Effect of different multipurpose tree prunings and placement method on the growth and development of rape *(Brassica napus* L.)

BY

MICHAEL KOKERA BUTAI

A research project submitted in partial fulfilment of the requirements of the Bachelor of Science Natural Resources Management and Agriculture Agronomy Honours Degree

Department of Agronomy

Faculty of Natural Resources Management and Agriculture

Midlands State University

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DECLARATION

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ABSTRACT

Production of vegetables in the smallholder sector of sub-Saharan Africa (SSA) is affected by poor soil fertility with nitrogen (N) being the most limiting nutrient. Continued nutrient mining without adequate replenishment has led to a corresponding decline in soil fertility and crop yields due to failure by farmers in SSA to purchase inorganic fertilisers. Leguminous multipurpose tree (MPT) prunings have widely been promoted as alternative sources of N but nutrient release is affected by type of MPT and quality attributes such as total N, total carbon(C), lignin, polyphenols and C:N ratio. The aim of this study was to evaluate various MPTs which can provide adequate N to *Brassica napus* L. (rape) which is a short season but high N demanding crop harvested over multiple times. An experiment was therefore, conducted at the Midlands State University to determine the yield response of rape to legume prunings of different quality. The experiment was arranged as a 2 x 7 factorial treatment structure in a randomised complete block design (RCBD) with placement method (mulching or soil incorporated) being the first factor and pruning type (*Tithonia diversifolia, Gliricidia sepium, Calliandra calothyrsus*, *Acacia karoo, Acacia angustissima, Leucaena pallida and Leucaena trichandria*) being the second factor. The tree prunings were applied at a rate to achieve 150 kg N ha^{-1}. The crop was transplanted at 4 weeks after sowing. Data on LAI, fresh and dry weight readings as well as leaf chlorophyll readings were taken fortnightly and subjected to an analysis of variance (ANOVA). Incorporation of prunings achieved the highest total dry mass of 1,046 t ha^{-1} compared to mulching which had 0.580 t ha^{-1}. The two Acacia species achieved the lowest dry mass (DM) yields while *G.sepium* and *C.calothyrsus* achieved the highest DM yields. *A. angustissima* and *A. karoo* achieved the lowest total fresh leaf yield of 1.681 and 1.910 t ha^{-1} respectively while *L. trichandria* was the highest yielding at 1.996 t ha^{-1} for mulched treatments. Under incorporated treatments *L. trichandria* and *A. angustissima* gave the lowest total yields of 2.206 and 2.033 t ha^{-1} respectively while *T. diversifolia* was the highest yielding at 2.377 t ha^{-1} fresh weight. These results showed that soil incorporation gives the highest yields for fresh and dry weight. From the results it can therefore be recommended that farmers should use *T. diversifolia* and *L. trichandria* prunings over the Acacia species prunings for high fresh weight yields.

Key words: Alternative fertiliser, nitrogen, incorporation, vegetable yield.

DEDICATION

This project is dedicated to all the farmers in Zimbabwe as we work together in ensuring that the nation remains food secure. The project is also dedicated to my family members as well as my late grandfather (Mr E.G Gozo) who passed away prior to the submission of this research project.

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LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance

mm – Millimeter

LSD – Least Significant Difference

^oc – Degrees celcius

N – Nitrogen

RCBD – Randomized Complete Block Design

t ha^{-1} – Tonnes per hectare

WAT – Weeks After Transplanting

MPT – Multipurpose Tree

LAI – Leaf Area Index

LCR – Leaf Chloropyll Readings

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CHAPTER ONE

1.0 INTRODUCTION

Vegetable production in sub-Saharan Africa's (SSA) smallholder sector (SHS) is very important as a source of food, nutrition, income generation and can be used to fight poverty. The demand for vegetables from the smallholder sector is fast increasing due to increased demand from the rapidly increasing urban populations in Africa. There is also potential for growth of the export market particularly to European markets during their winter seasons (Kuntashula *et al.,* 2004). Rape (*Brassica napus* L.) is one of the most popular leafy vegetables with rapid accumulation of biomass over a short period of time. The crop is a good source of vitamins A and C which aid in good eyesight and development of healthy gums respectively (Chandiposha, 2007). Like most vegetables, rape is also a good source of minerals and roughage both of which are essential for good skeletal development and prevention of constipation (Nyakudya, 2010). Due to its nutritional benefits, there is a high demand for vegetable rape among urban dwellers who cannot produce their own vegetables due to lack of access to farming land. Despite the high demand, yields of vegetable rape have been declining due to the depletion of soil nutrient levels with nitrogen (N) being the most limiting nutrient (Sanchez, 2002).

In high nutrient demanding vegetables such as rape, nitrogen is the most critical nutrient and is required (150 kg N ha^{-1}) for the continued production of vegetative tissue (leaves) throughout the crops growing season. Due to continuous cultivation of the land in SSA most soils are now barren as smallholder farmers fail to significantly replace nutrients leading to low crop yields (Mafongoya and Nair, 1997). The failure to replenish the soil with nutrients in SSA is mainly due to lack of financial capital to procure inorganic fertilisers which are at times out of reach or very expensive (eight times the world average price) for the farmers

(Bationo et al., 2008). Annual N losses in the SSA are estimated to be 4.40 million tons per annum compared to a replenishment of 0.80 million tons per annum (Bationo et al., 2008). With such low fertiliser application rates, crop yields continue to be on a decline hence the need for alternative fertiliser sources.

MPTs are widely being promoted as sustainable N sources for farmers in SSA including Zimbabwe (Mafongoya et al., 1998; Palm et al., 2001). The release of N from MPTs is determined by factors such as pruning quality and has been found to be negatively correlated to C:N ratios. Lignin :N, Polyphenol to N and (lignin + polyphenol): N ratios (Semwal et al., 2003). Different levels of N are released from the prunings depending on the quality of the MPTs used which determines the decomposition and mineralisation rates of the MPTs used (Palm et al., 1997). Work done by Mafongoya et al., (1998) suggests that a high soluble C content in the C:N ratio leads to net immobilisation as microbiota degrade the soluble C first.

Despite the promising potential of MPTs to be used as a nutrient source, there are certain challenges brought about by the use of this technology. The major challenge is failure to synchronise N supply with N demand due to factors in the soil as well as those to do with pruning quality (Brady and Weil, 2002; Zingore et al., 2008). According to Palm et al., (1997) using high quality prunings results in faster decomposition rates and mineralisation, provided that the MPTs are applied in a way that increases decomposition and mineralisation. Based on the application methods of prunings, soil incorporated prunings will mineralise faster than mulched prunings which are in direct contact with light causing them to lose N through volatilisation of N to ammonia (Brady and Weil, 2002). Surface applied MPTs are also lost due to removal by wind and other agents all of which reduce the extent of N synchrony with crop demand. The resultant asynchrony will cause low nutrient availability in times of high demand which will translate to low rape yields. Also during times of high nutrient release and low demand the resultant leaching of nitrates or loss through denitrification to give nitrous oxide and N will become prevalent (Brady and Weil, 2002; Chirinda et al., 2010).

Due to the above mentioned problems of asynchrony, various strategies have been developed to try and synchronise N release with crop demand. These include using varied application methods of incorporating MPTs in the soil such as surface and ground incorporation (Mafongoya et al., 1998). Mixing MPTs of varying quality (low and high) to reduce the period of time were N will be immobilised, and supplementing applied MPTs with inorganic N during times of high N demand to achieve synchrony. Although a lot of work has been carried out on the use of MPTs and other organic residues in Zimbabwe, the majority has been limited to cereals such as maize grown under dry land conditions (Mafongoya et al., 1998; Mapfumo et al., 2007; Nyamadzawo et al., 2014). Few studies have been carried out on the production of vegetable rape with MPTs as an alternative fertiliser source. Since rape is a heavy feeder requiring more N than cereals that are harvested once towards the end of their growing season, there was need to do similar studies for rape in order to increase the current low yields.

