EFFECT OF MULCH TYPE AND NPK (17-17-17) RATES ON SOIL NUTRIENT CONTENT, GROWTH AND YIELD OF CABBAGE (*Brassica oleracea* var. *capitata*) IN VOLCANIC HIGHLAND REGION OF RWANDA

UWITUZE CHANTAL

A Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Award of Master of Science Degree in Soil Science of Egerton University.

EGERTON UNIVERSITY

DECEMBER, 2017

DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been submitted wholly or in part for any award in any Institution.

Signature.. Date..............................

Uwituze Chantal

KM13/14285/15

Recommendation

We confirm that this thesis was prepared under our supervision and has our approval to be presented for examination as per Egerton University regulations.

Signature... Date.....................................

Dr. Joyce J. Lelei Ndemo, Ph.D.

Department of Crops, Horticulture and Soils,

Egerton University,

P. O. Box 536-20115, EGERTON

Signature… Date……………………………

Dr. Hamudu Rukangantambara, Ph.D.

Department of Soil sciences,

College of Agriculture, Animal sciences and Veterinary Medicine,

University of Rwanda,

P. O. Box 210, MUSANZE

COPYRIGHT

DEDICATION

With honour, I dedicate this work to my husband Marcellin, our son Fils Marcellin, family and friends for their endless love and moral support.

ACKNOWLEDGEMENT

First and foremost I wish to thank the almighty God for what He has done towards completion of this work. I sincerely thank the Egerton University administration, particularly the Department of Crop Horticulture and Soils for the opportunity and the knowledge package given to us which contributed immensely towards the success of the study. I also thank my supervisors Dr. Joyce J. Lelei Ndemo from Department of Crops, Horticulture and Soils at Egerton University and Dr. Hamudu Rukangantambara, from Department of Soil sciences, College of Agriculture, Animal sciences and Veterinary Medicine at the University of Rwanda for their mentorship and invaluable academic input. This material is based upon work supported by the United States Agency for International Development, as part of the Feed the Future initiative, under the CGIAR Fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013. Special thanks go to the University of Rwanda for providing the experimental field, laboratory facilities and granting me study leave during this period. I owe a lot to my husband, Shumbusho Marcellin for his boundless patience. Not only he has been a source of encouragement and moral support throughout my study period, but has also cared for our son Fils Marcellin. My greatest debt is to our son, Shema Fils Marcellin, who missed my care at his very early childhood and tolerated my two years of absence from him. To him I am indebted forever! I thank College of Agriculture, Animal sciences and Veterinary Medicine staff; agronomist Eric, lab technicians Job and Prosper for their help during field and laboratory work. I also acknowledge my classmates Macalou, Innocent and Rukia at Egerton University for their encouragement and support during the study period.

ABSTRACT

Soil fertility decline, due to soil loss by erosion, nutrient mining and sub optimal fertilizer use, is the major constraint in cabbage production in the volcanic highland region of Rwanda. The objective of the study was to assess the effect of mulch type and NPK (17-17-17) fertilizer rates on growth, nutrient uptake, yield of cabbage (*Brassica oleracea* var. *capitata*) and soil nutrient content in the volcanic highland region of Rwanda. Field experiments were conducted in two cropping seasons; September 2016 to January 2017 and December 2016 to March 2017 at the experimental farm of the College of Agriculture, Busogo sector, in the northern-west region of Rwanda. A "3×4" factorial experiment in a Randomized Complete Block Design (RCBD) with three replications was used. Factors were three mulching treatments; black plastic, wheat straw and an un-mulched control and four rates of NPK (17-17-17) fertilizer; 0kgha^{-1}, 60kgha^{-1}, 120kgha^{-1} and 180kgha^{-1}. Soil samples were collected twice; before transplanting and after harvesting. Cabbage growth parameters were measured at early and late stage. Dry matter accumulation and nutrient uptake (N, P, and K) were analyzed at cabbage heading. Head weight and diameter were recorded at commercial maturity. The data obtained was subjected to ANOVA using SAS version 9.3 software and mean separation was done using LSD at 95% confidence level. Main effect of wheat straw mulch significantly increased cabbage height (32.79cm), interactions of wheat straw mulch and fertilizer rate of 120kgha^{-1} significantly increased stem diameter (23.46cm), while interactions of black plastic mulch and fertilizer at rate of 120kgha^{-1} significantly increased head diameter (26.80cm) and yield (4850.44g per plant). Main effects of fertilizer at rate of 60kgha^{-1} and 120kgha^{-1} respectively increased K (88.76kgha^{-1}) and P (41.66kgha^{-1}) uptake in cabbage leaves while interactions of black plastic mulch and fertilizer application at rate of 120kgha^{-1} significantly increased N uptake (58.52kgha^{-1}). There was higher soil moisture under black plastic mulch (33.83%) and fertilizer application at 180kgha^{-1} (36.08%). Interactions of black plastic mulch and fertilizer application at rate of 180kgha^{-1} and 120kgha^{-1} significantly increased soil P (158.12ppm) and K (0.37cmol$_c$kg^{-1}) availability respectively and interaction of wheat straw mulch and 120kgha^{-}1 significantly increased soil total N (0.43%). The recommended combination was wheat straw mulch with 120kgha^{-1} for increased soil moisture content and nutrient availability, uptake and cabbage growth and yields in volcanic highlands of Rwanda.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AAS	Atomic absorption spectrophotometer
AEZ	Agro ecological zone
ANOVA	Analysis of Variance
Asl	Above sea level
$Cmol_c kg^{-1}$	Centimole charge per kilogram
CV	Coefficient of variation
DAT	Days after transplanting
Ha	Hectare
K	Potassium
Kg	Kilogram
LA	Leaf Area
LAI	Leaf Area Index
LSD	Least significant difference
N	Nitrogen
^oC	Degree centigrade
OM	Organic matter
P	Phosphorus
Ppm	part per million
RSSP	Rural Sector Supporting Project
SE	Standard error
T	Ton
UR – CAVM	University of Rwanda - College of Agriculture, Animal Sciences and Veterinary Medicine

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Rwanda is a relatively small mountainous and land locked country in sub-Sahara Africa, with 26, 338 km^2 surface area, including rivers and lakes (Verdoodt and Van Ranst, 2003), 900 to 4507 m asl altitude and receives annual rainfall of 1212 mm. The country has a population of 12 million people. More than 80% of the population lives on agriculture.

The government of Rwanda views agriculture as major driver of national economic growth through national agricultural policy. Vision 2020, 2030 and 2050 sets out a key target to be achieved by the agricultural sector, particularly cruciferous family, especially cabbage (*Brassica oleracea* var. *capitata*) for economic development and poverty reduction strategy (EDPRS) and improved livelihood.

