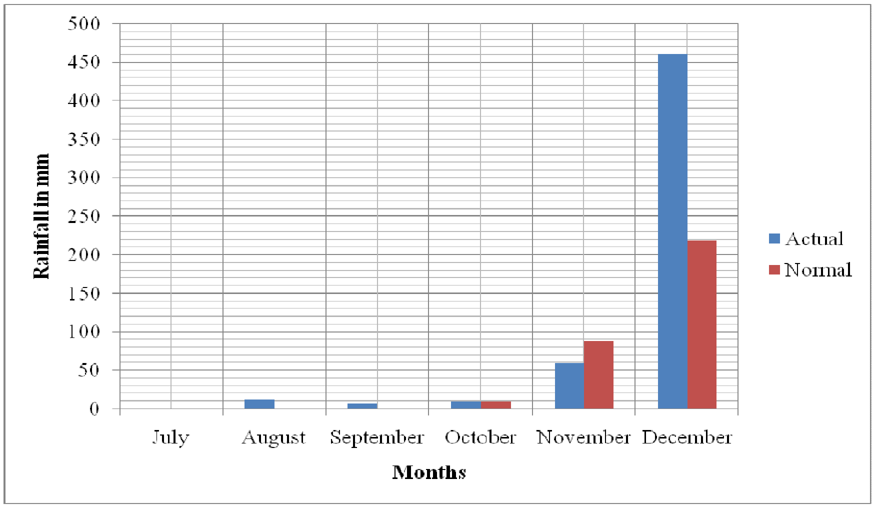

Figure 1: Actual and normal rainfall for July to December 2012 at Msekera

Figure 1 shows that July had no rains and it was expected. August and September received rains which were above normal. In November, Msekera received rains which were below normal yet in December Msekera received rains which was double the normal rainfall. Normal rainfall was determined by finding the average of rainfall recorded over the period of 30 years.

3.1.5 Temperature

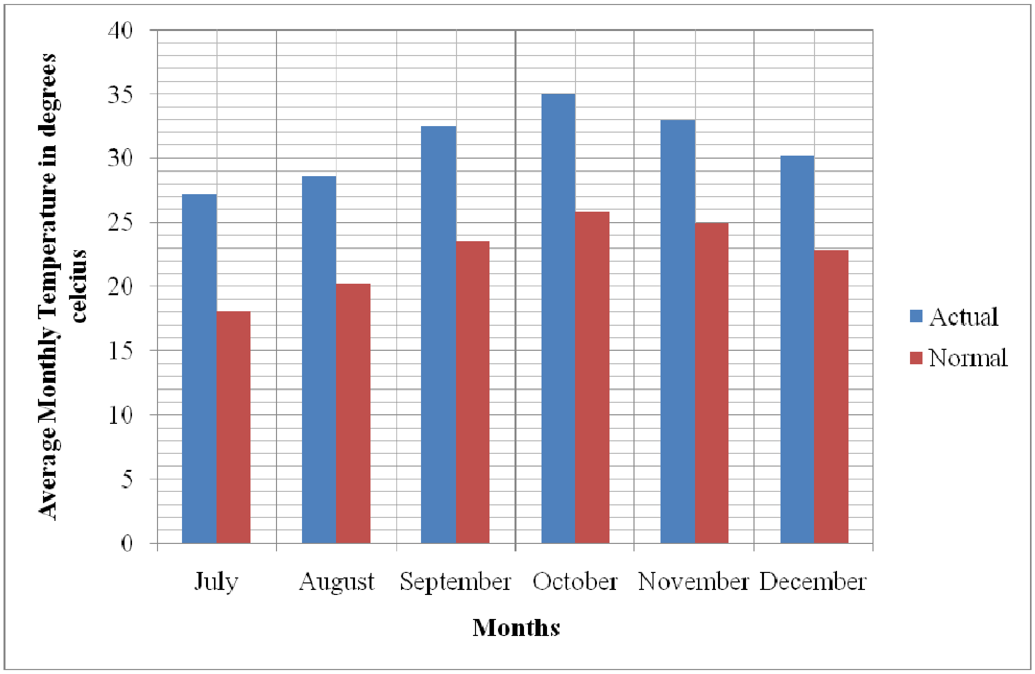

Figure 2: Actual and normal average monthly temperature for July to December 2012 at Msekera

Figure 2 show that for the period of July to December 2012, average monthly rainfall for Msekera were above normal. The normal monthly temperature in figure 2 was determined by finding the average of the mean monthly temperatures over the period of 30 years.

3.1.6 Relative humidity

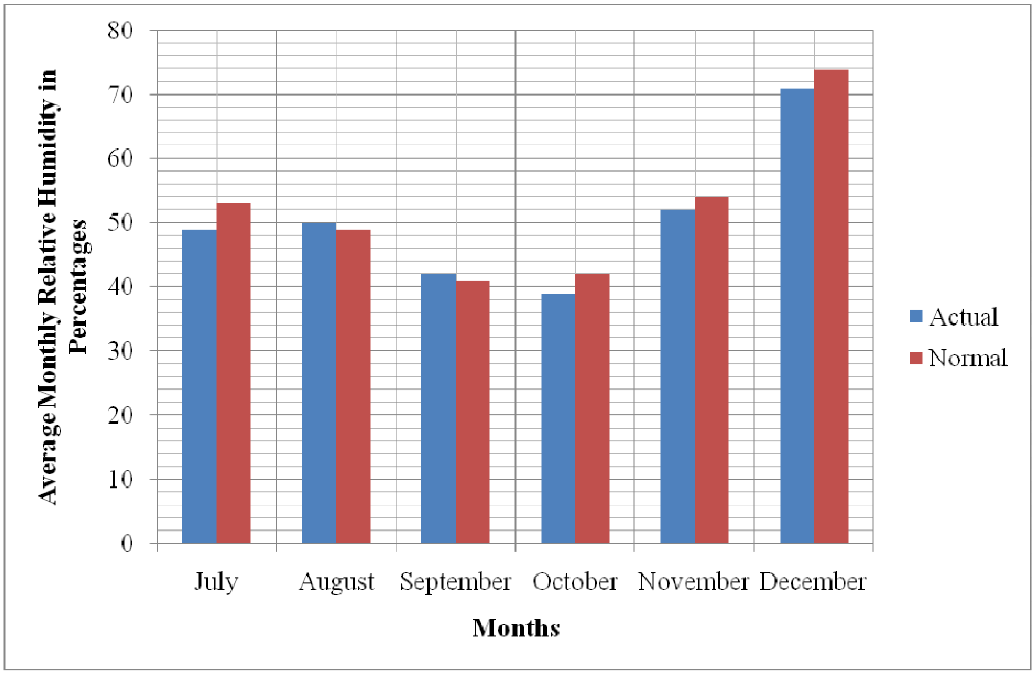

Figure 3: Actual and normal Average Monthly Relative Humidity for July to December 2012 at Msekera

Figure 3 shows that Msekera Research Station had experienced more relative humidity than normal for the months of August and September and it experienced less humidity than normal for the months of July, October, November and December. Similarly, the normal monthly relative humidity was found by finding the average of monthly mean relative humidity over the period of 30 years.