This study seeks to evaluate the performance of MPTs as alternative sources of N with the potential of sustaining high yields in rape throughout the growing season. The study also seeks to establish which placement method between mulched and soil incorporated produces higher crop yield. The best yielding prunings will be recommended to vegetable farmers in an effort to provide a viable alternative/substitute to the expensive inorganic fertilisers which have relatively shorter soil persistence compared to organic fertilisers.

1.1 OBJECTIVES

1.1.1 MAIN OBJECTIVE

To evaluate the effect of MPT pruning type and method of application on the growth and development of Brassica napus

1.1.2 SPECIFIC OBJECTIVE

1) To determine the effect of pruning type and method of application on the growth rate of rape

2) To determine the effect of pruning type and method of application on LAI and leaf chlorophyll

1.1.3 HYPOTHESES

1) Pruning type and method of application have a significant effect on the growth rate of rape

2) Pruning type and method of application have a significant effect on LAI and Leaf chlorophyll

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 History of vegetable rape

Rape (*Brassica napus*) belongs to the family Brassicaceae in the brassica genus comprising of 100 species (Mvere and Toxopeus, 2004). The earliest origins were believed to be from the Mediterranean area and Asia. It was later believed to have come from Western Europe where several types were developed and spread (Kuntashula *et al*., 2004). During colonial periods it was then introduced to Southern Africa were it has become a vegetable with a high demand on the market. Rape is a cool season crop favouring an optimum growth temperature of about 18 ^{o}c though it can be grown all year round. The plant is a heavy feeder requiring high amounts of nitrogen to continuously produce leaf material which is harvested for consumption more often than other crops.

2.2 Economic importance of vegetable rape in Zimbabwe

Vegetable rape is important to the livelihoods of people (Bennett, 2012). It provides a source of income to rural folks as they sell their produce to the city folks (Loehr *et al.,* 1998; Kuntashula *et al.,* 2004). In intensive cropping systems, vegetable rape provides a source of employment for the farm workers who receive income for their services which in turn helps the workers purchase food products thereby making them food secure (Bennet, 2012). Apart from the farmers, the transporters of the produce also cash in on the demand for the crop in urban settlements as they ferry the produce to market places in towns using trucks/cars depending on the amount that is being transported.

Livestock farmers who keep small ruminants such as rabbits and poultry which are normally kept in confinement can use vegetable rape as a substitute for roughage which is found in commercial feeds especially when the animals are being fed on unprocessed maize or maize meal (Bennet, 2012). The ability of rape to act as a fodder preventing constipation in animals lies through the cellulose contained in the cell walls of its leaves. This helps farmers to continue on rearing livestock improvising with unprocessed produce on the farm or home in cases where processed feeds are too expensive to feed only as the sole feed (Jones, 2000). This ensures that the farmers are still able to realise income through animal husbandry thus making the farmers food secure through income generated by animal husbandry.

Restaurant owners use the vegetable during preparation of meals to serve to customers for their lunchtime or supper requirements were it accompanies the main course meal in a carbohydrate based diet (Mvere and Toxopeus, 2004). In elite restaurants, the rape seedlings are used as a salad dressing to add onto other vegetables incorporated in the salad to improve on the visual appearance of the salad. Through commercial food preparations involving rape, employment is provided for the restaurant attendants.

Finally vegetable rape is an important source of employment for farm labourers who get money to buy foodstuffs and thus become food secure through the income acquired through rape production. Rape being a source of vitamins and other minerals also contributes to the health of the nation/labour force thus maintaining the productivity of the country's industrial sector.

2.3 Uses of Vegetable rape in Zimbabwe

Vegetable rape is used as a relish that normally accompanies a sauce in a carbohydrate based diet (Mvere and Toxpeus, 2004). In times of excess production, vegetable rape is normally sun dried as a way of preserving it for future use or for sale. Vegetable rape is also used to feed domesticated animals such as rabbits and poultry in both rural and urban settlements. Although vegetable rape is commonly used to accompany the main course meal, it can also be used to make packed lunches for children as it can be spread on bread to make sandwiches for them (Mvere and Toxopeus, 2004).

2.4 Constraints to rape production

The high cost of inorganic fertilisers has made them inaccessible to most small scale farmers in Sub-Saharan Africa (SSA) (Palm *et al*., 2001). Inorganic fertilisers have made remarkable improvements in yield obtained per unit area of land as farmers apply them at different rates to suit the needs of the crops being grown (Proctor *et al*., 2000). However the resource poor rural farmers cannot afford the fertilisers and let alone incur the cost of transporting them from point of purchase (mostly urban settlements) to their fields as most of them are not employed and, do not have a fixed source of income to fund their farming activities. According to ICRISAT (2006) only 5 % of small holder farmers in SSA apply inorganic fertilisers to crops in their fields. Due to failure to access inorganic fertilisers, small holder farmers in SSA have failed to realise the full yield potential of their crops and thus need an alternative fertiliser source to help them cope with their current farming practices.

Most Rural farmers are not well versed with current farming practices recommended by agronomists (Proctor *et al*., 2000). Among these farming practices include liming soils to reduce the effects of acidity and knowing which type of plants to use as soil organic ammendments (Proctor *et al*., 2000; Nyirenda et al., 2010). With soil organic amendments being of different qualities, incorporating multipurpose tree (MPT) prunings of low quality rich in soluble carbon (C) delays the rate of decomposition and nutrient release by microbiota leading to immobilisation of nutrients (Palm *et al*., 1997). This is due to the availability of a soluble C source which the microbiota start to degrade first before breaking cellulose and lignin structures of MPTs to initiate mineralisation (Palm *et al*., 1997; Mafongoya *et al*., 1998). Lack of understanding of the manner in which organic residues decompose in the soil may lead to asynchrony of N with crop demand with rapid mineralisation rates occurring towards the end of the growing season (Bationo *et al*., 2008).

Use of animal manure by most rural farmers as the preferable fertiliser of choice for them has very detrimental effects as the manure is heavily contaminated by weed seeds of mostly pasture land grasses and shrubs (Nyirenda *et al*., 2010). Though this effect is not felt in cattle fed solely on commercial feed, manure from free range cattle causes weed problems in vegetable beds. The types of weeds differ from place to place among them black jack, mexican poppy, wondering jew, purple and yellow nut sedge just to mention a few. These weeds compete with plants for nutrients and their seeds can remain dormant in the soil for several years (Ronald *et al*., 2011). Continued addition of manure contaminated with weed seeds further increases the weed seed bank of the involved piece of land and thus renders farming activities and soil nutrient replenishment a challenge due to the presence of weeds (Ronald *et al*., 2011).

Insect pests which are always present in vegetable production systems which do not practice crop rotations and the use of pesticides are a major constraint in vegetable rape production (FAO, 1997; Proctor *et al*., 2000; Nyirenda *et al*., 2010). Among these pests are grasshoppers, semi-loopers and aphids which are cutting and chewing as well as sap-sucking pests irrespectively. Grasshoppers and semi-loopers inflict damage by consuming the leaf which is the marketable part of the plant while aphids suck sap from the leaf thus, retarding growth by consuming assimilate that the leaf needs to increase its surface area (Sibanda *et al*., 2014).