Cabbage (*Brassica oleracea* var. *capitata*) is an important vegetable crop in the country the second after tomatoes with high demand especially in urban centers. Low yields are, however, obtained in small holder farms mainly due to deficiencies of nitrogen (N), phosphorus (P) and potassium (K). Cabbage is a heavy nutrient feeder and to form full, green heads, it requires adequate supply of these nutrients (Kelly and Murekezi, 2000; Maniriho and Bizoza, 2013). N promotes leafy growth and green colour, P promotes root and flower growth while K is needed for overall plant health (Nina *et al.*, 2012).

Deficiencies of N, P and K in small holder farms have resulted from nutrient mining due to over cultivation of land without adequate replenishment of nutrients lost through harvested products, due to unaffordability of fertilizers, leaching and soil erosion. Erosion has affected half of Rwanda's farming land, with estimated soil losses of between 2.6 to 21.5 t $ha^{-1}year^{-1}$ reported (Kagabo, 2013).

Adequate soil management in the Rwandan highlands is still lacking. Policies promoted by the Government, through the Rural Sector Support Project (RSSP) for soil management like terracing, use of cover crops and agroforestry, have been faced with low efficiency and adoption, compared to the population density and need for food (Minirena, 2007; Nabahungu, 2013). Research on ways of improving soil fertility for improved productivity in the highlands is required (Liang *et al.*, 2002; Rutunga *et al.*, 2007). Application of mulch combined with mineral fertilizer can improve fertility, soil's health, and subsequently lead to increased cabbage yields. Mulching materials include organic substances, mineral materials and prefabricated substances (Broschat, 2007; El- Shaikh and Fouda, 2008). Mulches are applied beneath soil around crops to improve the fertility and health of soil, conserve moisture, reduce weeds and prevent soil erosion (Liang *et al*., 2002). Plants benefit from weed reduction as competition for water and nutrients is reduced. Mulch prevents loss of water by evaporation, reduce temperature fluctuations and promote productivity (Gary *et al*., 2014). Identifying suitable mulch material in combination with inorganic fertilizer rate that optimizes cabbage production in the highlands of Rwanda is important. This will help meet the high demand for cabbage especially in urban centers.

1.2 Statement of the problem

The volcanic highlands of Rwanda is found in the agriculture zone of the birunga group where volcanic soils called “Andosols” are the most fertile soils in the country. The volcanic highlands of Rwanda descend from the limit at an altitude of 2,500m to an altitude of 1,900m and even below 1600m, with regularly distributed rainfall, varying between 1,300and 1,500mm but its distribution is uneven while farming system in this region belongs to rainfed agriculture. The volcanic highlands region of Rwanda, and the whole country in general is highly vulnerable to climate change. Increase in temperature and changes to rainfall patterns result in floods, landslides and droughts that significantly reduce crop yield and negatively impacting livelihoods, food security and export earnings.

During droughts, the moisture content of soil for earlier part of the growing season remains high and decline later which significantly affect expected reasonable yield. Cabbage growth is highly nutrient dependent and decline in fertility of soil, due to inadequate replenishment of nutrients taken up by crops or losses through erosion which lead to removal of top fertile soils hence nutrient loss, leaching and low moisture conservation to favour nutrient uptake has led to low cabbage yields. Soil conservation practices such as terracing, use of cover crop and agroforestry have not been well adopted by farmers, hence need for alternative methods like mulching to help in moisture retention, increase nutrient uptake and minimize soil detachment by reducing raindrop impact; but the major constraint is lack of knowledge on fertilizer rate in combination with a mulch type that can optimize cabbage yield in the volcanic highlands region of Rwanda.

1.3 Objectives

1.3.1 General objective

To contribute towards food security through assessment of the effect of mulch types and NPK (17-17-17) fertilizer application for increased cabbage (*Brassica oleracea* var. *capitata*) growth, yields, soil moisture and nutrients in the soil in highlands zone of Rwanda.

1.3.2 Specific objectives

The specific objectives of the study were; to determine the:

1. Effects of mulch type, fertilizer rate and their interactions on growth and yield of cabbage.
2. Effects of mulch type, fertilizer rate and their interactions on N, P and K uptake by cabbage
3. Effects of mulch type, fertilizer rate and their interactions on soil moisture, available P, K and total N content.

1.4 Hypotheses

1. Mulch type, fertilizer rate and their interactions have no effect on growth and yield of cabbage.
2. Mulch type, fertilizer rate and their interactions have no effect on N, P and K uptake by cabbage.
3. Mulch type, fertilizer rate and their interactions have no effect on soil moisture, available P, K and total N content.

1.5 Justification

Rwanda population is the densest in sub-Saharan Africa with 459.73 inhabitants per km^2. The population growth rate is 2.8 percent per year and is estimated to double in 25 years (Bidogeza *et al.*, 2015). 80% of population is involved in agricultural activities. The total annual losses of nutrients due to erosion all over the country is estimated to be 945200t OM; 41210t N; 280t P; and 3055t K (Nabahungu, 2013). Effective soil management is needed to ensure soil nutrients conservation and subsequently increase in productivity. Mulching therefore can play a vital role by conserving soil moisture hence increasing the efficiency use of fertilizer by plants, suppression of weeds and erosion control (Cregg and Schutziki, 2009).

Cruciferae family, particular cabbage (*Brassica oleracea var. capitata*) is the basket food for Rwanda and neighboring countries. It provides substantial income to the farmers.

But limitations due to the generally mined soil nutrients by crop harvesting through over-cultivation, high leaching and erosion on small family plots has led to food insecurity in some parts.

Farmers need to adopt mulching practice it as it does not consume space on the fields or compete with crops for nutrients unlike other form of biological erosion control; the cause for non-adoption of the latter. Terraces are not favoured because of costs incurred in construction and maintenance. There are no known NPK rates for cabbage production in volcanic highlands of Rwanda and researchers have recommended further research to acquire reliable data for the appraisal of fertilizer profitability (Kelly and Murekezi, 2000). Hence current study “effect of mulch type and NPK (17-17-17) fertilizer rates on soil nutrient content, growth and yield of cabbage (*Brassica oleracea* var. *capitata*) in the volcanic highlands region of Rwanda”has been undertaken to come up with beneficial and cheaper mulch and right dose of NPK fertilizer able to increase cabbage growth and yield in the highland regions of Rwanda to promote it for its food value and to meet the growing demand.

