# EVALUATION OF MORINGA (*Moringa oleifera* (Lam) AS A SHADE TREE FOR RAPE PRODUCTION IN THE LOWVELD SEMI-ARID REGION OF ZIMBABWE

**BY**

**MISHECK CHANDIPOSHA**

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**Department of Crop Science**

**Faculty of Agriculture**

**University of Zimbabwe**

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# ABSTRACT

Rape (*Brassica napus*) is the most popular vegetable in semi-arid region Zimbabwe owing to its nutritional value and income generation. This leafy vegetable is a cool-season crop and its production is limited to periods of low temperature especially in the semi-arid region of Zimbabwe, which is characterized by hot dry conditions during hot season. Since rape production is difficult due to high temperatures, excessive radiation, and disease prevalence among other causes, production under tree shade can assist by modifying the microclimate. A factorial experiment was carried out at Chiredzi Research Station in the 2006/7 rainy season to study the effects moringa shade on rape vegetable grown in March and June. Pruning consisted of two levels: pruning and no pruning while, cropping system consisted of sole moringa and moringa/rape intercrop. Two factors were considered, cropping system (moringa/rape intercrop and sole moringa) and pruning (pruning and no pruning of moringa).The control treatment was sole rape (control). Moringa shade reduced rape dry weight in the moringa/rape mixture for both March and June rape crops by 35.9 % and 60.6 % respectively. Pruning moringa coupled with low moringa height significantly increased rape dry weight by 7.3 % in the moringa/rape mixture for the March crop. The negative effect of reduced rape yield was moderated by pruning moringa to reduce its height. Rape/moringa stands led to the reduction in weed densities and weed biomass, and at the same time increased gravimetric moisture levels. Based on these results rape/moringa mixtures are recommended as they are more productive, giving greater biomass outputs than sole rape. These conclusions are based on March to June tests hence assessments for the July to February are recommended.

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# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF APPENDICES

# ABBREVIATIONS

ANOVA- Analysis of variances

CRS- Chiredzi Research Station

$Log_{10}$- logarithm to base 10

LSD-  Least Significant Difference

NS- Not significant at $P < 0.05$

$^{o}C$- Degrees of Celsius

Sed- Standard error of the difference between means

$P < 0.05$ – probability less than 5 %

WAT- weeks after transplanting rape crop

# CHAPTER ONE

# INTRODUCTION

A survey carried out by Turner and Chivinge (1999) in Mashonaland East province of Zimbabwe revealed that rape (*Brassica napus*) is among the most popular vegetables. Rape production among smallholder farmers is important for its nutritional value, income generation and social value (FAO, 1997; Turner and Chivinge, 1999 and Acquaah, 2005). Like most dark-green leafy vegetables, rape is generally a moderate to good source of Vitamin A and C. Vitamin A is important for good vision and its deficiency result in blindness whilst Vitamin C is important for the immune system (FAO, 1997).

Rape is a cool season crop (Decoteau, 2000) and its production is limited to periods of low temperature especially in the semi- arid region of Zimbabwe. Semi- arid regions of Zimbabwe which cover more than 43% of land are characterized by hot, dry conditions and low rainfall, below 450mm per annum (Gore, Katerere and Moyo, 1992). These conditions that is less than ideal for rape, limit production of this crop to months with cooler temperatures. The limitation of rape production in cool season in semi- arid region of Zimbabwe constrains farmers' livelihoods and compromises their nutritional well being during hot season.

Since rape production in hot season is difficult due to high temperatures, excessive radiation and disease prevalence among other causes, production under shade can assist in two main ways: reduction of temperature caused by direct sunlight and minimization of radiation load. Whilst artificial shade is expensive and non-practical, alternatively tree shade is both cheaper and more practical, being accessible to communities with low-resource endowment Generally, shading causes reduction of temperature and temperature fluctuations together with vapour pressure deficit (VPD) under tropical conditions (Nair, 1993). Examples can be drawn from Barradas and Fanjul (1986) who compared shaded versus open- grown coffee and discovered that in a coffee plantation under shade of *Inga jinicuil* the average maximum temperature was 5 $^{o}$C, lower and minimum temperature 1,5 $^{o}$C higher. It was reported that VPD was substantially reduced as compared to open grown coffee. The smaller temperature fluctuations under shade were attributed to reduced radiation load on the coffee plants during the day and reduced heat loss during the night.

Similar results indicating microclimate amelioration were reported for combination of coconut and cacoa in India (Nair and Balakrishnan, 1977) and for an alley cropping system of millet and Leucaena in India (Corlett, Ong and Black, 1989). The reduction of VPD is likely to cause a corresponding reduction in transpiration and hence less likelihood of water stress for the shaded crop (Willey, 1975) and (Rosenberg, Blad and Verma (1983). This could be beneficial especially during short periods of drought and may result in production increases as in the case of increased tea yields under shade in Tanzania during the dry season (Willey, 1975). Similarly, bean plants associated with *Grevillea robusta* showed no signs of wilting in hot afternoons whereas those grown on a field without trees did (Neumann and Pietrowicz, 1989).

An ideal shade tree should have a sparse, small crown to permit sunlight (Chundawat and Gautam, 1993). Potentially, *Moringa oleifera* can be used for shade under the Zimbabwe semi-arid conditions since it exhibits an open crown that can allow radiation to penetrate understorey crop (Nair, 1993). In addition, moringa is a drought – tolerant tree most suitable for semi-arid conditions (Palada and Chang, 2003). Moringa is a multi-purpose tree with many uses including fencing, wind protection, and support for climbing garden plants. In addition, moringa has high levels of vitamin A and C, protein and minerals such as iron and calcium. Other uses of moringa include oil extraction and water purification (Price, 2000).

Shade tree over vegetable crops could have additional advantages. A reduction of weeds due to the presence of trees has been reported for many ecological zones (Nair, 1993). There is a possibility of using shade trees in situations where weed control is a serious land-use problem, as in the vast areas of tropical humid lowlands infested with obnoxious weeds such as *Imperata cylindrical.* Presence of shade trees in vegetables can also result in insect pest reduction (Innis, 1997). Growing of moringa together with rape can reduce insect pests like aphids problematic to rape production.

However, trees for shade may create a source of competition for space, radiation, moisture and nutrients, which may reduce food crop yields (Vergara, 1992). In stands with more than one species, competition for limited resources is inevitable. As in the free market economy, competition can increase production by the system as a whole or can help to stabilize outputs when the supply of resources is erratic (Monteith, Ong and Corlett, 1991).

Where competition occurs between the shade and understorey crop, pruning of shading trees can help to reduce the negative effects (Nair, 1993). It is assumed that shading by overstorey species is undesirable and a major emphasis of agroforestry research is to develop pruning regimes to improve the light available to understorey crops (Monteith et al, 1991).

Moringa has been extensively studied for its medicinal properties (e.g. Njoku and Adiwa, 1997; Kumar and Goel, 1999); nutritional attributes (e.g. Kulkarni and Kulkarni, 1993) and industrial properties (e.g. Ndabigengesere and Narasiah, 1998) but there is no evidence that it has been evaluated in semi-arid region as a shade tree under different pruning regimes and how it performs in intercrop situations. The study reported here aims to evaluate moringa as a shade tree for rape and assess if pruning may moderate shade effects, and whether there are other effects whether positive, such as reduction of weeds, or negative such as increased moisture stress.

### 1.1 Specific Objectives

1.1.1. To evaluate moringa as a shade tree on rape weight and number of leaves.

1.1.2. To measure the extent of competition for water and radiation between moringa and rape and whether competition can be moderated by pruning.

1.1.3. To determine whether moringa shade reduces weed density and biomass, and insect pest damage

### 1.2 Hypotheses

1.2.1. The use of moringa as a shade tree will reduce temperature and excess radiation load for the rape and ultimately improve crop yield, and can be moderated by pruning.