Depending on where the farming activity is being carried out, environmental factors such as droughts or long dry spells can be a limitation to vegetable rape production by farmers (Vanlauwe *et al*., 1996). The plant being a leafy vegetable has more exposed surface area for transpiration and thus loses more water especially when grown in the warm summer months. Such rapid water loss without replenishment can lead to low nutrient uptake through active transport by plants, low rates of decomposition of organic soil amendments and an overly low vegetable yield of the crop due to reduced leaf area and fresh weight as a result of water shortage (Handayanto *et al*., 1997; Greenwood and Allan, 2001; Kuntashula *et al*., 2004).

The proposed technology of using multipurpose tree prunings will aim to counter most if not all the above mentioned constraints to vegetable rape production.

2.5 Importance of nitrogen (N) in rape production

Nitrogen is an important mineral that is responsible for the formation of vegetative tissue (Leaves) which are important for the process of photosynthesis as well as food through the harvest of the leaf in rape production. The N content of the leaves is represented by thylakoids and the proteins of the Calvin cycle with the latter taking part in dark reactions of photosynthesis to produce plant assimilate (Greenwood and Allan, 2001). The resultant assimilate is transferred to sinks within the plant to provide energy to enzymes that aid/help with tissue development in the plant.

Nitrogen is a constituent of chlorophyll were it is found in the chemical structure of the compound. N is responsible for the green colour of the leaf through its accumulation in the palisade cells which increases the photosynthetic ability of the plant (Greenwood and Allan, 2001). N is also a constituent of plant proteins, therefore availability of N in the soil translates to the ability of the plant to produce proteins. The resultant proteins are constituents of enzymes that will help with the cellular processes in the plant such as the calvin cycle and other cell respiratory activities both which enhance growth and development of the plant (Greenwood and Allan, 2001).

Deficiencies of N result in chlorosis, stunted growth in plants and eventually low crop yields particularly for the plants whose vegetative parts are harvested for food such as rape. Chlorosis which is the loss of the green colour of the leaf (to give a pale green colour) leads to low rates of photosynthesis and which translate to shorter plant heights or lower foliage production rates in vegetable rape.

There is need to apply appropriate N rates in crop production as excess applications can lead to rank growth, loss of the nitrates through leaching or denitrification. Therefore excess applications correspond to loss of nitrates and can also result in diminishing returns when supply exceeds plant demands.

2.6 Benefits of using MPTs as an alternative fertiliser source

MPTs increase the water holding capacity of the soil as they are able to absorb water available in the soil and in the process prevent it from moving out of the root zone (Vanlauwe *et al*., 1996; Greenwood and Allan, 2001). It has been documented that organic matter can hold up to 10 times its own weight in water. Through this water holding capacity, plants have moisture available for active uptake of nutrients and moisture required for tissue generation in the plant and the occurrence of photosynthesis.

MPTs offer adsorption sites for soil nutrients already existing in the soil and those supplemented by application of chemical fertilisers to (Lines-Kelly, 2004). These sites hold the nutrients preventing them from being leached by both surface and underground runoff (Brady and Weil, 2002). This retention of available nutrients through charge induced adsorption helps in the provision of nutrients to the plant and also prevents eutrophication of water bodies by limiting the amount of nitrate deposited into water bodies by rain or irrigation water (Brady and Weil, 2002).

MPTs offer a relatively weed free soil organic matter amendment that does not expose the crop to competition and also the pests and diseases that can overwinter in weeds and their residues. MPTs contribute positively in reducing the weed seed bank of soils in relation to cattle manure which actually introduces and has the effect of continuously increasing the size of the weed seed bank (Ronald *et al*., 2011).

Finally MPTs are easily and readily available in all parts of the country, though varying in their quality and the type of trees they are coming from, they are more abundant than cattle manure.

2.7 Examples of MPTs used in crop production

2.7.1 *Gliricidia sepium*

A medium sized thornless leguminous tree which grows up to 12 m in height. The tree produces bright pink to lilac flowers and is native to Southern America. *G. sepium* is adapted to grow in well drained soils which are slightly calcareous limestone soils (Stewart *et al*., 2002). In its native area the tree grows well on soils of volcanic origin with a pH of 4.5 – 6.2. Some of the main uses include green manuring, forage for goats with a yearly 15 t ha^{-1} biomass production which is the equivalent of 40 kg ha^{-1} N every year. The plant is not a problematic weed in exotic places because of an absence in pollinators and unsuitable environments for seed set (Stewart *et al*., 2002). *G. sepium* produces high NO^{-3} levels during the rainy season and is deemed a nitrate accumulator. The tree produces an annual leaf dry mass of between 2 – 20 t ha^{-1}. In Nigeria *G. sepium* and panicum grass interplants give out a dry leaf mass production of 20 t ha^{-1} every year. Harvesting the leaves delays flowering and prevents loss of leaves due to leaf fall and maximum re-growth. The leaves are not toxic to cattle but have a serious damaging effect to horses and other ruminant.

2.7.2 *Acacia angustissima*

A. angustissima is a thorn-less shrub which can grow up to 2 – 7m high with variable venation, size of flowers and leaflets. The shrub is used as forage and green manure. In Zimbabwe it has much leaf drop and is utilised in wet season or conserved as leaf meal. *A. angustissima* is used to restore soil fertility in dry land cropping systems as well as for fuel wood. The shrub has the potential of becoming a problem weed and will spread under grazing if not controlled. The shrub can tolerate repeated coppicing. A high producer of leaf dry mass at 10 – 12 t ha^{-1} every year with 13t averaged in Australia. The shrub can produce dry matter even under the harshest of environments and has high crude protein content. The limitations of using the shrub are that it contains moderate quantities of condensed tannins with slow nutrient release from green manure and very small livestock weight gains. The green manure benefits of the tree are only realised in the second crop following application because the leaf protein is bound in complexes with condensed tannins resulting in slow N release for crop growth. The prunings have an average N content of 31g kg^{-1} (Muchecheti *et al*., 2013).

2.7.3 *Calliandra calothyrsus*

A small perennial thorn-less leguminous tree growing 2 – 12 m high and is native to South America (Chamberlain, 2001). The tree is mainly a multipurpose tree used mainly for forage as supplementation to low quality roughages. A green manure provides shade for coffee and tea, a good erosion controller plus land rehabilitator. In honey production the tree is used as a pollen source for honey production. It provides stakes for climbing beans in Uganda and

Rwanda. It is an excellent source of fuel wood as it produces a smokeless fire (Palmer and Jones, 2000). The first leaf harvesting is done 8 – 12 months after sowing and for maximum leaf production the tree is cut to a height of 1 m. Cutting the tree to a height of less than 30cm above ground level and allowing for it to be grazed reduces plant mortality. However the tree harbours pests such as the scale mite (*Pulvinarisca jacksoni*), stem borers, termites plus fungal diseases such as those of the Xylaria species. The tree produces a leaf dry mass of 3 – 14 t ha^{-1} every year depending on climate and soil fertility (Chamberlain, 2001; Palmer and Jones, 2000). The prunings have an average N content of 3.4 %.

2.7.4 *Tithonia diversifolia*

The tree has been identified to produce nutrients to lowland rice in Asia and maize in Southern Africa. *T. diversifolia* biomass decomposes rapidly after application to the soil (Jama *et al*., 2000). In some cases maize yields were higher when incorporated with *T. diversifolia* than with mineral fertilisers of similar concentration (Chikuvire *et al*., 2013). Cutting and carrying to the fields of prunings is a labour intensive task and should be done for vegetables with a high market value than for low value crops like maize (Jama *et al*., 2000). The tree is used as a fodder, poultry feed, fuel wood, soil erosion controller and extracts have medicinal value for hepatitis. The tree produces 1 – 3,9 t ha^{-1} leaf dry mass in 8 month old stands. The prunings have an average N content of 3.5 %.