CHAPTER TWO
LITERATURE REVIEW

2.1 Cabbage production

2.1.1 Origin and description of cabbage

Cabbage is a worldwide vegetable that originated from Europe. Its cultivation has expanded because of its varied climatic and soil adaptations. Cabbage (*Brassica oleracea* var. *capitata*) has an adventitious root and unbranched stem which is about 30 cm long. It is a biennial vegetable propagated by seeds. Cabbage is a member of "Brassicaceae" family, genus "Brassica". Some cabbages are red and others green. For the green ones the inner leaves are white. There are many varieties for example Napa, Choy sum, Earl Jersey Wakefield, Portugal and January king cabbages. Leaves can be smooth or wrinkled and their heads have different shapes such as ball – headed, drum – headed, conical and sugarloaf – headed. Commercial cultivation of cabbage can be very successful due to high market demand (Kenneth, 2013; Sajib *et al.*, 2015).

2.1.2 Agro ecological requirements of cabbage

Cabbages achieve high yield when planted in altitudes of ≥ 700 m and temperatures ranges of 15^{o}C to 24^{o}C. Loamy or sandy loamy soils best fit growth. For oxygen availability the soil must be well drained to avoid diseases such as black rot and soft rot. The pH for optimum yield is 5.5 to 6.8 (Isaac, 2006). They need well distributed rainfall of about 750mm during the growing period, and large headed varieties grow well in areas having 2000mm annual rainfall (Onduso, 2011).

The selection of variety is important because it must suit climatic conditions, be resistant to pest and diseases and must be preferred to the market for best returns. Before planting, the nursery should be well established because it results in; cost reduction, as fewer seeds are used, good seedlings growth and transplantation selection of disease free and vigorous seedlings (Isaac, 2006). The nursery should be well observed during germination and seedling development to maintain optimum conditions regarding pest control and water or nutrients provision (ADFSC, 2015).

2.1.3 Rank of cabbage in Rwanda

Cabbage is a horticultural crop ranked the second vegetable which is promoted in Rwanda after tomato because they thrive in temperate climates. The two are the most important in terms of area planted and the weight of production. Their production is similar, but the area occupied by cabbage is greater, which is an indication of its lower yield per hectare. Local eggplants are the third in terms of space cultivated and weight. Northern Province production accounts about the half of national output where 51% of cabbage yield is sold, 37% farmer's consumption, 11% gifted, 1% for other purposes and 0% stored for season A of the year 2013 (Rwanda, 2014).

Cabbage is also exported and imported. About12% goes to Kigali, 2% exported to neighbouring countries, and a very small amount is exported internationally. In 2013 for vegetables with an export or import weight of over 100,000kg or value of over 50,000US$; it represented export weight of 1,052,434kg, the value was 212,329US$ and the unity price was 0.20US$ while the import weight was 379,163kg, value of 61,438US$ and unity price of 0.16US$. At national level, four crops comprise over two-third of the gross sales value of organizations where tomatoes (28%), onions (14%), cabbage (13%) and pineapple (13%). The remainder is generated mainly by local eggplants, carrots, sweet peppers, French beans and papaya. Cut flowers account for only 0.4% and plants grown for the extraction of essential oils only 0.1% (Rwanda, 2014).

2.2 Fertilizers use

2.2.1 Cabbage fertilization

Cabbages are heavy feeders and need adequate soil nutrients to form full, green heads; N for leafy growth and green color, P to promote root and flower growth and K for overall plant health (Nina *et al*., 2012). For better production; soil analyses for fertilizer recommendation must be done (Kołota and Chohura, 2015). In volcanic highlands of Rwanda, there are no known NPK rates for cabbage production. Kelly and Murekezi (2000) recommended further research to acquire reliable data for the appraisal of fertilizer profitability.

2.2.2 Fertilizer use in Rwanda

Fertilizer use in Rwanda like other sub-Saharan Africa countries is characterized by utilization of very low amounts, due to high cost. The farmer cooperatives exceptionally use considerable amount of fertilizers with the help of Rural Sector Supporting Project (RSSP). Rapid loss in nutrients occur due to slow rate of growth in fertilizer use ($kgha^{-1}$), inadequate biomass production that can be used to recycle soil nutrient and organic matter and the negative environmental consequences such as high erosion (Kelly and Nasseem, 1999;

Sommer *et al*., 2013). The estimated soil nutrient losses, in 2002-2004 cropping seasons was 77 kg ha^{-1} for Rwanda and interpreted as high, meaning > 60 kg ha^{-1}(WDI, 2016). Fertilizer use in Rwanda has been low in past years and assumed at 6, 27 and 29 kg ha^{-1} in 2006, 2011 and 2012 respectively. Through farmer's education on its importance and methods of application, fertilizer use is projected at 45kgha^{-1} in 2017 (Nabahungu, 2013).

The population increase is a factor leading to scarcity of arable land in Rwanda and has resulted in deforestation and cultivation of steep slopes; there is no adoption of fallows and cultivation with hoe is done twice per year that has led to high runoff and erosion risks while the size for farmland is small per family (Cody *et al*., 2009). The latter slows the adoptability of conservation measures even though the policy of land consolidation has been recently initiated.

2.2.3 Factors and constraints to fertilizer use

Fertilizer use is based mainly on factors related to historical background including colonial heritage, demography, policy influence, agro ecological zones, the country's infrastructure and income and also the choice of crop and prices for better profitability (Zoe and Jesus, 2012). Constraints to fertilizer use are based on profitability and affordability. For profitability the marginal return in quantity is low due to less or no knowledge of fertilizer use, fertilizers are inadequate and not available at time, low soil quality, and lack of insurance in case of climate hazards like drought. Affordability is also a major constraint to farmers due to high fertilizer prices because of high transport costs and unavailability of supply (Omotayo and Chukwuka, 2009; Zoe and Jesus, 2012).

2.3 Soil erosion and its impact

Soil erosion is a natural process consisting of deterioration of soil by the physical movement of soil particles and does occur during geological time. Nowadays, soil erosion is a most important concern because of its significant acceleration caused mostly by human deed, animals, water and wind (Ipromo Course, 2015).

Most of the soil's nutrients and organic matter are found in top soils and erosion causes these substances to move and leave behind soil with poor structure having low water-holding capacity, low nutrients content and acidic pH (Cotching, 2009). Tons of agricultural soils are lost every year and it is a big problem. Proper techniques for soil erosion control have therefore to be taken into consideration. To restore soil composition; fertilizers and organic matter can be added. A soil that is poor in nutrients also produces crops which are poor in terms of nutrients content and then poor food for the consumers (Philip, 2013).