1.2.2. There is no competition for light and water between moringa and rape

1.2.3. Additional benefits are that moringa shade will reduce weed density and biomass, and insect pest damage.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Rape Production

### 2.1.1 Importance of Rape in Zimbabwe

A survey carried out by Turner and Chivinge (1999) in Mashonaland East Province of Zimbabwe revealed that most popular vegetables are rape, rugare and cabbage in that order of importance. Rape can be harvested in a short period of time with multiple harvests and its taste is preferred to rugare and cabbage. Rape is grown in Zimbabwe for various reasons and these include income generation, nutritional, and recreational purposes. Rape and other most-green leaf vegetables are generally moderate to good source of Vitamin A and C. The major role of vitamin A in body is good vision as it keeps the front of the eye (the conjunctiva and the cornea) strong, clear, and moist. Vitamin A deficiency causes blindness and even death especially in children. Whilst Vitamin C on the other hand is important for the growth and maintenance of healthy bones, teeth, gums, ligaments and blood vessels. Prolonged deficiency of Vitamin C in the diet causes scurvy, a disease in which the body's immune system is weakened (FAO, 1997).

### 2.2.2. Challenges Associated with Rape Production in Zimbabwe.

Smallholder farmers have a problem of pests and diseases in rape production. Almost every farmer perceives aphids as the common pest of rape while leaf spot was regarded as a common disease (Turner and Chivinge, 1999). Pests and diseases in rape production are worsened by high temperatures and shortage of water (Acquaah, 2005). A survey carried by Turner and Chivinge (1999) revealed that the majority of farmers do not use pesticides to control pests and diseases in their vegetable production.

Apart from pests and diseases, seasonality is a major barrier to obtaining the benefits of fruits and vegetables especially in tropical countries (FAO, 1997). Seasonality is mainly caused by climatic factors like temperature and radiation, which limit some vegetables to be grown at specific times of the year. Rape is a cool season crop (Decoteau, 2000) and as such is grown during the time of the year when temperature is low (Acquaah, 2005). Rape production is limited in winter for semi-arid region since their summer is characterized by dry and very high temperatures (Gore et al., 1992). Seasonality of rape vegetable constrains smallholder farmers' livelihoods and compromise their nutritional wellbeing.

Since rape production in summer is difficult due to high temperatures, excessive radiation and disease prevalence among other causes, production under shade can assist. Whilst artificial shade is expensive and non-practical, alternatively tree shade is both cheaper and more practical, being accessible to communities with low- resource endowment.

## 2.2 Tree Shading

### 2.2.1 Use of Moringa as a Shade tree in Semi-arid Hot Areas

*Moringa oleifera* can be used as a shade tree since it exhibits an open crown that allows radiation to penetrate understorey crops (Nair, 1993). This is supported by Chundawat and Gautam (1993) who hypothesized that a shade tree should have a sparse, small crown to allow sunlight in.

In addition, moringa is a drought- tolerant tree most suitable for semi-arid conditions. Moringa grows best in temperatures ranging from 25°C to 35°C, but will even tolerate warm temperature up to 48°C. The drought tolerant tree grows well in areas receiving annual rainfall amounts between 250 to 1500 mm. Moringa grows best in altitudes below 600m, typical of semi- arid regions, although it can still adapt up to 1200m in the tropics (Chang and Palada, 2003).

Other benefits of growing moringa as a shade tree are numerous since it is a multi-purpose tree. Moringa leaves have high levels of Vitamin A and C, protein and minerals such as iron and calcium. In addition, moringa leaves are incomparable as a source of sulphur -containing amino acids methionine and cystine which are often in short supply. Other uses of moringa include fencing, wind protection, oil extraction, water purification, and support for climbing garden plants (Price, 2000).

However, shading may cause negative effects on understorey crops and such negative effects may need to be moderated. Previously in Zimbabwe, cover crops intercropped with coffee were shown to predispose the coffee to leafminer and frost damage (Clowes, 1973). Among measures to moderate competition from shade trees for light pruning can be used to regulate the amount of light to be transmitted.

### 2.2.2 Pruning of Shade Trees

Monteith et al (1991) assumed that shading by overstorey species is undesirable and a major emphasis of agroforestry research is to develop pruning regimes to improve the light available to understorey crops (Miah et al, 1995). Tree management practices like side-branch pruning are important techniques to minimize the effect of light stress on the growth, development, and yield of understorey annual crops (Kang, van der Kruijs and Cooper, 1989 and (Kang and Wilson, 1987)). Though pruning of the lower branches may reduce the light interception by the tree canopy, severe pruning may be useful to expose the understorey crops to the most of the incident light to avoid a shading effect (Chundawat and Gaautam, 1993). Pruning of shade trees also enables the farmers to use the leaves as food, fodder or medicine. The farmer will harvest from both annual crop and tree species. The leaves that are pruned if left on the ground will decompose and supplement nutrients to the annual crop. Kang, Wilson and Sipkens (1981) reported that, with the continuous addition of *Leucena leucocephala* prunings, higher soil organic matter and nutrient levels were maintained compared to no addition of prunings.

### 2.3 The Effect of Climatic Factors on Understorey Crops

#### 2.3.1 The Effect of Radiation on Understorey Crops

In systems of vegetable and shade trees, light availability may be the most important limitation to the performance of the vegetable, particularly where the shade tree forms a continuous shading canopy (Miah et al, 1995). Light is important for the production of ATP and NADPH and thus at low light intensities, these products are not produced in adequate amounts (Acquaah, 2005). ATP and NADPH are important products that are used in the Calvin Cycle of photosynthesis.

However, when light intensity is extreme other factors such as carbon dioxide may be limited causing rate of photosynthesis to decline (Acquaah, 2005). Low absorption of carbon dioxide at high light intensities result in carbon limiting in the Calvin Cycle of photosynthesis and this will result in reduced biomass accumulation. In addition, extreme light intensities result in low availability of ADP and NADP substrates to accept electrons for the production of ATP and NADPH which are important prerequisites of the Calvin cycle, and this will also result in reduced biomass accumulated over time (Loomis and Amthor, 1999).

### 2.3.2 The Effect of Temperature on Understorey Crop

According to Brenner (1996), many developmental processes are temperature controlled with their rate increasing linearly above a base temperature. For example the rate of germination of millet seed increases linearly with soil temperature from $10^{o}$C to an optimum of $32^{o}$C, then decrease linearly to a lethal temperature of around $40^{o}$C. It has been suggested that one of the major causes of improved crop growth under a canopy of *Faidherbia albida* is reduction of soil temperature at the beginning of the season, as a result of shading of the soil by the canopy since in the semi-arid tropics temperature can exceed $50^{o}$C (Brenner, 1996).

Photosynthetic rate is decreased in cold temperatures because the fixation stage is temperature sensitive. However, under conditions in which light is a limiting factor (low light conditions), for example in shaded crops the effect of temperature on photosynthesis is minimal. Generally, if light is adequate, the photosynthesis rate is found to approximately double the rate in plants for each $10^{o}$C rise in temperature (Acquaah, 2005).

## 2.4 Effects of Shading

### 2.4.1 The Effect of Shading on Soil Water Content

The presence of trees in vegetables may have both positive and negative overall effects on the water budget of the soil and crops growing in between or beneath them (Nair, 1993). Bronstein (1984) examined the water content of the top 0.1m in Costa Rica and found higher moisture content under *Erythrina poeppigiana* or *Cordia alliodora* than in open fields during the dry season. The light transmission through the canopy of the *Erythrina* was only 40 %, while *Cordia* was leafless at that time. He hypothesized that the higher soil moisture under *Erythrina* may have been partly due to lower evaporative water losses as a function of lower soil temperatures.

However, in some situations, especially in semi arid regions, the transpiration of shade trees may actually increase water stress to the understorey crops (Nair, 1993). When plants grow under conditions of moisture stress because of low soil moisture, enzymatic activities associated with photosynthesis in the plants slow down. Stomata close under moisture stress, reducing carbon dioxide availability and consequently decreasing photosynthetic rate (Acquaah, 2005).

### 2.4.2. The Effect of Shading on Stomatal Resistance

The opening and closing of stomata is a function of vapour pressure deficit (VPD), leaf water status, leaf temperature, and internal carbon dioxide concentration. Shading by trees reduces radiation, VPD and leaf temperature causing changes in stomatal resistance. The competition for water between shade tree and vegetable changes leaf water status and thus altering the activity of stomata. So plants growing under trees may have different stomatal resistance from those grown in monoculture, changing their evaporation and photosynthetic rates (Brenner, 1996).