2.8 Problems affecting N release in MPT prunings

Decomposition rates for organic amendments are determined by the prevailing environmental conditions, nature and availability of decomposer organisms as well as the quality of the organic amendments used (Mafongoya *et al*., 1998). The nutrient content and the organic constituents of the material define the parameters for resource quality (Palm and Rowland, 1997). Nutrient release is controlled by these parameters and the length of the growing season of the particular crop grown will determine how the quality parameters are expressed (Kazombo-Phiri, 2005). Resource quality refers to the available carbon for utilisation by decomposer organisms and the total available carbon is dependent on the lignin, cellulose and soluble carbon concentrations (Palm and Rowland, 1997; Mafongoya *et al*., 1998). High quality soluble carbon is associated with storage carbon as well as the metabolic carbon which promote soil microbe activity. The total amounts of soluble carbon determine the rate of immediate immobilisation or mineralisation of N. High amounts of carbon that is soluble with smaller N values lead to net immobilisation (Mafongoya *et al*., 2008). The cellulose polysaccharides and lignin are attacked by microbes later on after soluble carbon is depleted thereby prolonging the decomposition process. Lignin was once considered as having very strong influence on the rate of mineralisation but it has been identified that, lignin plays a very minor role in terms of energy provision to decomposing microbes with maximum provisions being towards the end of the decomposition period (Palm and Rowland, 1997; Mafongoya *et al*., 1998).

Polyphenols though contained in less amounts have a very significant impact on the rate of decomposition with an inverse relationship being present between the polyphenol content and the rate of N mineralisation (Palm and Rowland, 1997). Polyphenols act as inhibitors in the decomposition process of organic residues by soil microbes. Condensed tannins a type of polyphenol and hydrolysable tannins can react with amino groups or the nitrogen contained within the soil matrix which delays the rate of N release (Mafongoya *et al*., 2000). Condensed tannins may simply bind to the proteins of the plant cell walls and simply slow the decomposition rate by making the cellulose cell walls inaccessible to the decomposers in a similar manner as does the lignins.

The measurement of nutrient quality in an organic residue is usually related to the organic and cell wall bound N (Mafongoya and Nair, 1997). Finally the total nitrogen released is relative to whether green manure was used or if litter was used. Litter tends to have lower N levels due to the nutrient withdrawal from the leaves prior to leaf drop in trees.

2.9 Approaches to manipulating decomposition rates of N prunings

2.9.1 Producing prunings of varying qualities

The choice of prunings used has an effect on the maximum potential of nutrients released through mineralisation (Muchecheti *et al*., 2013). There is a high chance of obtaining varying litter qualities from the same species and regulations on pruning performance can also be based on pruning age or selecting different plant parts such as leaves or woody branches. The stresses experienced by the prunings before harvest bring out a marked difference in the nitrogen quality of the prunings (Palm and Rowland, 1997). N limitations during tree growth also have an impact on the total polyphenol content. In agroforestry practices, applying N to MPTs has an effect on the nitrogen content that the leaves end up with a high nitrogen content, reduced soluble polyphenol content and a lowered protein binding capacity of polyphenols. Thus ensuring the above qualities can increase N fixation and effective nodulation that will increase mineralisation (Mafongoya *et al*., 2006).

2.9.2 Managing prunings to alter their quality

Application of fresh prunings without drying or directly to soil has more rapid decomposition and causes greater N recovery by plants but this is dependent on synchrony with crop growth. Mafongoya *et al*., (2008) realised greater yields through using fresh than sundried prunings in maize yields. The reason was attributed to the issue of sun-dried prunings immobilising N for more than eight weeks. Drying prunings especially through sun-drying reduces the recovery of soluble polyphenols due to the elevated temperatures. These same temperatures can also increase the lignin content due to the non enzymatic browning between polyphenols, protein degradation and carbohydrate polymers which raise lignin artificially (Mafongoya *et al*., 2006). The extent of chopping and mixing will determine the initial rate of microbial attack, reduces the extent of nutrient leaching (Nyamadzawo *et al*., 2014). The incorporation of nutrients into the soil causes faster decomposition due to the close contact of prunings with soil and also being maintained in a relatively moist environment in the soil that is more favourable for decomposition. Incorporation of organic residues gives rise to a more bacterial dominated soil community, while fungi dominate in surface placement. Such differences have an advantage in relation to nutrient release based on carbon to nutrient ratios of carbon assimilation efficiencies of the bacteria and fungi.

2.9.3 Field management of prunings

It was documented that rapid decomposition and greater N recovery of *L. leucocephala* and *G. sepium* prunings occurs when they are soil incorporated, and similar results have been evident in a variety of species with both low and high quality prunings. Timing of applications can also help synchronise nutrient release with crop demand (Mafongoya *et al*., 1998).

2.10 The cycling of N in the soil and atmosphere

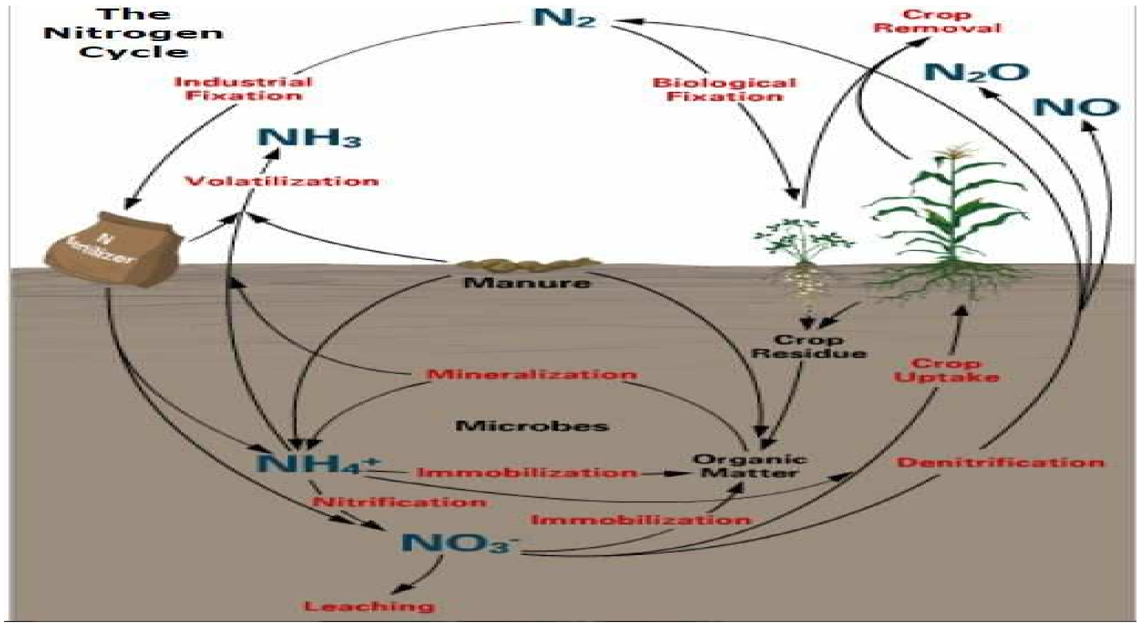

Fig 2.1 The N cycle and the cycling of nutrients

Nitrogen is the most abundant element in the Earth's atmosphere and it constitutes 78% of the atmospheric gases. Nitrogen (N) cannot be utilized directly by the plants unless it is converted into compounds easily accessed by plants. Certain bacteria convert the nitrogen gas (N2) to ammonium (NH_4) which the plants can use. Decomposer bacteria are responsible for converting the nitrogen-rich waste compounds into simpler ones. Denitrification is the last step in which other bacteria convert the simple nitrogen compounds back into nitrogen gas (N2) which is then released back into the atmosphere to begin the cycle again (Brady and Weil, 2002). The process is called the Nitrogen cycle. Organic materials as compound such as the pruning also join the nitrogen cycle hence there conversion rate make them accessed by plants.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Experimental site