2.4 Control of soil erosion

2.4.1 Soil physical properties

Soil texture is one of properties that determine the susceptibility of a soil to erosion. Clays are sticky and tend to bind soil particles together and resist erosion but also they are easily transported once they have eroded. Decrease in soil clay content implies increase in soil erosion (Cotching, 2009). Sandy soils have low water holding capacity and low surface area meaning that they also retain small amount of nutrients; for silt soils they are highly and easily erodible. Well - graded and well - drained gravels are the least erodible soils (Fitzpatrick, 1986).

Bulk density of a soil influence the extent of soil erosion; conventional tillage is one factor leading to soil compaction as pores sizes decrease and large pores are eliminated. Over cultivation is also the cause of decrease in soil organic matter (SOM) content and weakening of soil aggregates stability making them susceptible to erosion; Heavy equipment travel and tillage result in soil layers compaction and increase soil bulk density and this causes high flow of water transporting the fertile top soil and reduces its agricultural produce (Navar and Synnott, 2000). It is then good to manage soil bulk density, by limiting compaction affecting soil structures and organic matter replenishment (USDA-NRCS, 2013).

2.4.2 Land cover effect

High soil loss occurs in uncovered beds. Where there is no land cover availability of loose surface material is dominant caused mainly by ploughing the soil and loosening of soil aggregates (Castillo *et al*., 1997). When rain drop intensity is high then the soil is easily eroded. Cover is important in erosion control as it helps reduce splash erosion from raindrops or wind falling on bare soils causing detachment of soil particles. Land cover favours water infiltration into the soil by speeding down the flow of water over the soil surface (IDNR, 2006). To avoid loss of productivity, soil erosion in cropping land can be controlled by maintaining as much cover on the surface of the soil as possible and by managing run-off (Land, 2015).

2.5 Mulches

2.5.1 Overview

Mulches are into two types; inorganic and organic. Those materials are applied beneath soil around crops to improve the fertility and health of soil, conserve moisture, reduce weeds and prevent soil erosion (Liang *et al*., 2002). The layers can be 5cm or more. All mulches are important; they reduce weeds by preventing them from receiving the sunlight needed for growth and help retain soil moisture. Plants benefit from weed reduction as competition for water and nutrients is reduced. Mulch prevents loss of water by evaporation, reduce temperature fluctuations and promote productivity (Gary *et al*., 2014).

Mulching materials include organic substances such as peat, wood chips, pine needles; mineral materials such as sand, gravel, stones, granite chip, rock wool and other synthetic materials (Broschat, 2007; El- Shaikh and Fouda, 2008).

The research conducted on fleece and net covers in white cabbages (*Brassica oleracea*) cultivation to determine their effect on soil erosion, growth and diseases revealed that by using fleece cover; soil loss reduced by 76% while for net cover the reduction was 48% in comparison to non-covered treatment (Übelhör *et al.*,2014). There are many advantages of using row covers as suitable erosion control strategy as some of them like straw mulch are inexpensive, quick and easy to apply, and has high moisture retention and no water needed for application (Zaniewicz *et al.*, 2009).

Plastic mulch has been reported to increase yield dry weight (Russo *et al.*, 1997). Mulches can be used for mitigation of the harmful effect of soil fungi and nematodes (Djigal *et al.*, 2012). Organic and synthetic mulches are important in the production of horticultural crops for water conservation, provision of required temperature and reduction of nutrient loss by leaching (Gordon *et al.*, 2010). Without mulches; rain drop intensity is not reduced which lead to high erosion risks, leaching of essential nutrients, no moisture retention resulting in high evaporation, high crop damage, high weeds growth and then low yield (Hooda *et al*., 1999).

Different mulch textures of same category moderate temperature differently with that under fine being cooler than coarse textured and that is the same for organic mulches. Mulches also affect soil temperature; some heat the soil because of the absorption of solar radiation compared to the living mulches and bare soils (Linda, 2007; Linjian *et al*., 2016).

2.5.2 Organic mulch

Organic mulch is derived from decaying materials such as leaves, grasses and other crop residue. They add nutrients to the soil when they decompose. Wheat straw mulch provides light, fluffy mulch around vegetable and reduces the rain drops intensity. It is also quickly broken down, and it can be turned into the soil each season and replenished. It adds organic matter to the soil and it easy to apply (Liang *et al*., 2002). Straw mulch reduces soil compaction and increases biotic activity (Ingle, 1981). Its cost is low and can be affordable for farmers. Organic mulch like straw mulch acts as a soil temperature buffer (Trdan *et al.*, 2008). Changes in the soil hydrothermal regime for straw mulch can increase the density and spread of roots. Organic mulches can temporarily tie up soil nitrogen levels as they decay and can reduce loss of nitrate, sulfate, calcium, magnesium and potassium (Traunfeld and Nibali, 2013).

2.5.3 Inorganic mulch

Inorganic mulches are man-made mulches. This category does not add nutrients to the soil but they control weeds, erosion and are not replaced every season. They retain moisture and also control soil temperatures (Jiang *et al*., 2016). Plastic mulches are available in different colours and are made from 100 per cent recycled products. Different colours have proven to influence soil temperature differently (Farias-Larios and Santos, 1997). A thin plastic film is placed over the ground and holes are poked considering the spacing needed and then seedlings are planted in those holes. Those films remain in the field for the duration of cultivation which is usually between 2 to 4 months. Synthetic mulches like clear polyethylene permit more divergent temperature fluctuations; warm in day time and cooler at night (Steven, 2012).

Transparent mulch films encourage early plant growth and cropping and can also keep weeds growing while black mulch films keep soil warm by heat retention and inhibit weeds growth by blocking out sunlight resulting in nutrient availability. Transparent polyethylene mulch has the effect of repelling pest and vector insects like aphids because of its reflective property due to UV light helping in aphid’s confusion preventing their alighting on plants and that decreases the probability for virus attack. For soil cooling; aluminum and white mulch can be used because of their reflective properties (Farias-Larios and Santos, 1997; Bhardwaj, 2013).

Soil temperature is increased under plastic mulch; clear plastic mulch has found able to capture more heat under tropical conditions making it to be more effective than white and black (Farias-Larios *et al.*, 1994).