3.2 Treatments and experimental design

The four main treatments under this trial included Control (No fertilization), fresh *Leucaena leucocephala* biomass, fresh *Gliricidia sepium* biomass and inorganic fertilizers (D-compound and urea applied at 200kg/ha). The amount of nitrogen applied to soil when inorganic fertilizer of 200 kg/ ha was applied was 112 kg/ ha.

Both fresh *Leucaena leucocephala* and *Gliricidia sepium* biomass were incorporated into the soil at 35ton/ha. In terms of Nitrogen, the amount of Nitrogen incorporated into the soil from fresh *Leucaena leucocephala* and *Gliricidia sepium* biomass was 367.5 kg/ha and 323.8 kg/ha respectively. On the other hand, this experiment had three sub-treatments namely 3, 5 and 7 days irrigation intervals. The four main treatments were replicated three times making a total of 36 plots for this experiment. The experimental design used under this experiment was 'Randomized Block Design'. Appendix 1 shows the experimental layout for this experiment.

3.3 Onion variety and planting

Onion (*Allium cepa L.*) was evaluated in this experiment. The variety was 'Texas Grano'. On the nursery, the recommended period is 10 to 12 days and 200 days is the actual days recommended from sowing to harvest. However, onion under this experiment spent 120 days from sowing on the nursery to harvest. The average yield for this variety ranges from 20 to 34 tons per hectare.

Each plot under this experiment was 1.2 m x 3.0 m with a net plot of 80 cm by 100 cm. Onion spacing was 20 cm x 10 cm giving a plant density of 50 plants per metre square. Onion was planted to the sunken basins and this was done a week after biomass incorporation. During that week after biomass incorporation, all basins in which biomass was incorporated were watered to initiate the process of decomposition and to reduce the soil temperature which occurs in the soil immediately after biomass incorporation. It was also ensured that during planting, onion seedlings were not planted too deep in the soil. During the month of October, 2012, there was an outbreak of fungal disease which was controlled within 3 weeks.

3.4.1 Field Capacity Determination

Field capacity was determined by monitoring the soil moisture content for 7 days from initially saturated soil profile and covered with black plastic. The field capacity of 13% was determined. Appendix 2 shows the Neutron probe data recording sheet used in the field.

Figure 4: Determination of the 'Field Capacity' in the field.

3.4.2 Water Determination at the Field Capacity

Each plot for this experiment size was 300 cm x 120 cm. The deepest point or depth at which the moisture content was determined was 75cm. Using the general formula for volume: L x B x H, volume of soil plus water in the soil profile to a depth of 75 cm was 2,700,000 cm^3or 2,700 litres. Since Field Capacity was found to be 13%, the amount of water determined in the soil at field capacity was;

$$\frac{13}{100} x 2{,}700L = \underline{351L}$$

3.4.3 Determination of water to irrigate

Water to irrigate was determined through subtracting the water present in the soil before irrigating from the water which was present at the field capacity. For example, if at a particular time, soil moisture content was found to be 12%, then the amount of water required to irrigate on that particular plot was;

$$\left(\frac{13}{100} x 2{,}700\right) - \left(\frac{12}{100} x 2{,}700\right) = 27L / plot$$

3.4.4 Monitoring of soil moisture

The neutron probe of Model 503DR Hydro-probe manufactured by CPN International, Inc. (Martinez, CA) was used for monitoring soil water content in the top 75 cm at intervals of 15 cm from vertically installed access tubes installed to capture root zone moisture. For calibration using gravimetric method, soil measurements were collected from dry soil and very wet soil and corresponding neutron probe readings. To arrive at the formula for soil moisture determination, the following calibration formulae were used; (CPN 503 DR HYDROPROBE NEUTRON MOISTURE GAUGE, 1995).

Slope A = $\frac{MH - ML}{RH - RL}$

Intercept = B = ML – (A x RL)

Then: m = (A x r) + B

Where:

M = moisture content in centimeters per meter

r = Count Ratio

MH = high moisture value (centimeters per meter)

ML = Low moisture value (centimeters per meter)

RH = probe count ratio at the high moisture value

RL = probe count ratio at the low moisture value.

Table 8: Data used for Neutron Probe Calibration

CORE RING MOISTURE (%)		NEUTRON PROBE COUNTS	
wet	dry	dry	wet
MH	ML	RH	RL
12.986	7.229	9241.7	6954.7

From the collected data, the formula or model determined for determining the moisture content was;

$$m = 0.0024r - 10.147,$$

Where 'r' is the average count from the neutron probe.

3.5 Data analysis

Soil nitrate-N concentration, onion yield and water irrigated data were subjected to analysis of variance (ANOVA) using the 14th edition discovery statistical package. The least significant difference (LSD) was used to separate the treatment means where there were significant differences.