### 2.4.3 The Effect of Shading on Insect Pests

Shading of vegetable by trees has been found to reduce insect pest populations. An example can be drawn from growing spurry and cabbage at Costa Rica, which resulted in reduced number of insects (Innis, 1997). Such tree -crop combinations are important in reducing insect population, which presumably reduces insect damage and the incidence of those plant diseases that are carried by insects.

There are several ways in which tree-crop combinations can control insect pests. One theory is that aromatic or strong smelling intercrops will keep away pests. This may be true but has not been proven scientifically. Generally researchers accept the physical confusion of insects by tree- crop mixture as an explanation for its success in controlling insect pests. In a sole crop, the insects, which eat the crop, have easy success in finding crops to eat and suitable places to lay eggs. In northern Nigeria, a pest called Manica causes great damage in commercial fields of monocropped cowpeas. However the problem is minimal in intercrop of sorghum-millet fields since grains shade the cowpeas (Innis, 1997).

Shade trees may provide a home base for useful predator insects and spiders that attack bugs, which damage the main crop. Harmful insects cannot become immune to this method of control. Heliothis bollworm, which eats cotton in Peru, can be almost completely eliminated by planting maize every tenth row. Four species of useful bugs hatch out in the silk of the maize and the adults fly to the cotton where they eat the eggs and young of Heliothis (Innis, 1997).

However not all tree-crop combinations reduce insect and disease damage because some insects eat more than one crop. In India, pyrilla, an insect pest, increased in numbers when the two grains jowar and bajri were grown together, but its population was reduced considerably when jowar was intercropped with the legumes, pigeon pea and blackgram.

### 2.4.4 The Effect of Shading on Crop-Weed Competition

A reduction of weeds due to the presence of trees has been reported from many regions. For example. *Cassia siamea* was reported to control weeds better than *Gliricidia sepium* or *Flemingia macrophylia* and this was attributed to the greater shade under *Cassia* (Nair, 1993).

In the presence of adequate water and nutrients and favourable temperatures, available light sets the limits for plant productivity and photosynthesis. Most weeds and crops reach their maximum photosynthetic and growth rates in full sunlight. Therefore any decrease in light incident from canopy shading by tree will decrease rates of growth and lower maximum photosynthetic rate (Bridgemohan, 1995).

Apart from reduction in plant productivity, weed seed germination can be influenced by light interception. The red portion of the light spectrum, which promotes weed seed germination, is absorbed by tree leaves in tree-crop combinations and reduces weed plant population. In shade and vegetable cropping system, it is the far red light that is transmitted through the canopy and is inhibitory to weed seed germination (Bridgemohan, 1995).

Plant species with greater allelochemical production suppress weeds better than those with low production (Bridgemohan, 1995). Many trees have been reported to possess allelopathic properties. The allelochemicals on other plants are known to be dependent principally upon the concentration and also the combination in which one or more of these substances are released into the environment. Moringa is said to compete well with weeds and it has been suggested that it is due to its allelopathic effects (Nair, 1993).

**2.5 Competition for Resources between Shade Trees and Understorey Crop.**

Sole crop have uniform genetic base and resources appear to be shared equitably except when overcrowding makes self-thinning avoidable. However, in stands with more than one species like tree-crop combinations, competition for limited resources is inevitable, both above and below ground, However, competition can increase production by the system as a whole or can help to stabilize outputs when the supply of resources is erratic (Monteith et al., 1991).

Shading was found to be more important than below-ground competition in an intercropping study with pearl millet and groundnut in India (Willey and Reddy, 1981). Similarly Verinumbe and Okali (1985) confirmed that competition for light was a more critical factor than root competition for maize - teak trees (*Tectona grandis*) combinations in Nigeria (Nair, 1993). While the availability of light may be the most limiting factor in many situations, particularly those with relatively fertile soils and adequate water availability, the relative importance of light will decrease in semi-arid conditions as well as sites with low fertility soils. Since crops differ in their responses to poor nutrition, competition for light or water may either be reduced or amplified by a shortage of nutrients (Cannel, 1983).

Water competition is likely to occur where a tree species is grown together with an annual crop at some point of time with the exception of areas with well-distributed rainfall or sites that receive continuous supply of below-ground water (Nair, 1993). An example can be drawn from cropping trials of *Leucaena* with cowpea, castor and sorghum under semi arid conditions in India. Competition for water appeared more important than shading effects (Singh, Vandenbeldt, Hocking and Karwar, 1989). Reductions of over 30% in water content occurred for the crops growing at a distance of less than 10m from the tree line (Malik and Sharma, 1990). Thus despite the use of drought-adapted trees, water competition is likely to determine the productivity of tree-crop combinations especially in semi- arid regions (Nair, 1993).

There are many studies indicating how competition for nutrients can reduce crop yields. The crop root system is usually confined to soil horizons that are also available to the roots of the trees but the roots can exploit soil volumes beyond the reach of the crop. Therefore, the effect of nutrient competition will be more severe for the crop components (Nair, 1993). However, direct evidence as to where and how severity nutrient competition occurs is limited due to difficulties of separating it from competition for light and water (Young, 1989).

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Research Site Characteristics

The studies were carried out at Chiredzi Research Station (CRS) in the 2006/07 rainy season. CRS lies between 21°33′S and 31°30′E in Masvingo Province of Zimbabwe. It has an altitude of 429m above sea level. CRS is characterized by hot, dry conditions and low rainfall of 500mm on average per annum. The average maximum temperatures for the 2006/07 season are as shown in Figure 3.1. The soils in the area are generally dark reddish brown clays derived from basic gneiss. The soils are classified as Triangle P2 series called paragneiss soils.

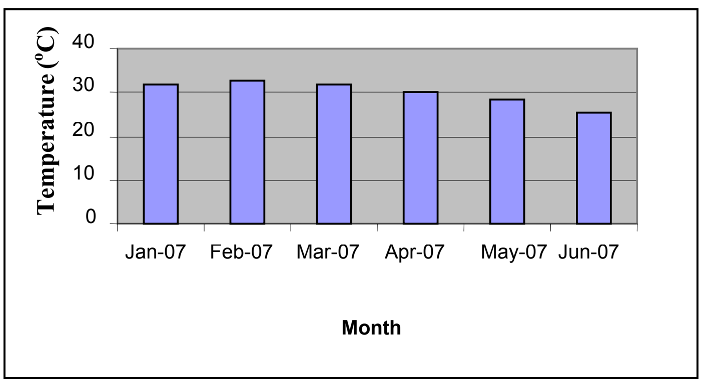


**Figure 3.1 Mean maximum temperatures (°C) for Chiredzi Research Station in 2007**

## 3.2 Trial Management

### 3.2.1 Nursery and Field operations

Moringa seeds purchased from a farmer residing in the vicinity of Chiredzi Research Station were sown in plastic pockets on 5 December 2006. Media used was of sand, compost manure and sugarcane filter cake mixed in the ratio of 4:3:1 respectively. Moringa seedlings were then hardened for three weeks on 7 February 2007 by placing them in direct sunlight. The land was ploughed and ridged using a tractor drawn plough and ridger respectively. The field was divided to plot sizes of $30m^2$ (6m x 5m) using a tape measure, string and pegs. Moringa seedlings were transplanted on the ridges at the end of February 2007. Moringa seedlings were planted into the holes of 0.15m deep on ridges and at a spacing of 1m x 1m.

At the end of February 2007, rape seeds (English giant variety) were sown in speedling trays with similar media as described above. After two weeks the seedlings were thinned to one seedling per hole. The seedlings were liquid fed using ammonium nitrate (34, 5%N), single super phosphate (20% $P_2O_5$) and muriate of potash (60% $K_2O$) mixed at the ratio of 4:3:1. Sixty grams (twelve teaspoons) of the mixture was dissolved in five litres of water and sprinkled to the leaves of the seedlings. The seedlings were then hardened for one week by reducing the frequency of watering gradually from three to two and then one. Rape seedlings were transplanted at the end of March in furrows between moringa hedgerows at the spacing of 0.5m inter row and 0.4m inrow. The basal fertilizer that was applied before transplanting is Cottonfert (6% N, 18% P and 10% K) at the rate of 700kg per hectare and was top-dressed at 4 weeks after transplanting rape (WAT) with ammonium nitrate at the rate of 100kg per hectare. Dimethaote 40 EC and Malathion 25 WP were used to control aphids and centre grub insect pests. Management practices were the same for sole rape, sole moringa and moringa-rape intercrops for each of March and June rape cycles.