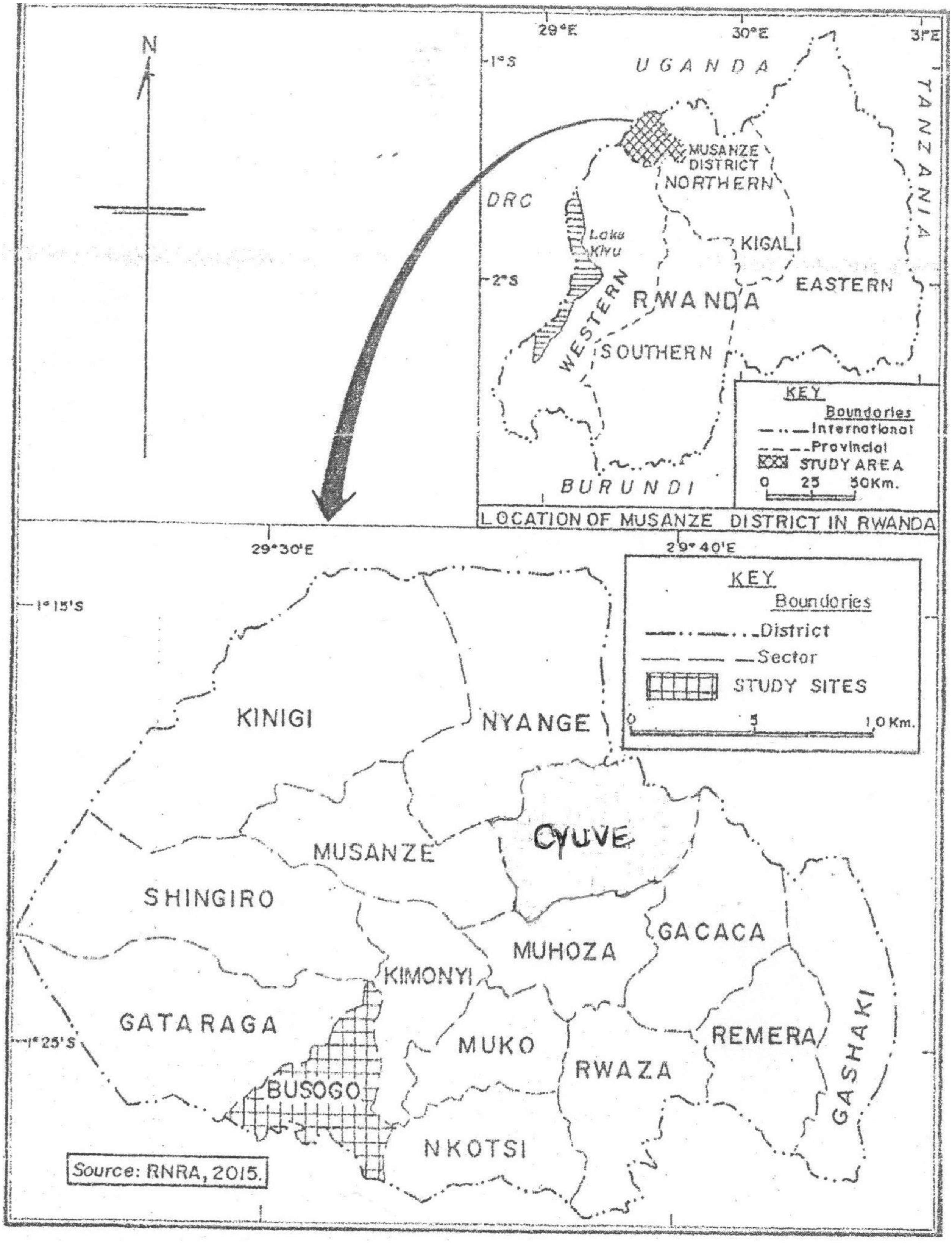
Plastic mulches are good in water and fertilizer management, weed control with low amount of herbicides application (Decoteau *et al.*, 1986). Fertilizer combined with mulch results in good response. Yang *et al*. (2015) reported that moderate fertilization of K in form of K_2O with plastic mulch increased seedling height, leaf area and dry matter.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study sites

Field experiments were conducted from September 2016 to March 2017 in Busogo sector, Musanze District, in the northern region of Rwanda (Fig. 1). The sector (1800 and 4200 m asl) is geographically located at $1^o33'26''$S and $29^o32'39''$E. The population density is 1,100 persons /km^2 (2012 census). Busogo's climate is warm and temperate; mean annual temperature is 16.2^{o}C and the average annual precipitation is 1420mm (Climate-data.Org, 2012). Four seasons are observed per year: two rainy seasons; February to June and September to December, and two dry seasons; between June to September and December to February (Kabirigi *et al.*, 2015). Climate data measured during study period are shown in Table 1. The site is occupied by volcanic soils, also called andosols due to volcanic eruptions. The region is surrounded by 5 of 8 volcanoes of Virunga chain (Kagabo, 2013). There is dominance of hilly topography with elevated slopes. Soil erosion and landslides are high because the soils are fragile (Luis and Byizigiro, 2012).

The initial soil properties (0-30 cm) showed that soil texture was loam , pH (H_2O) medium in season one and low in season two, high available P and medium total N (Table 2). Exchangeable calcium, magnesium and potassium, organic matter, organic carbon and cation exchange capacity were medium (Table 2). The values obtained from analyzed parameters were compared with those reported as high, medium and low (Landon, 1991). The main crops grown in the area are potatoes, beans, wheat and maize.



Source: Rwanda Natural Resource Authority, 2015

Figure 1: Map of study site

Table 1: **Climate data for experimental site during the experimental period**

Month	Relative humidity (%)	Temperature (^{o} C)	Precipitation (mm)
September	83.9	15.1	182.5
October	84.7	15.4	174.8
November	86.4	15.2	186.8
December	84.8	15.6	170.2
January	82.4	15.8	59.7
February	80.3	15.6	88.8
March	85.0	15.4	204.7
April	86.4	14.8	173.8

Source: Busogo meteorological station, 2017.

Table 2: **Initial soil properties (0-30 cm)**

Parameter	Units	Season 1	Season 2	Parameter	Unit	Season 1	Season 2
pH(H_2O)	-	5.8	5.4	Exc. Ca^{2+}	$cmol_c$/kg	5.27	4.71
Available P	Ppm	135	180	Exc. Mg^{2+}	$cmol_c$/kg	3.03	2.76
Total N	%	0.32	0.45	Sand	%	48.4	46.4
OM	%	7.84	9.46	Clay	%	21.6	21.6
OC	%	4.55	5.49	Silt	%	30	32
CEC	$cmol_c$/kg	20.67	20.00	Textural class		Loam	Loam
Exc. K^+	$cmol_c$/kg	0.66	0.60	TEA	$cmol_c$/kg	0.19	0.13

Key: TEA: Total exchangeable acidity, OM: Organic matter, OC: Organic carbon, CEC: Cation exchange capacity

3.2 Treatments and Experimental Design

The treatments were a '3 × 4' factorial arrangement of three mulching treatments (black plastic, wheat straw and unmulched control) and four NPK fertilizer rates (0, 60, 120 and 180 kg ha^{-1}) in a randomized complete block design (RCBD), with three replicates. Each replicate had 12 treatments and the unit plot measured 3.6m×2.4m. The distance between plots and blocks were 50 cm and 100 cm, respectively (Table 3; Fig 2). Two adjacent fields were used for seasons I and II; the first transplanting date was 22nd October, 2016 (season I) and second transplanting date was 22nd December, 2016 (Season II). All fields were harvested 90 days after transplanting.