CHAPTER FOUR

4.0 RESULTS

4.1 Soil nitrates

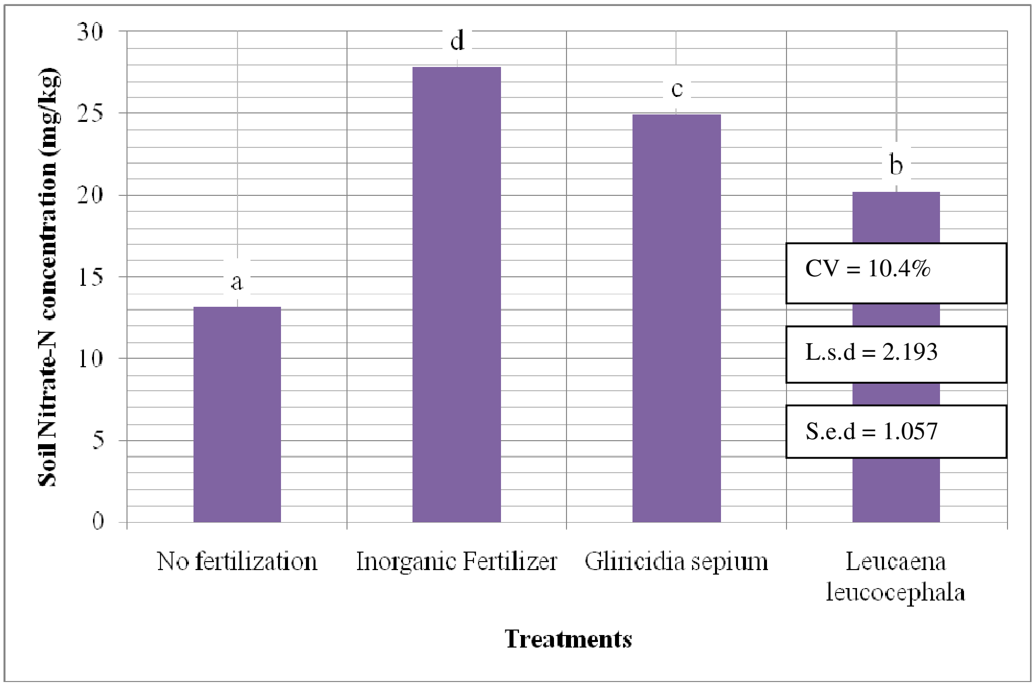

Figure 5: The effect of fertilization on nitrate concentration

Figure 5 shows that the mean Nitrate-N soil concentrations were statistically different between all the four main treatments. According to 'interpretative guide' as applied at the department of soil sciences in the school of Agricultural Sciences, 'No fertilization' treatment with 13.16 mg/kg mean soil nitrate-N can be described as 'medium soil nitrates', *Leucaena leucocephala* biomass (20.22 mg/kg) and *Gliricidia sepium* biomass (24.93 mg/kg) as 'medium soil nitrates', while inorganic fertilizers (27.84 mg/kg) as 'high soil nitrates'. These results were not expected because biomass was allowed to decompose in the soil for the period of five months during the onion growth period and biomass was expected to be as high as inorganic fertilizers.

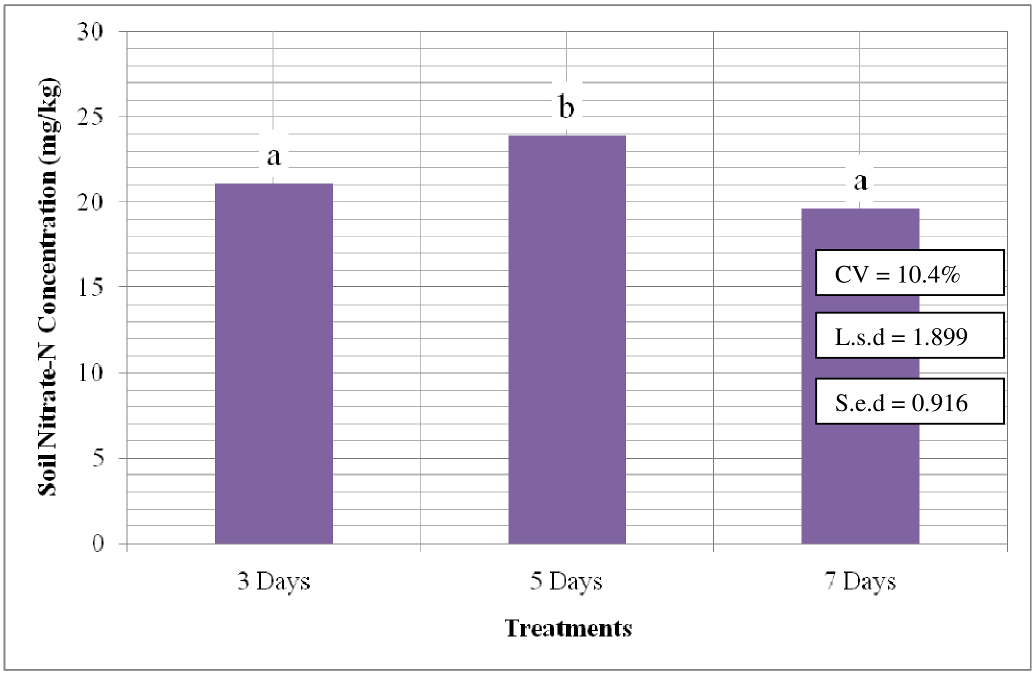

Figure 6: The effect of irrigation intervals on soil nitrate-N concentration

Figure 6 shows that statistically 3 and 7 days irrigation intervals had the same effect on soil nitrate-N concentration. Figure 6 also shows that '5 days irrigation interval' was statistically different from the other two sub treatments and it resulted in highest soil nitrate concentration. For analysis of variance for soil nitrate-N, refer to appendix 3.

4.2 Onion yield

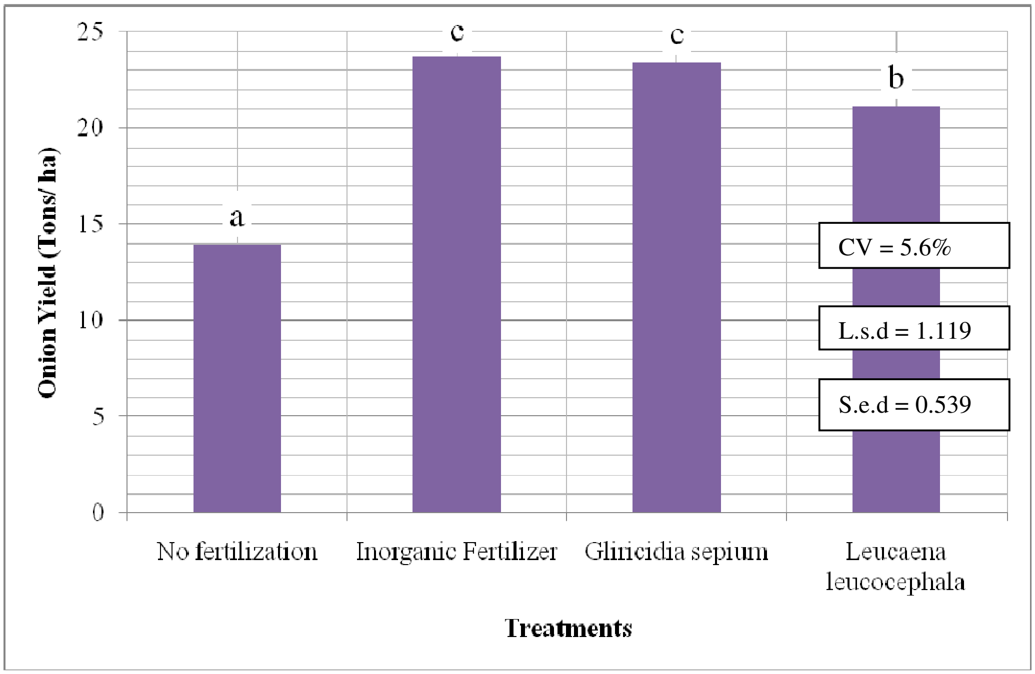

Figure 7: The effect of fertilization on Onion yield

Analysis of onion yield as shown in figure 7, inorganic fertilizer and *Gliricidia sepium* biomass were statistically the same and this was expected. *Leucaena leucocephala* biomass and ‘No fertilization’ were in different classes. *Leucaena leucocephala* was higher than ‘No fertilization’ treatment and this was expected. What was not expected was the fact that *Leucaena leucocephala* biomass resulted in lower onion yield than inorganic fertilizers and *Gliricidia sepium* biomass.