### 3.3 Experimental Design and Treatments

The experiment was set up as a 2 x 2 factorial in a randomized complete block design to test the effect of cropping system and pruning of moringa on weed density and biomass, soil water content, and moringa height. However, a randomized complete block design was used to test the effect of moringa shade (moringa pruned/rape, moringa unpruned/rape and sole rape) on rape fresh and dry weight and number of rape leaves, leaf temperature and stomatal resistance in March and June. The additional treatment used in both designs is sole rape (control).

Factor 1 was pruning, with pruned moringa and unpruned moringa and factor 2 was cropping system with sole moringa and moringa/rape intercrop. The treatments were replicated four times. The total treatment combinations are as outlined in Table 3.1.

**Table 3.1: Treatment combination of pruning, time of growing rape and cropping system**

| Treatment | Pruning | Cropping system |
|---|---|---|
| 1 | Pruned | Sole moringa |
| 2 | Unpruned | Sole moringa |
| 3 | Pruned | Moringa-rape |
| 4 | Unpruned | Moringa-rape |

For moringa pruning treatments, growing tops of 10 cm long were removed after four weeks of transplanting moringa and at three weeks interval thereafter until the end of the project.

### 3.4 Measurements

#### 3.4.1 Rape Yield

Fresh weight, dry weight and number of fully-grown leaves were measured from a net plot of 12 $m^2$. A sample of fresh leaves from each plot was weighed, oven dried at $110^oC$ for 48 hours and then re-weighed. A method of proportionality was used to approximate the dry weight of each plot using the following formula:

$$\frac{\text{Dry weight of sample x Total fresh weight of plot}}{\text{Fresh weight of sample}}$$

Only the total of first five harvests of rape for each cycle were considered in this experiment.

#### 3.4.2 Weed Counts

Weeds were counted in three randomly thrown 30 cm x 30 cm quadrants per plot at 4, 6 and 8 weeks after transplanting rape (WAT) before hoe weeding was done. The weeds were cut at ground level and oven dried at 110 $^oC$ for 48 hours and then weighed.

#### 3.4.3 Solar Radiation Capture

Two pairs of solarimeters and data logger were used to measure radiation. One sensor was placed under the canopy of randomly chosen plot of unpruned moringa, the other under the canopy of pruned moringa. The third solarimeter sensor was placed on a randomly chosen plot with sole rape. All the sensors were placed about 30 cm above ground. Solar radiation was measured at 4 WAT for March crop only

### 3.4.4 Gravimetric Soil Water Content (g)

Gravimetric soil water content was measured at 4 WAT for three times at irrigation interval for the March and June crops. The measurements were taken just before irrigation. Gravimetric method was used to determine the soil water content whereby metal tins with known volume were pushed into the soil to collect soil without disturbing it and weighed. The tins and soil contents were oven dried at 110 $^{o}$C for 48 hours and re-weighed.

### 3.5.5 Leaf Temperature ($^{o}$C)

Leaf temperature was measured at 4 WAT for the March crop only. A hand held infra red thermometer was used to measure temperature of healthy, fully expanded leaves. Three randomly chosen leaves from different plants of net plot were used. To ensure accurate measurement, calibration was done after going through every two plots.

### 3.4.6 Stomatal Resistance

Stomatal resistance was measured at 4WAT of the March crop only using the AP4 porometer (Delta-T, Burwell, Cambridge UK) on three leaves previously used to measure leaf temperature. To ensure accurate measurements, a new calibration curve was fitted every time when necessitated by a change in cup temperature (2 $^{o}$C on average).

### 3.4.7 Height of Moringa Trees (cm)

Measurements of moringa heights were done at 3 WAT and 6 WAT of March, June and August crops. A graduated 2 metre rule was used to measure the height.

**3.5 Data Analysis**

All the data was analysed using Genstat Version 8. Discrete data and data failing to meet the assumptions of normality, homogeneity, and randomness of residuals was transformed using box cox or square root or log to base 10. The test of the above assumptions was done using Bartlett's test. Mean separation was carried out where the ANOVA indicated a significant treatment effect at $P<0.05$ and treatment means were separated using Least Square Differences (LSD).

# CHAPTER FOUR

# RESULTS

## 4.1 Rape Yield For March And June Crops

### 4.1.1. Fresh Weight of Rape For March And June Crops

Moringa shade had a significant effect (P< 0.05) on total rape fresh weight for both March and June crops. Sole crop had the highest fresh weight for March and June crops while rape under Moringa unpruned gave the lowest yield (Table 4.1). The presence of Moringa reduced rape fresh weight by 39.4% and 39.5% respectively for March and June crops. Pruning moringa only resulted in 11.6% and 33.4% reduction in rape fresh weight for March and June respectively. Rape fresh weight for pruned moringa and unpruned moringa was not significantly different (P> 0,05) for the June crop (Table 4.1).

**Table 4.1: Effect of Moringa shade on total rape fresh weight (kg/ha) for March and June crops**.

| Treatment | Total Fresh weight for March | Square root total Fresh weight For June |
|---|---|---|
| Moringa- pruned rape | 5375.0 [b*] | 55.8 [a] (2594.7) |
| Moringa- unpruned rape | 3687.5 [a] | 61.5 [a] (3151.9) |
| Sole rape | 6083.3 [c] | 92.3 [b] (7099.4) |
| P value | < 0.01 | 0.010 |
| $LSD_{0.05}$ | 569.16 | 20.49 |
| Sed | 232.58 | 8.3 |

* Means with the same letter in the column are not significantly different at P < 0.05.
LSD- Least Significant Difference
Sed- Standard error of the difference between means
Figures in brackets are the original means were data was transformed

### 4.1.2 Dry Weight of Rape For March And June Crops

Similarly, Moringa shade had a significant (P< 0.05) effect on total rape dry weight for both March and June crops. Sole crop had the highest dry weight for March and June crops while rape under Moringa unpruned gave the lowest yield (Table 4.2). The presence of Moringa reduced rape dry weight by 35.9% and 60.6% respectively for March and June crops. However, pruning moringa resulted in 7.3% increase in dry weight and 65.6% reduction in rape dry weight for March and June crops respectively. Total rape dry weight was not significantly different (P< 0.05) for pruned moringa and sole rape for March crop, however it is significantly different (p< 0.05) for June crop. Similarly with fresh weight, rape dry weight for pruned moringa and unpruned moringa was not significantly different (P > 0,05) for June crop (Table 4.2).

**Table 4.2: Effect of Moringa shade on total rape dry weight (kg/ha) for March and June crops**.

| Treatment | Square root total Dry weight for March | $Log_{10}$ Total dry weight For June |
|---|---|---|
| Moringa- pruned rape | 6.110 [b*] | 2.568 [a] (308.2) |
| Moringa- unpruned rape | 5.419 [a] | 2.627 [a] (353.0) |
| Sole rape | 6.028 [b] | 3.031 [b] (894.9) |
| P value | 0.017 | 0.008 |
| LSD0.05 | 0.4419 | 0.2530 |
| Sed | 0.1806 | 0.1034 |

* Means with the same letter in the column are not significantly different at P < 0.05.
LSD- Least Significant Difference
Sed- Standard error of the difference between means
Figures in brackets are the original means were data was transformed

### 4.1.3 Number of Rape Leaves For March And June Crops

Similarly, sole rape had the highest number of leaves harvested while rape under moringa unpruned gave the lowest number of leaves (Table 4.3). The presence of moringa reduced number of rape leaves by 12.4% and 32% for March and June crops respectively, while pruning reduced number of rape leaves by 3.4% and 38.1% for March and June crops respectively. The number of rape leaves for pruned and unpruned moringa where not significantly different ($p > 0.05$) for the June crop (Table 4.3).