Table 3: Treatment Combinations

Mulch type / NPK (17-17-17) rates	**No mulch (M0)**	**Black plastic (M1)**	**Wheat Straw (M2)**
0kgha^{-1} (F0)	M0F0	M1F0	M2F0
60kgha^{-1} (F1)	M0F1	M1F1	M2F1
120kgha^{-1} (F2)	M0F2	M1F2	M2F2
180kgha^{-1} (F3)	M0F3	M1F3	M2F3

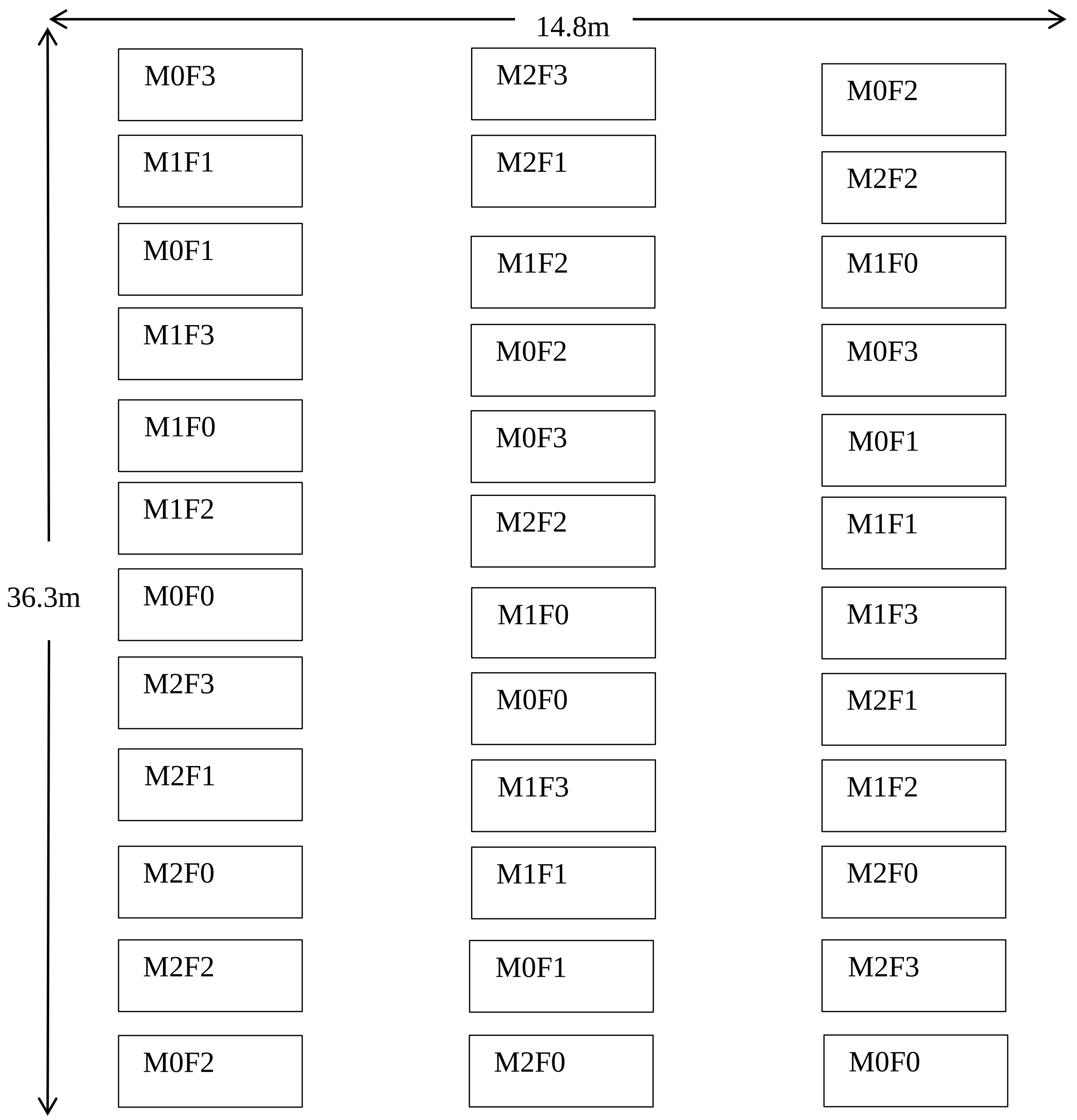


Figure 2: Experimental layout

Key: M0: No mulch; M1: Black plastic mulch; M2: wheat straw mulch; F0: No fertilizer; F1: 60 kg ha^{-1} NPK, F2: 120 kg ha^{-1} NPK, F3: 180 kg ha^{-1} NPK.

3.3 Agronomic practices

The experimental field was cleared of vegetation four weeks before planting. Land preparation was done using hand implements, a week before planting. Cabbage seeds were sown in a well prepared nursery. The white cabbage variety *Brassica oleracea* var. *capitata* was used. Disease and pest control measures and irrigation were done, to obtain quality seedlings. Plastic mulch was laid to the soil before transplanting and holes were pocked on it. Well grown seedling from the nursery (>1.5 cm height) were transplanted in all plots, in both rainy seasons (Seasons I and II), at spacing of 60 cm × 60 cm to give a plant population of 27,778 plants per hectare (Onduso, 2011).Wheat straw mulch was placed around seedlings after transplanting in layers of 5 cm thickness in respective treatment which is about 3.28tons ha^{-1} (NRCS, 2002). NPK (17-17-17) fertilizer was applied once, by banding, and was mixed well with soil before transplanting. Nutrient content (kg) in 60kg NPK (17-17-17) fertilizer is 10.2 - 10.2 - 10.2 respectively for N, P_2O5 and K_2O; in 120kg NPK (17-17-17) fertilizer it is 20.4 - 20.4 - 20.4 respectively for N, P_2O5 and K_2O while for 180kg NPK (17-17-17) fertilizer it is 30.6 - 30.6 - 30.6 respectively for N, P_2O5 and K_2O (Kanyanjua and Ayaga, 2006). Weed control was done manually, twice during the growing period, i.e. one and two months after transplanting. Pesticides and fumigants were applied weekly to avoid pest damage and disease occurrence.