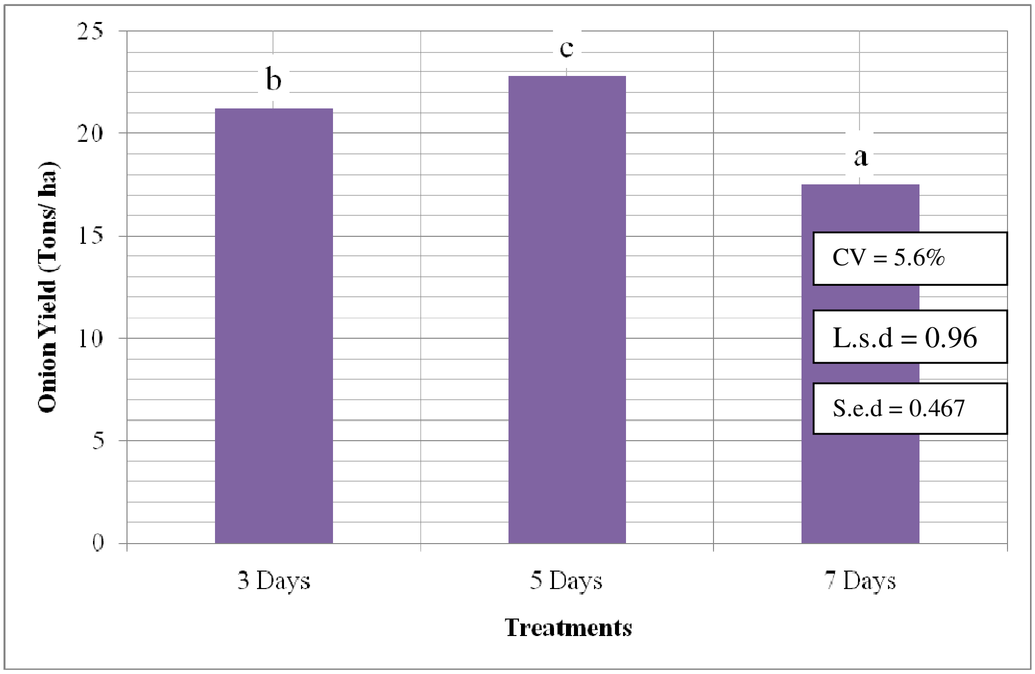

Figure 8: The effect of irrigation intervals on onion yield

Figure 8 shows that statistically each of the three irrigation intervals had a unique effect on onion yield. Five days irrigation interval resulted in highest onion yield while the least onion yield was from seven days irrigation interval. For the onion yield analysis of variance, refer to appendix 4. Figure 9 shows the author of this thesis measuring the onion bulb at harvest.

Figure 9: Measurement of onion bulb diameter at harvest

4.3 Mean water irrigated

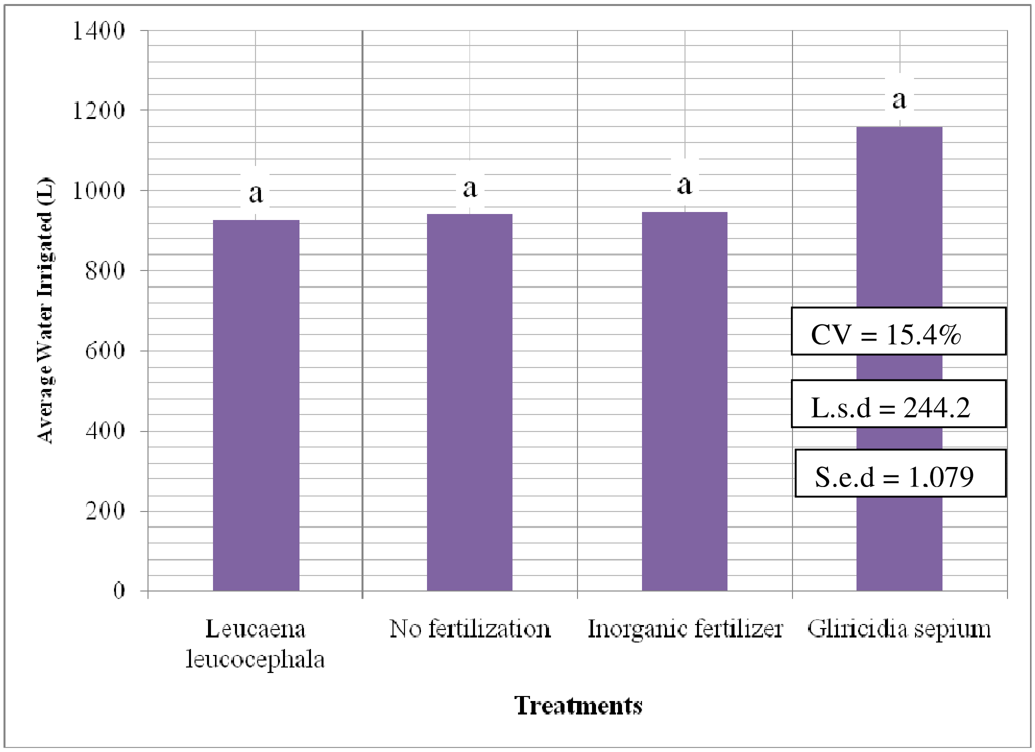

Figure 10: Mean water irrigated across the main treatments

Though water was irrigated at different intervals across the main treatments, the average amount of water irrigated per treatment was not significantly different as shown in figure 10. Water irrigated under *Gliricidia sepium* biomass treatment was higher than any other treatment but statistically it was not different from any other treatment, in terms of water irrigated. For analysis of variance (ANOVA) of mean water irrigated, refer to appendix 5.