The experiment was carried out at Midlands State University found in Zimbabwe's Natural Farming Region III at the following compass coordinates ($19^o45^'$ S and $29^o84^'$ E). The site is located 12 km south east of Gweru's Central Business District at an elevation of 1428 m above sea level. The average rainfall of the area is 674 mm with the average mean temperature being 18 ^{o}c. The experimental site has sandy loam soils belonging to the fersiallitic group with kaolinite clay minerals (Nyamapfene, 1991)

3.2 Experimental Design and Treatments

The experiment was laid out in a 2 x 7 factorial design arranged in a Randomised Complete Block Design (RCBD) with three replicates. Two factors were used with placement method (mulching or soil incorporated) being the first factor and pruning type (*Tithonia diversifolia, Gliricidia sepium, Calliandra calothyrsus*, *Acacia karoo, Acacia angustissima, Leucaena pallida and Leucaena trichandria*) being the second. Slope was the blocking factor.

3.3 Choice of variety

The English Giant rape variety was used for the experiment because it would be easier to monitor nitrogen release rates of the MPTs in a variety with larger leaves (foliage development) than smaller leaves as produced by the covo varieties.

3.4 Agronomic Practices

3.4.1 Land preparation

The land was manually prepared using a pick, hoe, garden rake and a garden line which was used to align the experimental plots into straight rows. The pick was used to dig the ground to loosen up the soil and create an environment conducive for plant growth in which the soil is loose enough to allow for root penetration and water absorption. The hoe was used to create ridges to hold up irrigation water as well as to break up soil clods which would hinder plant emergence once the experiment commences. The garden rake was used to level the soil in the experimental plots and also to break up minor soil clods which the hoe would have failed to break.

Plots measuring 1 m x 1 m were constructed and spaced at a spacing of 50 cm in between them. Boarder rows were constructed right round the whole experiment where the English Giant cultivar was also planted to try and ward off any problematic pests that would creep in from the sides of the experimental land.

3.4.2 Planting

MPT prunings were applied at a rate of 150 kg N ha^{-1}. The prunings were weighed by a scale before application. The soil incorporated prunings were laid down to a depth of between 5 – 6 cm underground which was measured using a 30cm ruler. Surface incorporated residues were applied directly on the surface. A compound fertiliser was added to the control plots at a rate of 150 kg N ha^{-1} compound D.

Three seed drills spaced 30 cm apart and 20 cm away from the ridges were made inside the 1 m^2 experimental plots. Rape seeds were planted into the drills at a rate of 20 seeds per drill (60 seeds per plot) before covering them with soil.

3.4.3 Transplanting

The resulting rape seedlings were transplanted at 4 weeks after planting in the plots they had been grown to remove excess plants and remain with 6 plants per 1 m long row.

3.4.4 Watering

Watering was done through the use of a 10 l watering can fitted with a rose to provide a fine spray of water which would not unearth the seeds or cause puddles in the plots as water would drain faster than directly applying it to the plots. Each plot received a can of water during each irrigation operation and operations were scheduled based on the rate of water evaporating from the ground which would be seen by drying of some experimental plots. This was done so that water would not be a limiting factor in the experiment.

3.4.5 Fertilizer applications

No further fertilisers were applied after planting

3.4.6 Weed control

Plots were kept weed free throughout the whole growing period by means of hand pulling inside the experimental plots while those found outside the plots were controlled by mechanical means through the use of the garden hoe.

3.5 Data Collection

Data was collected for four parameters namely leaf area index (LAI), Leaf chlorophyll readings (LCR) and fresh and dry weight readings starting in the weeks that came after transplanting (WAT).

3.5.1 Leaf area index

LAI readings were taken from the fourth week after transplanting (4 WAT) up to 8 WAT using a non destructive method done through the use of the Li-Cor 2200 Plant Canopy Analyser. Three readings were taken per plot and averaged to get the average LAI reading per plot each time LAI recordings were done.

3.5.2 Leaf chlorophyll readings

LCR were taken at 8 WAT using the SPAD-502 chlorophyll meter to measure the chlorophyll content of the leaves. Three leaves were selected randomly and readings taken and averaged using the SPAD to get the average LCR per plot.

3.5.3 Fresh and Dry weight readings

Three plants were selected randomly per plot during each recording session for purposes of measuring the fresh and dry weight readings. Readings were taken from 2 WAT up to 8 WAT using a scale that records figures in fives for fresh weight and using a lab sensitive scale to measure the dry weight readings. An oven was used to dry the plants at 70 ^{o}c until no further change in dry weight was recorded. Plants were tied up with string and tagged before placing in the oven for purposes of identification after drying was complete.

3.6 Data Analysis

Data collected was subjected to Analysis of Variance (ANOVA) using GenStat Discovery Edition 4. Treatment means were compared by the Least Significance Difference test (LSD) at a 5% level of significance.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of placement method and pruning type on fresh weight yield of rape

There was no interaction ($p>0.05$) between placement method and pruning type on fresh yield of rape. There was significant difference ($p>0.05$) between the mulched and incorporated placement methods on fresh yield at 4 and 6 WAT. However, there was significant difference ($p<0.001$) of MPT prunings on fresh yield of rape at 4 WAT. *A. angustissima* had the lowest fresh weight readings at 0.194 t ha^{-1} though statistically it was the same as A. *karoo* and G. *sepium* while *L. Pallida* was the highest yielding with 0.337 t ha^{-1} though statistically it was the same as C. *calothyrsus* (Table 4.1). There was significant difference ($p<0.05$) of MPT prunings at 6 WAT with *A. karoo* recording the lowest fresh weight yield of 0.338 t ha^{-1} while *L. trichandria* had the highest fresh weight yield of 0.442 t ha^{-1}. Also there was significant difference ($p<0.001$) between placement methods at 8 WAT with incorporated MPT prunings recording a high fresh weight yield of 1.485 t ha^{-1} while mulched MPT prunings recorded a low fresh weight yield of 1.190 t ha^{-1} (Fig 4.1). There was also no significant difference ($p>0.05$) amongst the MPT prunings used. At 6 WAT the fresh yield due to Lucaena species and *T. diversifolia* were statistically similar to those of *C. calothyrsus* and *G. sepium* (Table 4.1).