**Table 4.3: Effect of Moringa shade on total number of rape leaves per ha for March and June crops.**

| Treatment | $Log_{10}$ Total Number of rape Leaves for March | Square root Total Number of rape leaves for June |
|---|---|---|
| Moringa- pruned rape | 2.4861[a*] (255222) | 15.01[a] (187750) |
| Moringa- unpruned rape | 2.4436[b] (231430) | 15.74[a] (206456) |
| Sole rape | 2.5009[c] (264070) | 19.09[b] (303690) |
| P value | < 0.01 | 0.020 |
| LSD0.05 | 0.01382 | 2.659 |
| Sed | 0.00565 | 1.087 |

* Means with the same letter in the column are not significantly different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of thedifference between means
Figures in brackets are the original means were data was transformed

## 4.2 Radiation Captured (W $m^2$) by Rape Leaves For March Crop

Although it was not statistically tested moringa shade had an effect on the radiation transmitted to rape (Figure 4.1). The radiation intercepted by sole rape was more than rape under moringa unpruned or pruned. Also pruning had an effect on the amount of radiation transmitted to understorey rape by moringa canopy (Figure 4.1). More radiation was transmitted to rape under pruned than unpruned moringa.

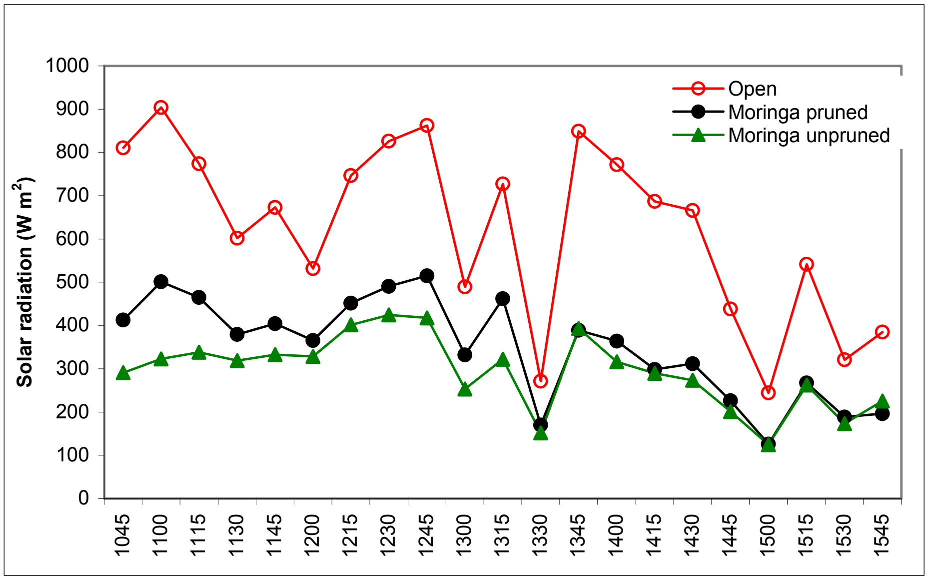


**Figure 4.1: The effect of moringa shade and pruning on radiation transmitted to rape for the March measured on 4 May 2007**

### 4.3 Rape Leaf Temperature for theMarch Crop

The rape leaf temperature recorded at 1229 and 1350 of the March crop showed significant difference ($p < 0.05$) where the sole crop had the highest temperature followed by moringa (pruned)/rape and unpruned-moringa rape had the lowest. Presence of moringa reduced leaf temperature by 25% and 29% at 1229 and 1350 respectively. No significant difference ($P < 0.05$) was shown for moringa-pruned /rape and moringa(unpruned)/ rape (Table 4.4).

**Table 4.4: Effect of Moringa shade on rape leaf temperature (°C) for March crop recorded at 1229, 1350, 1437 and 1459 on 4 May 2007**.

| Treatment Time | 1229-1244 | 1350-1414 | 1437-1458 | 1459-1513 |
|---|---|---|---|---|
| Moringa-pruned/ rape | 14.50[a*] | 21.33[a] | 19.00 | 20.92 |
| Moringa-unpruned/ rape | 14.50[a] | 18.58[a] | 17.58 | 21.00 |
| Sole rape | 19.33[b] | 26.17[b] | 19.92 | 22.42 |
| P value | 0.004 | 0.025 | NS | NS |
| LSD0.05 | 2.393 | 4.944 | 4.704 | 3.699 |
| Sed | 0.978 | 2.020 | 1.922 | 1.512 |

* Means with the same letter in the column are not significantly different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of the difference between means

### 4.3 Stomatal Resistance ($sm^{1}$) of Rape Leaves for March Crop

Moringa shade had no significant effect (p>0.05) on stomatal resistance of rape leaves. However, stomatal resistance was higher in rape leaves under unpruned moringa followed by pruned moringa and then sole rape (Figure 4.2). The stomatal resistance for pruned moringa/rape and unpruned moringa/rape is comparative although there are different from sole rape.

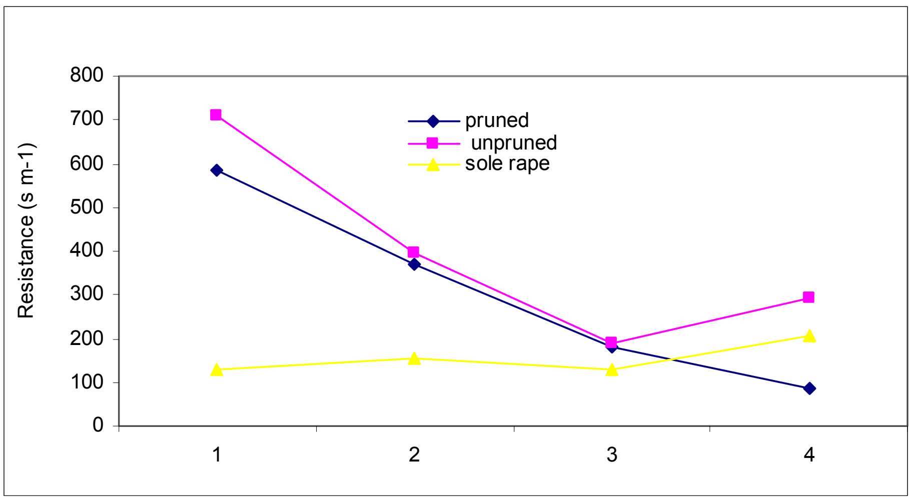


**Figure 4.2: The effect of moringa shade on rape leaf stomatal resistance measured on 4 May 2007**

### 4.5 Gravimetric Water Content (g) for March and June Rape Crops.

There was no significance different ($p > 0.05$) in gravimetric water content for March and June crops except at 4 WAT for June crop. Cropping system had a significant difference ($p < 0.05$) in gravimetric water content at 4 WAT for June crop (Table 4.5). For March and June crops, cropping system of moringa rape intercrop had the highest gravimetric water content over sole rape. Pruning had no significant difference ($p > 0.05$) in gravimetric water content although unpruned moringa gave the highest water content for March and June crops.

**Table 4.5: The effect of cropping system and pruning on gravimetric water content (g) at 4 WAT for June crop**

| | Pruning | | |
|---|---|---|---|
| Cropping system | Pruned Moringa | Unpruned Moringa | Mean |
| Sole Moringa | 59.2 | 59.8 | 59.5 [a*] |
| Moringa rape intercrop | 68.0 | 75.0 | 71.5 [b] |
| Mean | 63.4 | 67.4 | |
| | P value | $LSD_{0.05}$ | Sed |
| Cropping system | 0.012 | 8.68 | 3.84 |
| Pruning | NS | 8.68 | 3.84 |
| Cropping system x pruning | NS | 12.67 | 5.42 |

* Means with the same letter in the column are not significantly different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of the difference between means

### 4.6 Moringa Height (cm) For March and June Crops.

Pruning had a significant effect ($p < 0.05$) on moringa height at 3 WAT and 6 WAT for March and June crops while cropping system had a significant effect ($p < 0.05$) on moringa height at 6 WAT for the March crop and 3 WAT and 6 WAT for the June crop. Interaction of pruning and cropping system was significant ($p < 0.05$) at only 3 WAT of the June crop (Figure 4.3). Generally, moringa- rape cropping system had the highest moringa height over sole moringa at 3 WAT and 6 WAT for March and June crops. Unpruned moringa had the highest moringa height over pruned moringa at 3 WAT and 6 WAT for March and June crops.