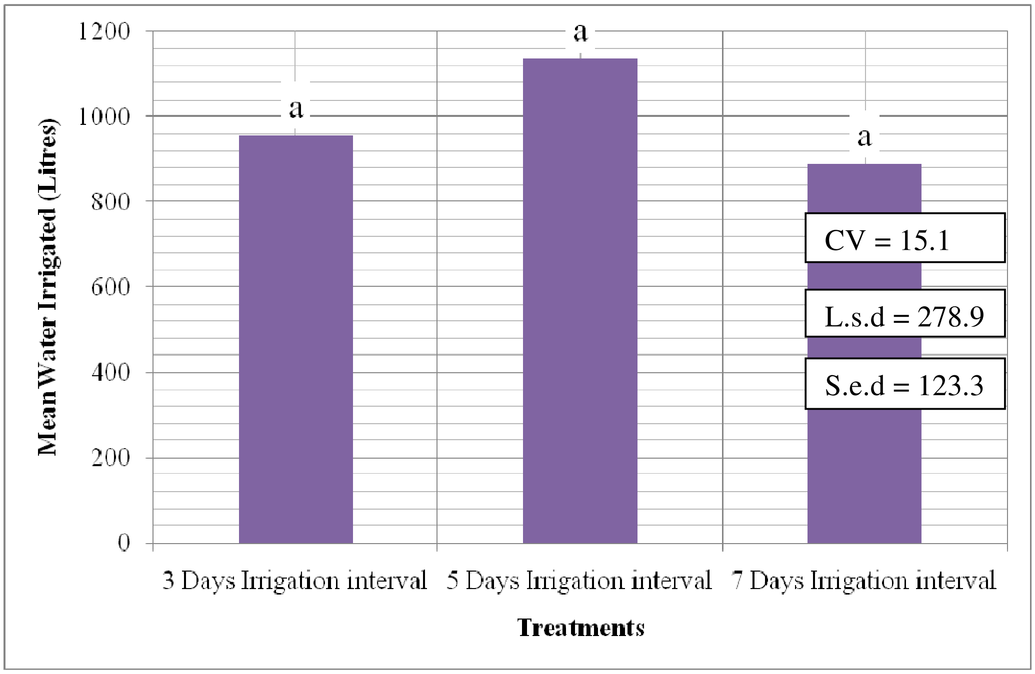

Figure 11: Mean water irrigated across the sub-treatments

Across the three irrigation intervals, there was no significant difference between them as shown in figure 11.

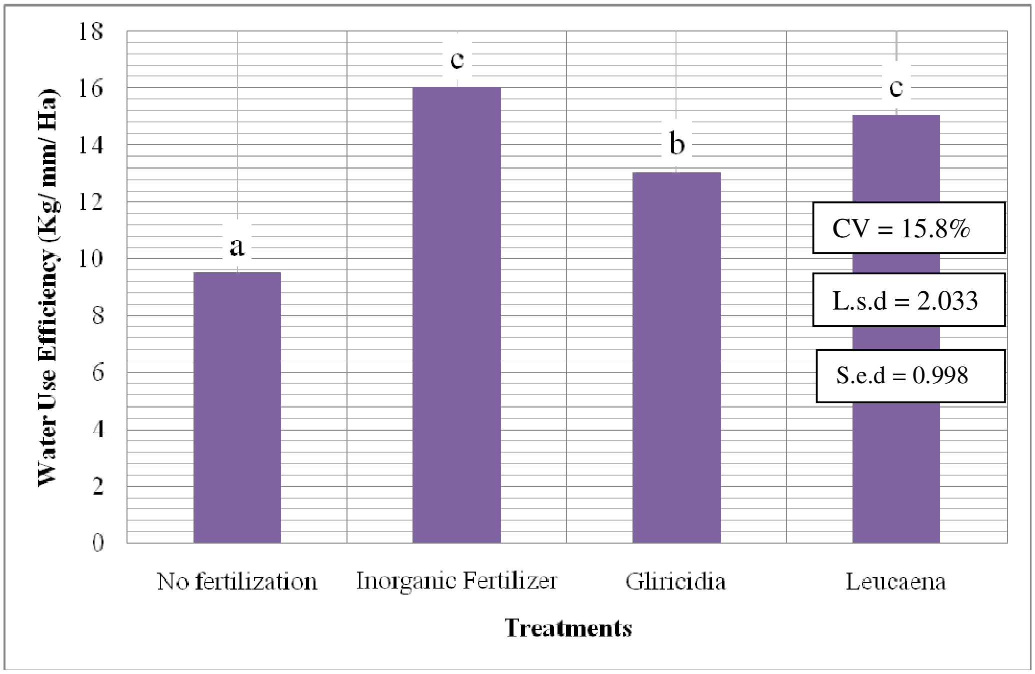

Figure 12: The effect of fertilization on water use efficiency

Results in figure 12 shows that water irrigated was optimally used in onion production under two main treatments. These treatments were inorganic fertilizers and *Leucaena leucocephala* biomass. On the other hand, *Gliricidia sepium* biomass was found to be a better option than 'No fertilization' treatment in as far as water use efficiency was concerned. These results were expected since 'No fertilization' treatment was expected to have the lowest yield yet same amount of water would be irrigated to each of the four main treatments.

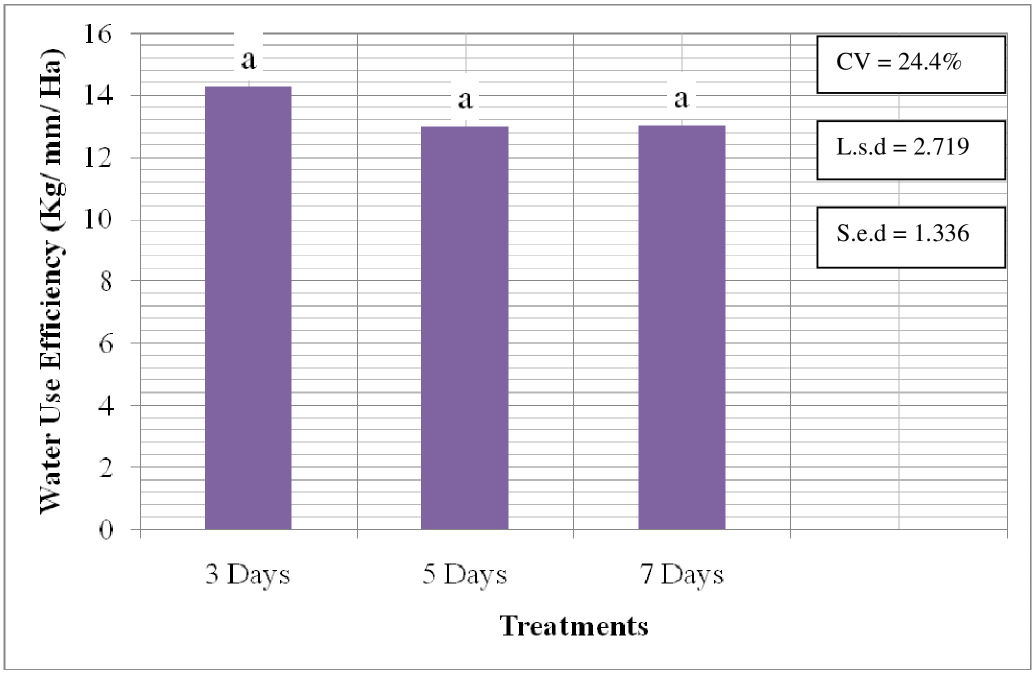

Figure 13: The effect of irrigation intervals on water use efficiency

Figure 13 shows that the effect of watering intervals on water use efficiency was not significant different between 3, 5 and 7 days irrigation intervals. For the analysis of variance for water use efficiency, refer to appendix 6.