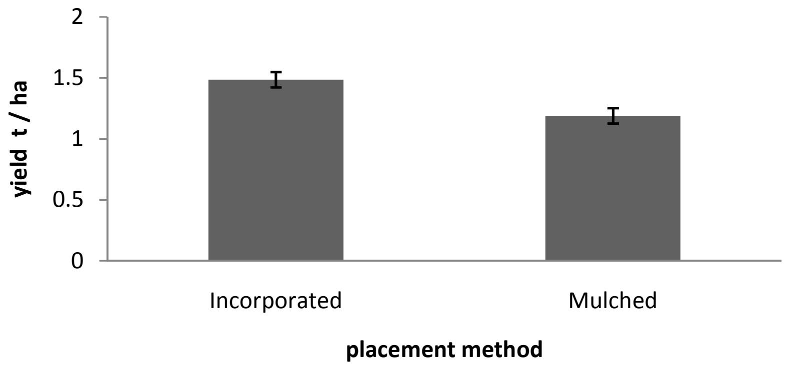

Fig 4.1 Effect of placement method on fresh yield of rape at 8 WAT

Table 4.1 Effect of MPT pruning on fresh yield of rape at 4 and 6 WAT

MPT prunning	Rape fresh yield at 4WAT (t ha^{-1})	Rape fresh yield at 6WAT (t ha^{-1})
A. karoo	0.230^{ab}	0.338^{a}
A. Angustissima	0.194^{a}	0.353^{ab}
C. calothyrsus	0.291^{cde}	0.404^{bc}
G. sepium	0.244^{abc}	0.399^{abc}
L. pallida	0.337^{e}	0.424^{c}
L. trichandria	0.324^{d}	0.442^{c}
T. diversifolia	0.281^{bcd}	0.432^{c}
LSD	0.053	0.061
CV%	16.5	13.0
p value	($p<0.001$)	($p<0.05$)

*Numbers with the same letter are not significantly different

4.2 Effect of placement method and pruning type on dry weight yield of rape

There was no interaction ($p>0.05$) between placement method and pruning type on dry weight yield of rape. There was no significant difference ($p>0.05$) amongst MPT prunings at 2 WAT. However there was significant difference ($p<0.05$) at 2 WAT between placement methods of MPT prunings with incorporated prunings recording the lowest yield at 0.008 t ha^{-1} while mulched prunings had the highest dry weight yield at 0.010 t ha^{-1} (Table 4.2). There was also a significant difference ($p<0.001$) between MPT placement methods at 6 WAT and 8 WAT (Table 4.2). The incorporated prunings had the highest dry weight yields of 0.271 and 0.683 t ha^{-1} at 6 and 8 WAT respectively while mulched prunings had the lowest dry weight yields of 0.121 t ha^{-1} and 0.366 t ha^{-1} at 6 and 8 WAT respectively. Also there was significant difference ($p<0.001$) amongst MPT prunings at 6 WAT with *T. diversifolia* recording the lowest dry weight yields of 0.167 t ha^{-1} while *G. sepium* recorded the highest yield of 0.219 t ha^{-1} (Table 4.3). There was also significant difference ($p<0.05$) amongst MPT prunings at 8 WAT with *A. angustissima* recording the lowest dry weight readings of 0.417 t ha^{-1} while *L. trichandria* had the highest dry weight yield of 0.626 t ha^{-1}. At 6WAT dry yields for *C. calothyrsus, G. sepium* and the Lucaena species were statistically similar while those for the Acacia species, *L. pallida* and *T. diversifolia* were statistically similar to each other at 8 WAT (Table 4.3).

Table 4.2 Effect of placement method on dry yield of rape at 2, 6 and 8 WAT

Placement method	2 WAT (t ha^{-1})	6 WAT (t ha^{-1})	8 WAT (t ha^{-1})
Incorporated	0.008^{a}	0.271^{b}	0.683^{b}
Mulched	0.010^{b}	0.121^{a}	0.366^{a}
LSD	0.001	0.013	0.070
CV %	22.9	10.2	21.0
P value	($p<0.05$)	($p<0.001$)	($p<0.001$)

*Numbers with the same letter are not significantly different

Table 4.3 Effect of MPT prunings on dry yield of rape at 6 and 8 WAT

TREATMENT	6 WAT (t ha^{-1})	8 WAT (t ha^{-1})
A. karoo	0.180^{ab}	0.420^{a}
A. Angustissima	0.176^{a}	0.417^{a}
C. calothyrsus	0.214^{c}	0.625^{b}
G. sepium	0.219^{c}	0.625^{b}
L. pallid	0.212^{c}	0.515^{ab}
L. trichandria	0.202^{bc}	0.626^{b}
T. diversifolia	0.167^{a}	0.444^{a}
LSD	0.024	0.131
CV%	10.2	21.0
P value	($p<0.001$)	($p<0.05$)

*Numbers with the same letter are not significantly different

4.3 Effect of placement method and pruning type on leaf area index (LAI) of rape

There was no interaction (p>0.05) between placement method and MPT prunings on LAI of rape. There was no significant difference (p>0.05) amongst the MPT prunings in relation to LAI of rape. However, there was significant difference (p<0.05) at 8 WAT between placement methods on LAI of rape with incorporated tree prunings recording the lowest readings of 2.8 while mulched readings had a LAI of 3.5 (Fig 4.2).

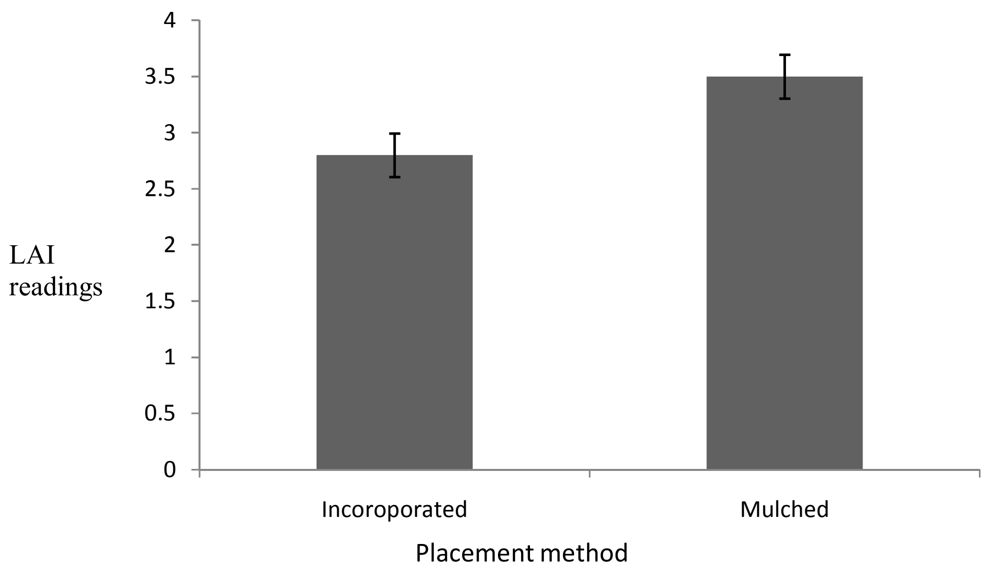

Fig 4.2 Effect of placement method on LAI of rape at 8 WAT

4.4 Effect of placement method and pruning type on leaf chlorophyll readings (LCR) of rape

There was no interaction (p>0.05) between placement method and MPT prunings on LCR of rape. There was no significant difference (p>0.05) amongst the MPT prunings used on LCR of rape. However there was significant difference (p<0.001) between placement methods on

LCR readings of rape at 8 WAT with incorporated MPT prunings recording a higher LCR of 49.8 while mulched prunings gave a lower LCR of 38.8 (Fig 4.3).