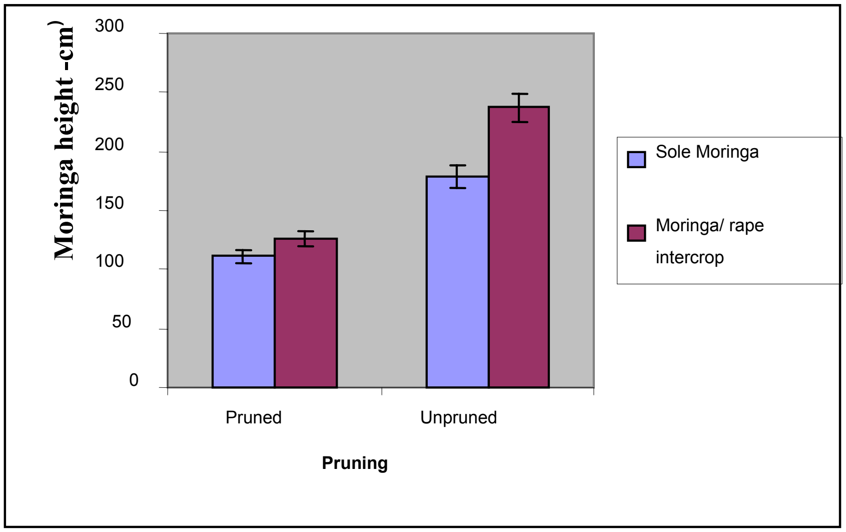


**Figure 4.3: The effect of cropping system and pruning on moringa height (m) at 3 WAT for the June crop. Bars represent standard error of the difference between means.**

### 4.7 Weed Densities and Biomass For March Rape Crop

Cropping system had a significant effect ($p < 0.05$) on total weed density and non – significant effect on weed biomass at 6WAT of the March crop. While pruning had significant effect ($p < 0.05$) on weed biomass and non-significant effect on weed density at 6WAT of the March crop (Table 4.6).

**Table 4.6: The effect of cropping system and pruning on square root weed biomass ($kg/m^2$) at 6 WAT for March crop.**

| | Pruning | | |
|---|---|---|---|
| Cropping system | Pruned Moringa | Unpruned Moringa | Mean |
| Sole Moringa | 4.606 | 4.226 | 4.416 |
| Moringa rape intercrop | 5.073 | 4.527 | 4.800 |
| Mean | 4.840 [a*] | 4.376 [b] | |
| | P value | $LSD_{0.05}$ | Sed |
| Cropping system | NS | 0.3965 | 0.1753 |
| Pruning | 0.027 | 0.3965 | 0.1753 |
| Cropping system x Pruning | NS | 0.5608 | 0.2479 |

* Means with the same letter in the column are not significantly different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of the difference between means

**Table 4.7: The effect of cropping system and pruning on weed density per $m^2$ at 6 WAT for March crop.**

| | Pruning | | |
|---|---|---|---|
| Cropping system | Pruned Moringa | Unpruned Moringa | Mean |
| Sole Moringa | 2.340 | 2.241 | 2.291[a*] |
| Moringa rape intercrop | 2.462 | 2.543 | 2.502[b] |
| Mean | 2.401 | 2.392 | |
| | P value | $LSD_{0.05}$ | Sed |
| Cropping system | 0.016 | 0.3965 | 0.0712 |
| Pruning | NS | NS | 0.0712 |
| Cropping system x Pruning | NS | NS | 0.1007 |

* Means with the same letter in the column are not significantly different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of the difference between means

### 4.8 Pest Damage in Rape Leaves For March Crop

There was no significant difference ($P > 0.05$) on the number of rape plants damaged by the centre grub and aphids for the March crop (Table 4.7). However, the highest number of plants damaged by aphids and centre grub where in sole rape. Pruned moringa/rape and unpruned moringa/rape recorded the lowest number of rape plants damaged by aphids and centre grub respectively (Table 4.8).

**Table 4.8: The effect of moringa shade on number of plants damaged by aphids and centre grub for the March crop.**

| Treatment | Square root rape plants damaged by aphids/ ha | Square root rape plants damaged by centre grub / ha |
|---|---|---|
| Moringa pruned- rape | 3.59 (10740) | 1.76 (2581) |
| Moringa unpruned- rape | 3.72 (11532) | 1.76 (2581) |
| Sole rape | 4.27 (15194) | 2.55 (5419) |
| P value | NS | NS |
| $LSD_{0.05}$ | NS | NS |
| Sed | 0.493 | 0.320 |

NS- not significant different at $P < 0.05$.
LSD- Least Significant Difference
Sed- Standard error of the difference between means
Figures in brackets are the original means were data was transformed

# CHAPTER FIVE

# DISCUSSION

The reduced number of rape leaves and lower dry weight of rape in mixed stands of moringa and rape over sole rape reflects that moringa had a negative effect on growth of rape. One likely explanation for reduced rape growth is the observed reduction in the amount of radiation intercepted by rape in a moringa/rape mixture. Radiation is the most important limitation to the performance of the vegetable, particularly where the shade tree forms a continues shading canopy (Miah et al, 1995). Whilst reduction in temperature of rape under moringa can also be considered as a possible explanation for reduced rape yield by unpruned moringa, as suggested by significant decrease in leaf temperature of rape under moringa, pruning moringa did not result in any temperature change. Since pruning resulted in moderation of rape yield, this rules out reduced temperature as the cause.

Higher number of rape leaves and increased dry weight in pruned over unpruned moringa in the March crop indicates that moringa reduced the negative effects of shading for the March crop. The higher radiation intercepted by rape in pruned over unpruned moringa shows that pruning moringa allowed more radiation to be transmitted through moringa resulting in higher rape yield for the March pruned crop. However, insignificant increase of rape dry weight and number of rape leaves in pruned and unpruned moringa for June crop implies that radiation had ceased to be important and was possibly low anyway. The low rape yields in June that are half the March crop yields suggests that the June conditions were less favourable for rape growth. Radiation levels are higher in March than June but were perhaps not excessive to reduce rape yields. Elsewhere, severe pruning is useful in exposing understorey crops to the most of the incident light to avoid a shading effect (Chundawat and Gautam, 1993). Even though pruning moringa increased rape yields when compared to those obtained under unpruned moringa stands, the rape yield level was similar to that obtained in sole rape stands. The implications are that since rape yield was maintained despite the presence of moringa, any moringa growth and biomass is additional output of the system. The moringa/rape combination is therefore more productive than sole raspe. The extra resource (moringa) could be useful as source of leaf vegetable, biomass for mulching or source of saplings for vegetable stakes and for other uses.

The significant increase of gravimetric soil water content in moringa/rape mixture over sole moringa reflects that moringa and rape did not compete for soil water. High gravimetric soil water content in mixed stand of moringa and rape is not attributed to reduced radiation as there was a non-significant effect of soil moisture between pruned moringa and unpruned moringa. Nair (1993) reported that water competition is likely to occur where a tree species is grown together with an annual crop. In this study, the soil water content in moringa/rape mixture increased instead of decreasing. The moringa/rape mixture retained higher moisture levels which can be useful if moisture supply systems become constrained and could result in higher rape productivity under such circumstances.

A significant decrease of weed density in moringa/rape mixtures over sole rape coupled with higher weed biomass in pruned moringa among treatments suggests that moringa shade reduced germination of weeds. The increase in weed biomass of pruned moringa over unpruned moringa is as a result of high weed numbers and not due to increased biomass accumulation of weeds. Weeds compete with crops for radiation, water and nutrients and this reduces crop yields. Elsewhere, *Cassia sepium* reduced weed problems due to shading effects (Nair, 1993). The reduction of weeds in moringa/rape mixture observed in this study did not result in the corresponding increase in number of rape leaves and dry weight. This implies that weeds had no effect on rape yield in this study. However, current reductions in weed densities may lead to reductions in the amount of weed seed heads at the end of the season. Lower numbers of seed heads will lead to reductions in weed seed banks in subsequent seasons and this will ultimately increase yields.

Reduction of pest rape damage by aphids and centre grub in moringa/rape mixture, though insignificant, may indicate that moringa decreased the population of aphids and centre grub in moringa/rape combinations. Presence of moringa in moringa/rape mixtures could have resulted in sporadic nature of aphids and centre grub by modifying microclimate as indicated by low leaf temperature and reduced radiation. Also high moringa heights in moringa/rape mixture could have physically confused aphids and centre grub (Innis. 1997). These findings need further assessment to have conclusive results.