4.2 DISCUSSION

4.2.1 The Effect of fertilization and irrigation intervals on soil nitrate Nitrogen concentration

The huge differences observed in nitrate-N concentration levels between control (no fertilization treatment) and biomass treatments were due to biomass decomposition. Karachi (2006), observed that both *Gliricidia sepium* and *Leucaena leucocephala* biomass consist of nitrate-N plus other plant nutrient elements which are released after decomposition. The concentration of soil nitrate-N plus other plant nutrient elements depend on the tree species and the decomposition period, Mafongoya et al (2008). In line with the tree species, under this experiment, the total nitrogen percentage determined in *Leucaena leucocephala* biomass (4.2%) was more than 3.7% determined in *Gliricidia sepium* biomass and equal amounts of biomass was applied for both biomass. However, higher nitrate-N concentration was determined in soils with *Gliricidia sepium* biomass after harvest. This observation can be attributed to the fact that *Gliricidia sepium* decomposes faster and releases plant nutrients faster than *Leucaena leucocephala* biomass. This fact is based on the report by Wilson *et al.,* (1986), who reported that half-life of prunings of *Gliricidia sepium* was found to be 20 days and it has been found to be relatively short compared with that of *Leucaena leucocephala* and *Flemingia macrophylla* (Budelman, 1988). On the other hand, the observed highest nitrates level in inorganic fertilizers soil was due to the fact that nitrogen in inorganic fertilizer was already in plant available form and it was not completely used by the onion plants by the time onion was harvested. In general, 3 and 7 days irrigation interval provided the same effect on soil nitrate-Nitrogen concentration. This is shown in the results in which there are no significant difference between them. On the other hand, 5 days irrigation interval retained the highest amounts of nitrates in the soil. This highest soil nitrate-N in '5 days irrigation interval' is attributed to the fact that adequate water was available for continuous biomass decomposition during plant growth. Seven days irrigation interval resulted in lower soil nitrate-N concentration than five days because adequate soil moisture did not last in the soil for the whole interval till the next irrigation. This effected biomass decomposition and hence most of the available plant nutrients were taken up by onion plants. Three days irrigation interval had adequate water throughout each interval but onion plant had taken most of the nitrate-N resulting in lower nitrate-N concentration than five days irrigation interval.

4.2.2 The effect of fertilization and irrigation intervals on onion yield

Previous studies have shown that fertilization using inorganic fertilizers, Agroforestry biomass or manures have a positive effect on crop yield. The results from this experiment are in agreement to those findings. Both inorganic and biomass fertilization increased the onion yield under this experiment. Inorganic fertilizers resulted in highest onion yield because plant nutrients in them were already in available form. *Gliricidia sepium* biomass resulted in same onion yield as inorganic fertilizers because of its fast decomposition rate that led to available plant nutrients. Though *Leucaena leucocephala* biomass has lower decomposition rate than *Gliricidia sepium* biomass Wilson *et al.,* (1986), It provided enough available plant nutrients to onion plants after decomposition and hence its yield came out to be higher than Control (No fertilization) but lower than *Gliricidia sepium* biomass. Each irrigation interval had a unique effect on onion yield as shown in onion yield results. Five days irrigation interval resulted in highest onion yield because of its optimal plant condition it provided to the onion plants. Soil moisture was adequate to make plant nutrients available to the plants. Onion plants were also not reaching the point of wilting before the next irrigation as it was the case for ‘7 days irrigation interval’. On the other hand, ‘3 days irrigation interval’ provided adequate soil moisture, hence its yield was higher than ‘7 days irrigation interval’ but lower than ‘5 days irrigation interval’. The higher yield in ‘5 days irrigation interval’ than ‘3 days irrigation interval’ is attributed to the fact that onion plant is a short rooted crop, it roots are concentrated to the upper 0.3 m (Shock et al., 2010) and probably the most adequate soil moisture content in the root zone was provided by ‘5 days irrigation interval’ which resulted in highest onion yield.

4.2.3 Water irrigated

The observed non-significant water irrigated to both main treatments and sub treatments was due to the fact that water was irrigated to the field capacity to all the treatments. This was done with the help of the neutron probe which was able to determine soil water content before irrigation. Water irrigated per main treatment under ‘7 days irrigation interval’ was the highest since soil moisture determined before any irrigation under this interval was the least among the three irrigation intervals. The least amount of water irrigated per main treatment was under ‘3 days irrigation interval’ due to shortest irrigation interval and the soil moisture content determined before any irrigation was highest among the three irrigation intervals. Water irrigated was influenced by rainfall in November and December since Msekera received more than 50 mm of rain per month but for August, September and October, the effect of rains on water irrigated was negligible since Msekera received less than 12 mm of rainfall per month. For November and December, it was observed that there was a general reduction in water irrigated to all the treatments due to rainfall.

The observed highest water use efficiency in inorganic fertilizers and *Leucaena leucocephala* biomass was due to the fact that these two fertilization treatments optimally converted water irrigated plus plant nutrients to onion crops. This was followed by *Gliricidia sepium* biomass and the least was control (No fertilization). On the other hand, irrigation intervals namely 3, 5 and 7 days irrigation interval resulted on same effect on water use efficiency.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has shown that both fresh *Gliricidia sepium* biomass and *Leucaena leucocephala* biomass are suitable to be used as a source of soil nitrate-N and they can supplement on inorganic fertilizers. This had been observed in soil nitrate-N levels after onion harvest and onion yield. Soil nitrate-N analysis showed that control (No fertilization), *Leucaena leucocephala* biomass, *Gliricidia sepium* biomass and inorganic fertilizers had nitrate-N concentrations of 13.16, 20.22, 24.93 and 27.84 mg/kg, respectively, indicating significant differences between control and biomass treatments. Onion yields showed that control, *Leucaena leucocephala* biomass, *Gliricidia sepium* biomass and inorganic fertilizers yielded 13.97, 21.13, 23.42 and 23.69 tons/ha, respectively and again indicating significant differences between control and biomass treatments. In addition to that *Gliricidia sepium* biomass and inorganic fertilizers were the same in terms of onion yield.

Among the three irrigation intervals namely 3, 5 and 7 days irrigation interval, '5 days irrigation interval' was determined to be the optimal irrigation interval with water application rate of 213,843Litres/ha on loamy sand soil (FAO: Ferric Lixisols) Five days irrigation interval resulted in highest soil nitrate-N and onion yield. Specifically, 3, 5 and 7 days irrigation interval resulted in 21.11, 23.89 and 19.62 mg/kg respectively, soil nitrate-N while the onion yield was 21.27, 22.85 and 17.53 tons/ha, respectively. All the three irrigation intervals resulted in same water use efficiency.