3.4 Soil and Plant sampling and Analysis

3.4.1 Soil sampling and analysis

Soil samples (0-30 cm), for characterization of initial properties (Table 2), were collected from the experimental field before planting and application of treatments, using the zigzag method. Composite samples, obtained using quartering method, were labeled, sealed and transported to the soil laboratory of the University of Rwanda - College of Agriculture, Animal Sciences and Veterinary Medicine (UR – CAVM). Air- dried and sieved (0.5 and 2 mm mesh) samples were analyzed using standard methods; pH using the glass electrode method (Okalebo *et al*., 2002); total nitrogen by Kjeldhal method (Rutherford *et al*., 2008); available phosphorus using Mehlich III method (reading by UV/Vis) (Ziadi and Sen, 2008); exchangeable bases using Ammonium acetate saturation method (Ziadi and Sen, 2008) (reading by AAS); organic carbon with loss by ignition (Estefan *et al*., 2013) and texture by Hydrometer method (Kroetsch and Wang, 2008).

Soil samples were randomly collected after harvesting at 0 – 30 cm depth per plot, and composited. They were labeled, sealed and taken to the soil laboratory of the University of Rwanda - College of Agriculture, Animal Sciences and Veterinary Medicine (UR – CAVM). Air dried and sieved samples, were analyzed for available P by Mehlich III (reading by UV/Vis) (Ziadi and Sen, 2008) , K by Ammonium acetate method (Ziadi and Sen, 2008) (reading by AAS) and Total N by Kjeldhal method (Rutherford *et al*., 2008). Soil moisture was monitored every 30 days after transplanting to commercial maturity by gravimetric method at 105^{o}c (Kroetsch and Wang, 2008).

3.4.2 Plant sampling and analysis

Four cabbages from the plot center having odd numbers (1, 3, 5 and 7) were sampled before heading (Hochmuth, 2012) from all plots. The samples were weighed fresh and sub samples were then oven dried at 70^{o}C till constant weight. The dried samples were weighed (Estefan *et al*., 2013) ground and sieved (1mm mesh). They were analyzed for concentrations of total nitrogen by Kjeldhal method (Rutherford *et al*., 2008) and phosphorus and potassium by wet oxidation (reading by AAS) (Estefan *et al*., 2013).

Nutrient uptake was calculated using the following formulae (Peterburgski, 1986);

Total nutrient uptake = nutrient concentration × dry matter yield …....……………. (1)

3.5 Growth and yield measurements

The measurement were taken from 8 cabbages occupying two rows in center of each plot; Cabbage height, stem diameter, leaf area index and head size were measured at early and late stage i.e. at 30. 45. 60 and 75 days after transplanting (DAT). Height was measured by normal scale (in cm) with a ruler; stem diameter by normal scale (in mm) with venire caliper and head size by normal scale in (cm) with venire caliper.

Leaf area index (LAI) was estimated using the following formulae:

LAI = (Leaf area × number of leaves)/Spacing (Augusto, 2014; Pearcy *et al.*, 1989)……………………………………………………………………………………..(2)

Where LA = (Length × Width) × F. (F is crop coefficient for the end of the late season stage and equals to 0.95 for cabbage) (Fao.org, 2017).

Heads of four marked cabbages in center of each plot having even numbers (2, 4, 6 and 8) were weighed at commercial maturity using a weighing balance.

3.6 Data Analysis

Data for measured parameters were subjected to ANOVA using SAS version 9.3. Mean separation was done using LSD at 95% level of significance (Gomez and Gomez, 1984).

3.6.1 Statistical model

$Y_{ijk} = \mu + M_i + F_j + (MF)_{ij} + \gamma_k + \varepsilon_{ijk}$

Where;

i = 1, 2, 3

j = 1, 2, 3, 4

k = 1, 2, 3

μ: Overall mean

M_i: Effect of i^{th} level of mulch

F_j: Effect of j^{th} level of fertilizer

MF_{ij}: Effect of interaction between i^{th} level of mulch and j^{th} level of fertilizer

γ_k: Effect of k^{th} block

ε_{ijk}: Random error term

Y_{ijk}: Overall observations

CHAPTER FOUR

RESULTS

4.1 Effect of mulch type, fertilizer rate and their interactions on cabbage growth and yield

4.1.1 Effect of mulch type, fertilizer rate and their interactions on cabbage height

Effect of mulch type

Mulch types affected cabbage height significantly ($P<0.05$) in both seasons (Table 4). In season I at 30 days after transplanting (DAT), wheat straw mulch had significantly higher means (19.01 cm) than bare soil (15.89 cm) and black plastic mulch (14.14 cm). At 45 DAT, wheat straw mulch had significantly higher means (23.48cm) than black plastic mulch (21.50 cm). The latter's mean was not significantly different from bare soil (22.30) at 45 DAT (Table 4). In season II, significantly higher cabbage mean height was obtained in wheat straw than black plastic mulch and bare soil, at 30, 45 and 60 DAT, in that order. Both black plastic and wheat straw mulch had significantly higher means than bare soil at 75 DAT (Table 4).

Effect of fertilizer rate

In season I, effect of fertilizer rate on cabbage height was significant ($P<0.05$) at 45, 60 and 75 DAT. Rates of 60 kgha^{-1} and 120 kg ha^{-1} had the significantly higher means (23.90 and 22.99 cm) than 180 kg ha^{-1} at 45 DAT. 60 kgha^{-1} rate had significantly higher means than 120 and 180kgha^{-1} at both 60 DAT (28.03 and 27.13) and 75 DAT (28.49 and 27.69). In season II; no fertilizer (0 kgha^{-1}) had highest mean height of 18.97, 28.98 and 31.63 cm at 30, 45 and 60 DAT, respectively, than application rate of 180kgha^{-1} which had means of 15.05, 23.90 and 27.88 cm at the respective dates. At 75 DAT, there were no significant differences in cabbage height in 0, 60, 120 and 180 kgha^{-1} fertilizer rates (Table4).

Effect of interaction between mulch type and fertilizer rates

The interactive effect of mulch and fertilizer on cabbage height was not significant ($P<0.05$).The lowest mean in season I was obtained in black plastic mulch in combination with 180kgha^{-1} and, bare soil with 180kgha^{-1} in season II (Table5).

Table 4: Effect of mulch type and fertilizer rates on cabbage height (cm) at different days after transplanting.