# CONCLUSIONS AND RECOMMENDATIONS

**The conclusions derived from this study were that:**

- Introducing moringa shade in rape stands does not increase rape yields in the Lowveld in the March to June period, contrary to the study hypothesis.
- Moringa shade reduced rape dry weight and number of rape leaves in the moringa/rape mixture over sole rape for both March and June rape crops.
- The negative effect of reduced rape yield seems to be due to shading and was moderated by pruning moringa to reduce its height.
- Positive attributes of rape/moringa stands are that the mixture led to increased biomass outputs, reductions in weed densities and weed biomass, and at the same time increased gravimetric moisture levels.

**Recommendations are that:**

- Rape/moringa mixtures are recommended as they are more productive, giving greater biomass outputs than sole rape.
- Moringa could provide extra leaf to rape leaf, hence improve nutritional wellbeing of communities in these agricultural zones.
- There is need to extent the period of testing beyond the March to June period as highest radiation levels within the Lowveld are usually experienced in August to January.

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# APPENDICES

**A1: The effect of moringa shade on square root rape dry weight of total harvest of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.11197 | 0.37066 | 5.68 | |
| Treatment | 2 | 1.14199 | 0.57099 | 8.75 | 0.017 |
| Residual | 6 | 0.39140 | 0.06523 | | |
| Total | 11 | 2.64536 | | | |

**A2: The effect of moringa shade on rape fresh weight of total harvest of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 14742500 | 4914167 | 31.53 | |
| Treatment | 2 | 17451667 | 8725833 | 55.99 | <0.01 |
| Residual | 6 | 935000 | 155833 | | |
| Total | 11 | 33129167 | | | |

**A3: The effect of moringa shade on square root weed density of the March crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.04392 | 0.01464 | 0.18 | |
| Treatment | 4 | 0.14209 | 0.03552 | 0.43 | 0.784 |
| Residual | 12 | 0.99139 | 0.08262 | | |
| Total | 19 | | | | |

**A4: The effect of moringa on square root weed biomass of the March crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 4.922 | 1.641 | 1.56 | |
| Treatment | 4 | 1.343 | 0.336 | 0.32 | 0.859 |
| Residual | 12 | 12.610 | 1.051 | | |
| Total | 19 | 18.875 | | | |

**A5: The effect of moringa shade on square root weed density of the March crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 5.6971 | 1.8990 | 3.15 | |
| Treatment | 4 | 22.3130 | 5.5782 | 9.24 | 0.001 |
| Residual | 12 | 7.2438 | 0.6036 | | |
| Total | 19 | 35.2538 | | | |

**A6: The effect of moringa shade on square root total weed biomass of the March crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.6066 | 0.5355 | 2.26 | |
| Treatment | 4 | 4.7526 | 1.1881 | 5.02 | 0.013 |
| Residual | 12 | 2.8427 | 0.2369 | | |
| Total | 19 | 9.2019 | | | |

**A7: The effect of moringa shade on total weed biomass of the March crop at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 872.60 | 290.87 | 4.80 | |
| Treatment | 4 | 519.30 | 129.83 | 2.14 | 0.138 |
| Residual | 12 | 727.90 | 60.66 | | |
| Total | 19 | 2119.80 | | | |

**A8: The effect of moringa shade on $\log_{10}$ total weed density of the March crop at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.066502 | 0.022167 | 2.67 | |
| Treatment | 4 | 0.097676 | 0.024419 | 2.94 | 0.066 |
| Residual | 12 | 0.099716 | 0.008310 | | |
| Total | 19 | 0.263894 | | | |

**A9: The effect of cropping system and pruning of moringa on weed biomass of the March crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 118.75 | 39.58 | 3.48 | |
| CS | 1 | 20.25 | 20.25 | 1.78 | 0.215 |
| Pruning | 1 | 2.25 | 2.25 | 0.20 | 0.667 |
| CS x pruning | 1 | 6.25 | 6.25 | 0.55 | 0.477 |
| Residual | 9 | 102.25 | 11.36 | | |
| Total | 15 | 249.75 | | | |

**A10: The effect of cropping system and pruning of moringa on square root weed density at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.10940 | 0.03647 | 0.42 | |
| CS | 1 | 0.04978 | 0.04978 | 0.58 | 0.467 |
| Pruning | 1 | 0.00084 | 0.00084 | 0.01 | 0.924 |
| CS x pruning | 1 | 0.00373 | 0.00373 | 0.04 | 0.840 |
| Residual | 9 | 0.77525 | 0.08614 | | |
| Total | 15 | 0.93899 | | | |

**A11: The effect of cropping system and pruning of moringa on square root weed density at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.20414 | 0.06805 | 3.35 | |
| CS | 1 | 0.17908 | 0.17908 | 8.82 | 0.016 |
| Pruning | 1 | 0.00033 | 0.00033 | 0.02 | 0.902 |
| CS x pruning | 1 | 0.03235 | 0.03235 | 1.59 | 0.238 |
| Residual | 9 | 0.18267 | 0.02030 | | |
| Total | 15 | 0.59857 | | | |

**A12: The effect of cropping system and pruning of moringa on square root weed biomass at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.6768 | 0.2256 | 1.84 | |
| CS | 1 | 0.5897 | 0.5897 | 4.80 | 0.056 |
| Pruning | 1 | 0.8585 | 0.8585 | 6.98 | 0.027 |
| CS x pruning | 1 | 0.0278 | 0.0278 | 0.23 | 0.646 |
| Residual | 9 | 1.1062 | 0.1229 | | |
| Total | 15 | 3.2590 | | | |

**A13: The effect of cropping system and pruning of moringa on weed density at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 396.19 | 132.06 | 2.78 | |
| CS | 1 | 95.06 | 95.06 | 2.00 | 0.191 |
| Pruning | 1 | 7.56 | 7.56 | 0.16 | 0.699 |
| CS x pruning | 1 | 68.06 | 68.06 | 1.43 | 0.262 |
| Residual | 9 | 427.56 | 47.51 | | |
| Total | 15 | 994.44 | | | |

**A14: The effect of cropping system and pruning of moringa on $log_{10}$ weed biomass at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.035785 | 0.011928 | 1.73 | |
| CS | 1 | 0.008484 | 0.008484 | 1.23 | 0.295 |
| Pruning | 1 | 0.021448 | 0.021448 | 3.12 | 0.111 |
| CS x pruning | 1 | 0.013726 | 0.013726 | 2.00 | 0.191 |
| Residual | 9 | 0.061890 | 0.006877 | | |
| Total | 15 | 0.141333 | | | |

**A15: The effect of cropping system and pruning of moringa on moringa height of theMarch crop at 3 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.46362 | 0.15454 | 6.43 | |
| CS | 1 | 0.05760 | 0.05760 | 2.40 | 0.156 |
| Pruning | 1 | 1.28822 | 1.28822 | 53.57 | <0.01 |
| CS x pruning | 1 | 0.00010 | 0.00010 | 0.00 | 0.950 |
| Residual | 9 | 0.21643 | 0.02405 | | |
| Total | 15 | 2.02597 | | | |

**A16: The effect of cropping system and pruning of moringa on moringa height at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 15.3970 | 5.1323 | 22.62 | |
| CS | 1 | 1.7822 | 1.7822 | 7.85 | 0.021 |
| Pruning | 1 | 3.9402 | 3.9402 | 17.37 | 0.002 |
| CS x pruning | 1 | 0.3660 | 0.3660 | 1.61 | 0.236 |
| Residual | 9 | 2.0421 | 0.2269 | | |
| Total | 15 | 23.5276 | | | |

**A17: The effect of moringa shade on box cox gravimetric soil water content of the March crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.029E-06 | 3.430E-07 | 0.18 | |
| Treatment | 4 | 1.714E-06 | 4.285E-07 | 0.23 | 0.917 |
| Residual | 12 | 2.245E-05 | 1.871E-06 | | |
| Total | 19 | 2.519E-05 | | | |

**A18: The effect of moringa shade on $log_{10}$ gravimetric soil water content of the March crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.022030 | 0.007343 | 1.70 | |
| Treatment | 4 | 0.015861 | 0.003965 | 0.92 | 0.484 |
| Residual | 12 | 0.051783 | 0.004315 | | |
| Total | 19 | 0.089674 | | | |