5.2 RECOMMENDATIONS

Considering the findings from this research, it is recommended that farmers are sensitized on optimal application interval for onion production. Since the half life of *Gliricidia sepium* and *Leucaena leucocephala* biomass ranges from 20 to 31 days, Wilson et al., (1986), it is recommended that biomass should be allowed to decompose in the soil for at least 2 months in order for biomass to completely decompose and release plant nutrients and elements before planting.

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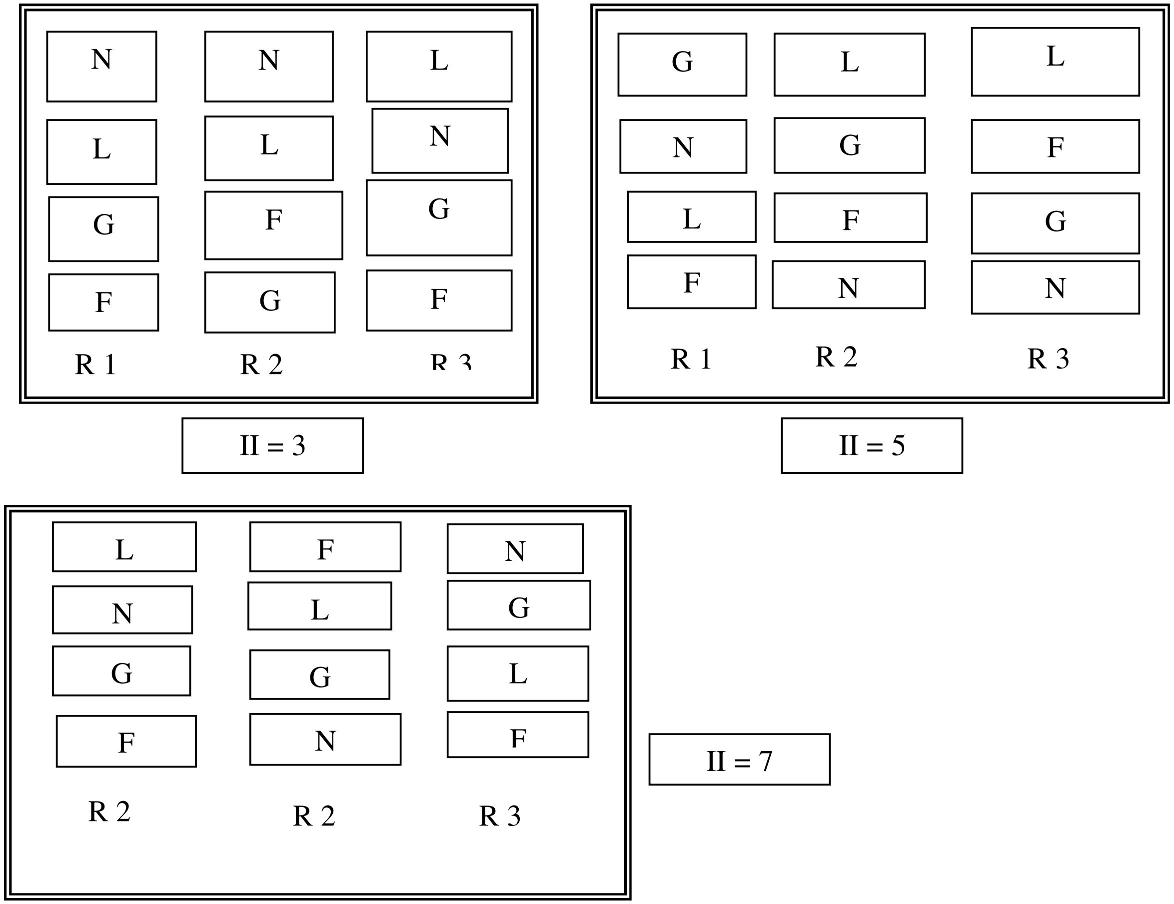
APPENDICES

APPENDIX 1: EXPERIMENTAL LAYOUT



KEY

N = No fertilization

F = Inorganic Fertilizer

G = *Gliricidia sepium*

L = *Leucaena leucocephala*

II = Irrigation interval in days

R = Replication

APPENDIX 2: NEUTRON PROBE RECORDING SHEET

Expt. Title: ....
Location: ....
Recorder: ....
Date: ....   Stand Count: ....

Plot No	**Main Treatment**	**Sub Treatment**	**Probe count at**		
			15 cm	30cm	45cm
Average Count					
Average Count					
Average Count					
Average Count					
Average Count					
Average Count					
Average Count					
Average Count					

APPENDIX 3: ANALYSIS OF SOIL NITRATE NITROGEN AFTER HARVEST

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GenStat Fourteenth Edition
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```

Analysis of variance

```
Variate: Nitrate_N_mg_kg

Source of variation              d.f.        s.s.        m.s.     v.r.   F pr.

Rep_No stratum                      2      11.420       5.710     1.13

Rep_No.*Units* stratum
Sub_Treatment                       2     112.661      56.331    11.19   <.001
Main_Treatment                      3    1108.490     369.497    73.43   <.001
Main_Treatment.Sub_Treatment
                                    6      20.778       3.463     0.69   0.661
Residual                           22     110.702       5.032

Total                              35    1364.051
```

Tables of means

```
Variate: Nitrate_N_mg_kg

Grand mean  21.54

    Sub_Treatments          3          5          7
                        21.11      23.89      19.62

  Main_Treatments           N          F          G          L
                        13.16      27.84      24.93      20.22

    Sub_Treatments  Main_Treatments        N          F          G          L
                 3                     12.50      28.27      24.83      18.83
                 5                     14.37      30.11      27.63      23.43
                 7                     12.60      25.13      22.33      18.40
```

Standard errors of means

```
Table             Sub_Treatment
                               Main_Treatment
                                                 Sub_Treatment
                                                Main_Treatment
rep.                         12             9                3
d.f.                         22            22               22
e.s.e.                    0.648         0.748            1.295
```

Standard errors of differences of means

```
Table                     Sub_Treatment
                                          Main_Treatment
                                                             Sub_Treatment
                                                            Main_Treatment
rep.                                 12                9                 3
d.f.                                 22              22                22
s.e.d.                            0.916            1.057             1.832
```

Least significant differences of means (5% level)

```
Table                     Sub_Treatment
                                          Main_Treatment
                                                             Sub_Treatment
                                                            Main_Treatment
rep.                                 12                9                 3
d.f.                                 22              22                22
l.s.d.                            1.899            2.193             3.798
```