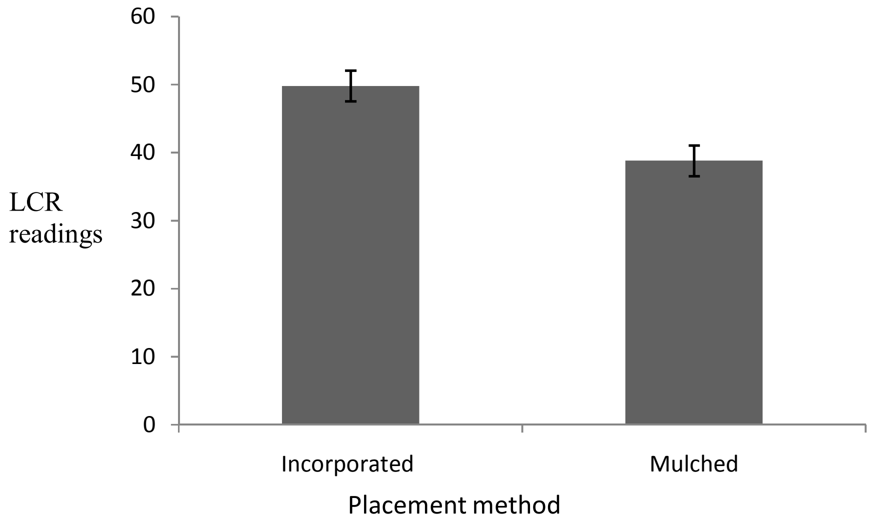

Fig 4.3 Effect of placement method on LCR of rape at 8 WAT

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of placement method and pruning type on fresh yield of rape

Highest fresh yield of vegetable rape due to incorporation can be attributed to the fact that incorporated prunings being underground are protected from environmental agents such as the sun which has the potential to reduce the N content of the prunings (Palm, 1995). The low yields in mulched treatments could be attributed to losses of N from the prunings through volatilisation by converting N contained in prunings into ammonia (Brady and Weil, 2002). The resultant loss will cause reduced N content in terms of N percentages of the mulched prunings which then puts the mulched prunings at a disadvantage with regards to total mineralisation rates.

Low mulched yields can also be attributed to lower surface area of the mulched MPT prunings that came in contact with the soil. According to Mafongoya *et al*., (1998), prunings without any soil contact risk low mineralisation rates due to lack of soil cover containing microbiota to degrade the mulched MPT prunings. With the above mentioned problems, it is possible that mulched prunings were at a disadvantage with regards to mineralisation rates hence their correspondingly low yield (Palm, 1995). Other factors can also be attributed to the low yield of mulched MPT prunings such as losses through wind erosion across the experimental site. Such losses could have reduced the targeted 150 kg N ha^{-1} application rate across all mulched experimental plots. The resulting effect is a reduction in total N production during the growing season which translates to the low yields obtained by mulched MPT prunings (Fig 4.1).

In incorporated MPT prunings, a high fresh yield could be attributed to the ability of incorporated prunings to retain water in the soil matrix and also provide adsorption sites for any mineralised nitrates (Brady and Weil, 2002). Water holding ability of incorporated MPT prunings could have meant that water was not limiting to the growth and development of plants due to retention of water in the soil by the MPT prunings. According to work done by Gardner, (2001) some organic residues have the ability to absorb up to ten times their own weight in water. With such a property it is possible that water was retained longer by incorporated MPT prunings hence the corresponding high fresh yield value (Fig 4.1). The development of adsorption sites in the incorporated MPT prunings could have attributed to nitrates being retained longer in the plant root zone (Palm, 1995). Unlike with mulched prunings were mineralised N could have been easily washed away with irrigation water due to the absence of soil organic residues, incorporated tree prunings had the ability to retain mineralised N for longer which corresponded to rapid leaf development as well as a high fresh yield (Fig 4.1).

With regards to pruning quality, it was expected that *G. sepium* would be the highest yielding MPT pruning due to its nature of being a high quality organic amendment. However, *T. diversifolia* and the Lucaena species were amongst the prunings that recorded high fresh weight readings (Table 4.1). According to work done by Chikuvire et al., (2013), it is expected for *T. diversifolia* to give a high fresh yield because of it being a high quality organic fertiliser whose performance is similar to that of ammonium nitrate. Though *G. sepium* recorded low fresh yield readings in comparison to *T. diversifolia* and the Lucaena species, this can be attributed to the reason that all the MPT prunings differed in chemical composition with regards to the C:N ratio, polyphenol and lignin content among others (Mafongoya *et al.*, 1998). Such differences in the concentrations of these chemicals could be attributed to the history of the trees that produced the MPT prunings. According to

Mafongoya *et al*., (1998), if trees are stressed due to salt stress, prolonged dry spells as well as a low nutrient status of a soil, the resultant tree prunings will have high concentrations of polyphenols and lignin among others which prolong decomposition. These varying chemical concentrations could have attributed to differing fresh yield readings irrespective of the quality of the prunings used. It is possible that even *G. sepium*, a high quality pruning took a longer time to decompose the above mentioned chemicals before mineralisation could take place (Palm and Rowland, 1997; Mafongoya *et al*., 1998). This would account for why *G. sepium* was out performed by a medium quality pruning *C. calothyrsus*. For the Acacia species low yields are charectaristic of low quality prunings which have slow nitrate mineralisation rates compared to the high quality (high yielding) prunings (Palm *et al*., 1995).

5.2 Effect of placement method and pruning type on dry weight yield of rape

There were significant differences in the dry yield of rape due to placement methods from 2 WAT, 4 WAT and 8 WAT (Table 4.2). These results showed that the incorporated placement method of MPT prunings gave higher yields when compared to the mulched MPT prunings. This could be attributed to the high mineralisation rates of incorporated prunings when compared to the mulched prunings (Palm, 1995; Mafongoya *et al*., 1998). The high mineralisation rates correspond to high leaf areas which mean that the plant has a higher photosynthetic ability. A high photosynthetic ability translates to higher production rates of assimilate which are translocated to the sinks for use (Greenwood and Allan, 2001). High incorporated MPT pruning yields could be attributed to high leaf development rates. Such high rates of leaf development could have led to high photosynthetic ability that led to a surplus of assimilate with time which was deposited in the plant for future use (Table 4.2).

There was significant difference in yields due to MPT prunings (Table 4.3). The high yields of *G. sepium*, *L. trichandria* and *C. calothyrsus* correspond to the quality of the MPT prunings which are regarded as high (*G. sepium*) and medium quality prunings. Such high yields could be attributed to rapid mineralisation rates which are probably maintained constant throughout the experiment with *G. sepium* being able to mineralise 30 - 70 % of the N it contains in the first year of application (Palm, 1995). The low yields of *T. diversifolia* could be attributed to the history of the area which the prunings came from as the prunings are high quality and can produce high nitrate rates (Chikuvire *et al.,* 2013; Muchecheti *et al*., 2013). However the same cannot be said for the low quality Acacia prunings which are expected to produce low yields due to their characteristic low mineralisation rates.

5.3 Effect of placement method and pruning type on leaf area index (LAI) of rape

There was significant difference between placement methods on the leaf area index of rape (Fig 4.2). Incorporated MPT prunings recorded lower LAI values compared to the mulched prunings. These results are in direct contrast with Palm *et al*., (2001) who found out that high quality prunings incorporated into the soil gave high mineralisation rates and consequently rapid growth rates. Growth being an irreversible increase in dry matter is responsible for a high LAI as incoming radiation is intercepted by a well developed leaf corresponding to a high LAI value (Greenwood and Allan, 2001). Such a contrast could be due to absorption, reflection or deflection of incoming radiation by surrounding structures such as trees which according to the PCA-2200 user guide can contribute to variations in expected results. However based on the obtained results, the contrast in results can be attributed to variations in leaf sizes. Though the incorporated prunings had high mineralisation rates initially, low incorporated LAI readings could be due to failure by prunings to continuously supply high amounts of nitrates in the last week of growth which translated to the low LAI readings. Such a development could be attributed to high evapotranspiration rates with low nitrate supply from the incorporated prunings at 8 WAT. Low nitrate supply, high evapotranspiration rates and reduced nitrate uptake by plants outweighed the benefits of incorporating MPT prunings. This can be attributed to larger leaf areas compared to mulched prunings which meant high water requirements for photosynthesis and dry matter accumulation. In the end, the mulched prunings with a smaller leaf area and low water requirements were able to deposit drymass hence the corresponding high LAI value (Greenwood and Allan, 2001).