**A19: The effect of moringa shade on box cox gravimetric soil water content of the March crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.220E-06 | 4.067E-07 | 0.17 | |
| CS | 1 | 8.883E-07 | 8.883E-07 | 0.36 | 0.562 |
| Pruning | 1 | 4.730E-08 | 4.730E-08 | 0.02 | 0.893 |
| CS x pruning | 1 | 6.310E-10 | 6.310E-10 | 0.00 | 0.988 |
| Residual | 9 | 2.206E-05 | 2.451E-06 | | |
| Total | 15 | 2.422E-05 | | | |

**A20: The effect of moringa shade on $log_{10}$ gravimetric soil water content of the March crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.010804 | 0.003601 | 0.70 | |
| CS | 1 | 0.006046 | 0.006046 | 1.17 | 0.307 |
| Pruning | 1 | 0.004894 | 0.004894 | 0.95 | 0.355 |
| CS x pruning | 1 | 0.001678 | 0.001678 | 0.33 | 0.582 |
| Residual | 9 | 0.046420 | 0.005158 | | |
| Total | 15 | 0.069841 | | | |

**A21: The effect of moringa shade on square root number of rape plants damaged by aphids of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.0122 | 0.3374 | 0.70 | |
| Treatment | 2 | 1.0364 | 0.5182 | 1.07 | 0.401 |
| Residual | 6 | 2.9115 | 0.4852 | | |
| Total | 11 | 4.9600 | | | |

**A22: The effect of moringa shade on square root number of rape plants damaged by centre grub of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.1018 | 0.0339 | 0.17 | |
| Treatment | 2 | 1.6513 | 0.8257 | 4.03 | 0.078 |
| Residual | 6 | 1.2284 | 0.2047 | | |
| Total | 11 | 2.9815 | | | |

**A23: The effect of moringa shade on rape leaf temperature measured on 4 May 2007 at 1229-1244 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 27.407 | 9.136 | 4.77 | |
| Treatment | 2 | 62.296 | 31.148 | 16.28 | 0.004 |
| Residual | 6 | 11.481 | 1.914 | | |
| Total | 11 | 101.185 | | | |

**A24: The effect of moringa shade on rape leaf temperature measured on 4 May 2007 at 1350-1414 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 27.435 | 9.145 | 1.12 | |
| Treatment | 2 | 117.907 | 58.954 | 7.22 | 0.025 |
| Residual | 6 | 48.981 | 8.164 | | |
| Total | 11 | 194.324 | | | |

**A25: The effect of moringa shade on rape leaf temperature measured on 4 May 2007 at 1459-1513 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 85.852 | 28.617 | 6.26 | |
| Treatment | 2 | 5.685 | 2.843 | 0.62 | 0.568 |
| Residual | 6 | 27.426 | 4.571 | | |
| Total | 11 | 118.963 | | | |

**A25: The effect of moringa shade on rape leaf temperature measured on 4 May 2007 at 1437-1458 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 13.370 | 4.457 | 0.60 | |
| Treatment | 2 | 11.056 | 5.528 | 0.75 | 0.513 |
| Residual | 6 | 44.352 | 7.392 | | |
| Total | 11 | 68.778 | | | |

**A26: The effect of moringa shade on rape leaf temperature measured on 4 May 2007 at 1459-1513 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 85.852 | 28.617 | 6.26 | |
| Treatment | 2 | 5.685 | 2.843 | 0.62 | 0.568 |
| Residual | 6 | 27.426 | 4.571 | | |
| Total | 11 | 118.963 | | | |

**A27: The effect of moringa shade on stomatal resistance measured on 4 May 2007 of the March crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 124533 | 41511 | 1.38 | |
| Treatment | 2 | 153150 | 76575 | 2.55 | 0.158 |
| Residual | 6 | 180373 | 30062 | | |
| Total | 11 | 458056 | | | |

**A28: The effect of moringa shade on square root rape fresh weight of total harvest of June crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 17.6 | 5.9 | 0.04 | |
| Treatment | 2 | 3081.7 | 1540.8 | 10.98 | 0.010 |
| Residual | 6 | 841.7 | 140.3 | | |
| Total | 11 | 3941.0 | | | |

**A29: The effect of moringa shade on $\log_{10}$ rape dry weight of total harvest of June crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 0.02804 | 0.00935 | 0.44 | |
| Treatment | 2 | 0.50785 | 0.25393 | 11.87 | 0.008 |
| Residual | 6 | 0.12834 | 0.02139 | | |
| Total | 11 | 0.66423 | | | |

**A30: The effect of moringa shade on square root number of rape leaves of total harvest of the June crop.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1.069 | 0.356 | 0.15 | |
| Treatment | 2 | 37.909 | 18.955 | 8.03 | 0.020 |
| Residual | 6 | 14.166 | 2.361 | | |
| Total | 11 | 53.144 | | | |

**A31: The effect of moringa shade on gravimetric soil water content of the March crop 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1471.00 | 490.33 | 10.05 | |
| Treatment | 4 | 1493.70 | 373.42 | 7.65 | 0.003 |
| Residual | 12 | 585.5 | 48.79 | | |
| Total | 19 | 3550.20 | | | |

**A32: The effect of moringa shade on gravimetric soil water content of theJune crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 418.0 | 139.3 | 0.88 | |
| Treatment | 4 | 368.5 | 92.1 | 0.58 | 0.682 |
| Residual | 12 | 1903.5 | 158.6 | | |
| Total | 19 | 2690.0 | | | |

**A33: The effect of moringa shade on gravimetric soil water content of the June crop at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 571.6 | 190.5 | 1.14 | |
| Treatment | 4 | 1526.5 | 381.6 | 2.29 | 0.120 |
| Residual | 12 | 2001.9 | 166.8 | | |
| Total | 19 | 4100.0 | | | |

**A34: The effect of moringa shade on gravimetric soil water content at of the June crop at 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1316.00 | 438.67 | 7.46 | |
| CS | 1 | 576.00 | 576.00 | 9.79 | 0.012 |
| Pruning | 1 | 56.25 | 56.25 | 0.96 | 0.354 |
| CS x pruning | 1 | 42.25 | 42.25 | 0.72 | 0.419 |
| Residual | 9 | 529.50 | 58.83 | | |
| Total | 15 | 2520.00 | | | |

**A35: The effect of moringa shade on gravimetric soil water content of the June crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 1112.50 | 370.83 | 4.93 | |
| CS | 1 | 2.25 | 2.25 | 0.03 | 0.867 |
| Pruning | 1 | 289.00 | 298.00 | 3.84 | 0.082 |
| CS x pruning | 1 | 72.25 | 72.25 | 0.96 | 0.353 |
| Residual | 9 | 677.00 | 75.22 | | |
| Total | 15 | 2153.00 | | | |

**A36: The effect of moringa shade on gravimetric soil water content of the June crop at 8 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 285.5 | 95.2 | 0.50 | |
| CS | 1 | 6.2 | 6.2 | 0.03 | 0.860 |
| Pruning | 1 | 25.0 | 25.0 | 0.13 | 0.724 |
| CS x pruning | 1 | 650.2 | 650.2 | 3.44 | 0.097 |
| Residual | 9 | 1700.0 | 188.9 | | |
| Total | 15 | 2667.0 | | | |

**A37: The effect of moringa shade on gravimetric soil water content at of the June crop AT 4 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 5761.1 | 1920.4 | 4.92 | |
| CS | 1 | 2194.9 | 2194.9 | 5.62 | 0.042 |
| Pruning | 1 | 22455.0 | 22455.0 | 57.50 | <0.001 |
| CS x pruning | 1 | 468.7 | 468.7 | 1.20 | 0.302 |
| Residual | 9 | 3514.7 | 390.5 | | |
| Total | 15 | 34394.4 | | | |

**A38: The effect of moringa shade on gravimetric soil water content of the June crop at 6 WAT.**

| Source | d.f | s.s | m.s | v.r | Fpr |
|---|---|---|---|---|---|
| Block | 3 | 9208.9 | 3069.6 | 8.60 | |
| CS | 1 | 5270.8 | 5270.8 | 14.76 | 0.004 |
| Pruning | 1 | 31987.3 | 31987.3 | 89.59 | <0.001 |
| CS x pruning | 1 | 1940.4 | 1940.4 | 5.43 | 0.045 |
| Residual | 9 | 3213.2 | 357.0 | | |
| Total | 15 | 51620.6 | | | |