Stratum standard errors and coefficients of variation

```
Variate: Nitrate_N_mg_kg

Stratum                                  d.f.                s.e.              cv%
Rep_No                                      2               0.690              3.2
Rep_No.*Units*                             22               2.243             10.4
```

Duncan's multiple range test

Sub_Treatments

```
             Mean
7            19.62   a
3            21.11   a
5            23.89   b
```

Main_Treatments

```
             Mean
N            13.16   a
L            20.22   b
G            24.93   c
F            27.84   d
```

INDEX 4: ONION YIELD ANALYSIS

```
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Analysis of variance

Variate: Yield_Ton_ha

Source of variation               d.f.        s.s.        m.s.      v.r.    F pr.

Rep_No stratum                       2       7.869       3.934      3.00

Rep_No.*Units* stratum
Sub_Treatments                       2     178.991      89.495     68.34   <.001
Main_Treatments                      3     556.045     185.348    141.53   <.001
Sub_Treatments.Main_Treatments
                                     6      11.134       1.856      1.42   0.253
Residual                            22      28.811       1.310

Total                               35     782.850


Tables of means

Variate: Yield_Ton_ha

Grand mean  20.55

    Sub_Treatments          3          5          7
                        21.27      22.85      17.53

  Main_Treatment           N          F          G          L
                       13.97      23.69      23.42      21.13

    Sub_Treatments  Main_Treatments         N          F          G          L
                 3                      14.43      25.03      24.93      20.70
                 5                      16.23      25.80      25.40      23.97
                 7                      11.23      20.23      19.93      18.73


Standard errors of means

Table               Sub_Treatments
                                Main_Treatments
                                             Sub_Treatments
                                            Main_Treatments
rep.                            12            9             3
d.f.                            22           22            22
e.s.e.                       0.330        0.381         0.661
```

```
Standard errors of differences of means

Table                  Sub_Treatments
                                      Main_Treatmentss
                                                         Sub_Treatments
                                                        Main_Treatments
rep.                               12               9                3
d.f.                               22              22               22
s.e.d.                          0.467           0.539            0.934


Least significant differences of means (5% level)

Table                  Sub_Treatments
                                      Main_Treatments
                                                         Sub_Treatments
                                                        Main_Treatments
rep.                               12               9                3
d.f.                               22              22               22
l.s.d.                          0.969           1.119            1.938


Stratum standard errors and coefficients of variation

Variate: Yield_Ton_ha

Stratum                               d.f.          s.e.          cv%
Rep_No                                   2         0.573          2.8
Rep_No.*Units*                          22         1.144          5.6


Duncan's multiple range test


Sub_Treatments

             Mean
7            17.53   a
3            21.27   b
5            22.85   c


Main_Treatments

             Mean
N            13.97   a
L            21.13   b
G            23.42   c
F            23.69   c
```

Note: Treatments with the same letters are not significantly different.

APPENDIX 5: ANALYSIS OF AMOUNT OF WATER IRRIGATED IN LITRES

```
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Analysis of variance

Variate: Water_Irrigated_L

Source of variation          d.f.        s.s.        m.s.     v.r.   F pr.
Main_Treatment                  2     130606.      65303.     2.80   0.113
Residual                        9     209706.      23301.
Total                          11     340312.


Tables of means

Variate: Water_Irrigated_L

Grand mean  994.

    Sub_Treatments         3          5          7
                        956.      1136.       889.


Standard errors of means

Table             Sub_Treatment
rep.                          4
d.f.                          9
e.s.e.                     76.3


Standard errors of differences of means

Table             Sub_Treatment
rep.                          4
d.f.                          9
s.e.d.                    107.9


Least significant differences of means (5% level)

Table             Sub_Treatment
rep.                          4
d.f.                          9
l.s.d.                    244.2
```

Stratum standard errors and coefficients of variation

```
Variate: Water_Irrigated_L

d.f.                         s.e.              cv%
 9                          152.6              15.4
```

Duncan's multiple range test

Sub_Treatments

```
              Mean
7             889.2   a
3             956.0   a
5            1136.2   a
```

Duncan's multiple range test

Main_Treatments

```
              Mean
L             926.3   a
C             941.0   a
F             947.7   a
G            1160.3   a
```

APPENDIX 6: ANALYSIS OF WATER USE EFFICIENCY

```
                       ________________________________________

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```

Analysis of variance

```
Variate: Water_use_Efficiency_kg_mm_ha

Source of variation          d.f.       s.s.       m.s.     v.r.  F pr.
Main_treatments                 3    222.978     74.326    16.59  <.001
Residual                       32    143.402      4.481
Total                          35    366.380
```

Tables of means

```
Variate: Water_use_Efficiency_kg_mm_ha

Grand mean  13.43

    Main_treatments         N          F          G          L
                         9.55      16.05      13.03      15.07
```

Standard errors of differences of means

```
Table                Main_treatments
rep.                               9
d.f.                              32
s.e.d.                         0.998
```

Least significant differences of means (5% level)

```
Table                Main_treatments
rep.                               9
d.f.                              32
l.s.d.                         2.033
```

Stratum standard errors and coefficients of variation

```
Variate: Water_use_Efficiency_kg_mm_ha

d.f.                  s.e.          cv%
 32                  2.117         15.8
```

Duncan's multiple range test

Main_treatments

```
              Mean
N             9.55   a
G            13.03   b
L            15.07   c
F            16.05   c
```

Analysis of variance

```
Variate: Water_use_Efficiency_kg_mm_ha

Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Sub_treatments                  2       12.86        6.43      0.60    0.554
Residual                       33      353.52       10.71
Total                          35      366.38
```

Tables of means

```
Variate: Water_use_Efficiency_kg_mm_ha

Grand mean  13.43

    Sub_treatments          3          5          7
                        14.27      12.99      13.02
```

Standard errors of means

```
Table                Sub_treatments
rep.                             12
d.f.                             33
e.s.e.                        0.945
```

Standard errors of differences of means

```
Table                Sub_treatments
rep.                             12
d.f.                             33
s.e.d.                        1.336
```

Least significant differences of means (5% level)

```
Table                Sub_treatments
rep.                             12
d.f.                             33
l.s.d.                        2.719
```

Stratum standard errors and coefficients of variation

Variate: Water_use_Efficiency_kg_mm_ha

d.f.	s.e.	cv%
33	3.273	24.4

Duncan's multiple range test

Sub_treatments

	Mean	
5	12.99	a
7	13.02	a
3	14.27	a

APPENDIX 7: HARVEST DATA FORM

			H	I	J	K
Plot No	Main Treatment	Sub Treatment	No of plants	Bulb diameter (mm)	Fresh plant weight (g)	Dry plant weight (g)