5.4 Effect of placement method and pruning type on leaf chlorophyll readings (LCR) of rape

There was significant difference between the incorporated and mulched MPT pruning LCR values (Fig 4.3). The incorporated prunings gave higher LCR values and this could be attributed to the relationship between N availability and chlorophyll formation. Incorporated prunings having high mineralisation rates than mulched MPT prunings will provide nitrates more rapidly which are taken up by plants and used in the development of chlorophyll thereby giving the plant a darker green colour (Palm, 1995; Greenwood and Allan 2001).

Low LCR readings observed in the mulched MPT prunings could be attributed to low mineralisation rates due to reduced interaction with soil microbiota as a result of them being surface applied (Mafongoya *et al*., 1998). Reduction in soil microbiota activity will cause prolonged decomposition periods which translate to reduced nitrate availability and consequently low chlorophyll production rates. These findings are consistent with work done by Kennedy, (1995) who noticed improvements in leaf chlorophyll build up when lettuce and spinach were fertilised with a nitrogenous fertiliser as a result of increased nitrate availability.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the above results it can be concluded that incorporation of MPT prunings gives higher fresh and dry weight yields. It can also be concluded that for high LCR incorporation of MPT prunings should be done. For dry weight yield, high and medium quality MPT prunings such as *G. sepium* and *C. calothyrsus* respectively give the highest yields. From the obtained results it can be concluded that, fresh weight readings of rape are not solely dependent on the quality of prunings only but, the history of the prunings as well after *G. sepium* a high quality pruning gave low yields compared to *C. calothyrsus* a medium quality pruning.

6.2 Recommendations

There is need for farmers to incorporate MPT prunings to achieve high crop yields and LCR. Farmers should use *G. sepium* and *C. calothyrsus* in order to increase dry matter production by their crops. There is also a need to repeat the same experiment again to reach a conclusion on how well high quality MPT prunings contribute to the fresh yield of rape. In future experiments the institute must avail funds for equipment to carry out experimental research as the SPAD used to measure chlorophyll readings (LCR) was purchased at 8 WAT. This caused lack of comparison in LCR with the previous weeks. Funds should also be availed for soil sampling since during the duration of the experiment, soil samples were taken but failed to go for analysis due to the lack of funds. Such a setback also presented challenges during the experiment to determine if the resulting yields are due to mineralisation or, some other factors within the experimental site. This led to difficulty in attaining a sound conclusion as to the benefit of the MPTs used to vegetable crops.

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LIST OF APPENDICES

Appendix 1: ANOVA for dry mass at 2 WAT

Variate: DM_2nd_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	4.429E-05	2.215E-05	5.68	
REPLICATION.*Units* stratum					
Placement	1	5.038E-05	5.038E-05	12.92	0.001
MPT	6	2.962E-05	4.937E-06	1.27	0.307
Placement.MPT	6	2.612E-05	4.353E-06	1.12	0.380
Residual	26	1.014E-04	3.899E-06		
Total	41	2.518E-04			

Appendix 2: ANOVA for dry mass at 4 WAT

Variate: DM_4th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.00000195	0.00000097	0.01	
REPLICATION.*Units* stratum					
Placement	1	0.00000754	0.00000754	0.10	0.758
MPT	6	0.00075656	0.00012609	1.62	0.180
Placement.MPT	6	0.00013944	0.00002324	0.30	0.932
Residual	26	0.00201898	0.00007765		
Total	41	0.00292447			

Appendix 3: ANOVA for dry mass at 6 WAT

Variate: DM_6th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.0011613	0.0005807	1.46	
REPLICATION.*Units* stratum					
Placement	1	0.2371509	0.2371509	595.20	<.001
MPT	6	0.0155933	0.0025989	6.52	<.001
Placement.MPT	6	0.0019168	0.0003195	0.80	0.577
Residual	26	0.0103593	0.0003984		
Total	41	0.2661816			

Appendix 4: ANOVA for dry mass at 8 WAT

Variate: DM_8th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.09970	0.04985	4.11	
REPLICATION.*Units* stratum					
Placement	1	1.05958	1.05958	87.27	<.001
MPT	6	0.35639	0.05940	4.89	0.002
Placement.MPT	6	0.12468	0.02078	1.71	0.158
Residual	26	0.31567	0.01214		
Total	41	1.95601			

Appendix 5: ANOVA for fresh yield at 2 WAT

Variate: Fresh_yield_2nd_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.00017433	0.00008717	1.00	
REPLICATION.*Units* stratum					
Placement	1	0.00016010	0.00016010	1.84	0.186
MPT	6	0.00117890	0.00019648	2.26	0.069
Placement.MPT	6	0.00038824	0.00006471	0.75	0.618
Residual	26	0.00225633	0.00008678		
Total	41	0.00415790			

Appendix 6: ANOVA for fresh yield at 4 WAT

Variate: Fresh_yield_4th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.013564	0.006782	3.39	
REPLICATION.*Units* stratum					
Placement	1	0.004647	0.004647	2.32	0.140
MPT	6	0.095575	0.015929	7.96	<.001
Placement.MPT	6	0.026819	0.004470	2.23	0.072
Residual	26	0.052043	0.002002		
Total	41	0.192649			

Appendix 7: ANOVA for fresh yield at 6 WAT

Variate: Fresh_yield_6th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.000453	0.000226	0.08	
REPLICATION.*Units* stratum					
Placement	1	0.007601	0.007601	2.84	0.104
MPT	6	0.056547	0.009425	3.52	0.011
Placement.MPT	6	0.010116	0.001686	0.63	0.705
Residual	26	0.069648	0.002679		
Total	41	0.144365			

Appendix 8: ANOVA for fresh yield at 8 WAT

Variate: Fresh_yield_8th_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.04953	0.02477	0.62	
REPLICATION.*Units* stratum					
Placement	1	0.91111	0.91111	22.99	<.001
MPT	6	0.18388	0.03065	0.77	0.598
Placement.MPT	6	0.05503	0.00917	0.23	0.963
Residual	26	1.03042	0.03963		
Total	41	2.22997			

Appendix 9: ANOVA for LAI at 4 WAT

Variate: LAI_4_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	1.3920	0.6960	3.43	
REPLICATION.*Units* stratum					
Placement	1	0.0180	0.0180	0.09	0.768
MPT	6	0.8577	0.1430	0.70	0.648
Placement.MPT	6	1.3727	0.2288	1.13	0.374
Residual	26	5.2736	0.2028		
Total	41	8.9141			

Appendix 10: ANOVA for LAI at 6 WAT

Variate: LAI_6_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.5176	0.2588	1.26	
REPLICATION.*Units* stratum					
Placement	1	0.7763	0.7763	3.78	0.063
MPT	6	1.1123	0.1854	0.90	0.509
Placement.MPT	6	0.4307	0.0718	0.35	0.904
Residual	26	5.3446	0.2056		
Total	41	8.1815			

Appendix 11: ANOVA for LAI at 8 WAT

Variate: LAI_8_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	2.6033	1.3017	3.36	
REPLICATION.*Units* stratum					
Placement	1	4.3715	4.3715	11.29	0.002
MPT	6	2.1506	0.3584	0.93	0.493
Placement.MPT	6	1.2763	0.2127	0.55	0.766
Residual	26	10.0634	0.3871		
Total	41	20.4651			

Appendix 12: ANOVA for SPAD readings at 8 WAT

Variate: SPAD_8_WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	108.61	54.31	1.07	
REPLICATION.*Units* stratum					
Placement	1	1270.50	1270.50	25.06	<.001
MPT	6	507.18	84.53	1.67	0.169
Placement.MPT	6	272.67	45.45	0.90	0.512
Residual	26	1318.09	50.70		
Total	41	3477.05			