	Height (cm)							
Treatment	Season I				Season II			
Mulch type	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	15.89^{b}	22.30^{ns}	29.30^{ns}	29.11^{ns}	13.99^{c}	22.80^{c}	25.66^{c}	27.20^{b}
Black plastic	14.14^{b}	21.50	27.75	29.87	17.69^{b}	27.11^{b}	30.66^{b}	31.05^{a}
Wheat straw	19.01^{a}	23.48	29.35	29.45	19.09^{a}	29.79^{a}	32.79^{a}	31.82^{a}
$LSD_{(0.05)}$	1.842	1.677	2.313	1.782	1.352	1.705	1.802	2.111
CV (%)	13.31	8.83	9.48	7.14	9.44	7.58	7.17	8.30
NPK rate								
0kg ha^{-1}	16.63^{ns}	21.92^{bc}	29.19^{ab}	30.16^{ab}	18.97^{a}	28.98^{a}	31.63^{a}	30.48^{ns}
60kg ha^{-1}	16.97	23.90^{a}	30.86^{a}	31.56^{a}	16.45^{bc}	26.89^{b}	29.67^{ab}	29.87
120kg ha^{-1}	16.93	22.99^{ab}	28.03^{b}	28.49^{bc}	17.22^{b}	26.49^{b}	29.63^{ab}	29.80
180kg ha^{-1}	14.85	20.91^{c}	27.13^{b}	27.69^{c}	15.05^{c}	23.90^{c}	27.88^{b}	29.95
$LSD_{(0.05)}$	2.127	1.936	2.671	2.058	1.562	1.968	2.081	2.438
CV (%)	13.31	8.83	9.48	7.14	9.44	7.58	7.17	8.30

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 5: Effect of interaction between mulch types and fertilizer rates on height (cm) at different days after transplanting.

		Height (cm)							
Mulch type	**NPK rate**	Season I				Season II			
		30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	0kg ha^{-1}	15.87^{ns}	21.54^{ns}	29.48^{ns}	28.26^{ns}	16.90^{ns}	26.52^{ns}	29.14^{ns}	27.69^{ns}
	60kg ha^{-1}	15.78	23.26	31.74	31.58	14.02	22.92	25.33	26.39
	120kg ha^{-1}	16.17	22.14	27.60	28.47	13.31	22.15	24.77	26.08
	180kg ha^{-1}	15.73	22.25	28.39	28.12	11.73	19.60	23.41	28.64
Black plastic	0kg ha^{-1}	14.41	21.28	26.98	30.78	19.60	30.01	32.76	32.09
	60kg ha^{-1}	15.34	24.06	30.75	32.34	17.31	27.86	30.20	30.84
	120kg ha^{-1}	14.77	22.44	28.14	28.74	18.69	27.26	31.39	32.37
	180kg ha^{-1}	12.04	18.24	25.12	27.62	15.17	23.32	28.29	28.92
Wheat straw	0kg ha^{-1}	19.60	22.93	31.10	31.44	20.41	30.42	32.99	31.65
	60kg ha^{-1}	19.79	24.38	30.07	30.78	18.03	29.89	33.49	32.39
	120kg ha^{-1}	19.87	24.38	28.34	28.27	19.65	30.07	32.73	30.95
	180kg ha^{-1}	16.77	22.24	27.89	27.33	18.25	28.77	31.92	32.30
LSD $_{(0.05)}$		3.666	3.337	4.603	3.547	2.692	3.393	3.587	4.202
CV (%)		13.31	8.83	9.48	7.14	9.44	7.58	7.17	8.30

Key: DAT= days after transplanting. ns: Means within column are not significantly different ($P < 0.05$).

4.1.2 Effect of mulch type, fertilizer rate and their interactions on cabbage stem diameter

Effect of mulch type

Effect of mulch type on cabbage stem diameter development was significant (P<0.05) (Table 6). In season I, at 30 DAT, bare soil (8.48 mm) and wheat straw mulch (8.41 mm) had significantly higher means than black plastic mulch (7.02 mm) (Table 6). In season II, wheat straw mulch and black plastic mulch had significantly higher stem diameter than bare soil from 30 DAT until cabbages attained commercial maturity (Table 6).

Effect of fertilizer rate

Fertilizer rate had no significant effect (P<0.05) on stem diameter in all DAT in season I. In season II, rates of 0, 60 and 120 kg ha^{-1} had significantly higher means than 180 kg ha^{-1} at 30 and 60 DAT. Application rates of 0 and 60 kg ha^{-1} at 45 DAT and 60 kg ha^{-1} at 75 DAT, had significantly higher values than 180 $kgha^{-1}$ (Table 6).

Effect of interaction between mulch type and fertilizer rate

Interaction between mulch and fertilizer in season I did not show any significant differences (P<0.05) in cabbage stem diameter in all DAT, and at 75 DAT in season II and was significant at 30, 45 and 60 in season II (Table 7). Bare soil with no fertilizer (0 kg ha^{-1}); black plastic with 0, 60 and 120 kg ha^{-1} rates, and wheat straw mulch with all fertilizer rates (0, 60, 120 and 180 kg ha^{-1}), had significantly higher values at 30, 45 and at 60 DAT in season II (Table7).

Table 6: Effect of mulch type and fertilizer rates on stem diameter (mm) at different days after transplanting**.**

	Stem diameter (mm)							
Treatment	Season I				Season II			
Mulch type	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	8.48^{a}	15.36^{ns}	20.82^{ns}	26.07^{ns}	9.89^{c}	14.46^{b}	19.53^{b}	26.00^{b}
Black plastic	7.02^{b}	14.91	20.88	27.05	11.05^{b}	17.46^{a}	22.36^{a}	29.28^{a}
Wheat straw	8.41^{a}	15.43	21.97	25.78	11.82^{a}	18.51^{a}	22.88^{a}	29.85^{a}
LSD $_{(0.05)}$	1.010	1.595	1.935	1.918	0.764	1.230	1.242	1.682
CV (%)	14.97	12.37	10.77	8.61	8.26	8.64	6.80	7.00
NPK rate								
0kg ha^{-1}	7.94^{ns}	15.13^{ns}	21.50^{ns}	26.69^{ns}	11.74^{a}	18.08^{a}	22.68^{a}	29.21^{ns}
60kg ha^{-1}	8.07	15.79	21.91	26.54	10.83^{b}	16.91^{a}	21.78^{a}	29.37
120kg ha^{-1}	8.28	15.24	21.23	26.25	11.32^{ab}	16.82^{ab}	21.80^{a}	27.61
180kg ha^{-1}	7.60	14.78	20.25	25.72	9.77^{c}	15.42^{b}	20.10^{b}	27.32
LSD $_{(0.05)}$	1.166	1.842	2.234	2.215	0.882	1.421	1.435	1.942
CV (%)	14.97	12.37	10.77	8.61	8.26	8.64	6.80	7.00

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 7: Effect of interaction between mulch types and fertilizer rates on stem diameter (mm) at different days after transplanting.

		Stem diameter (mm)							
Mulch type	**NPK rate**	Season I				Season II			
		30 DAT	45 DAT	60DAT	75 DAT	30 DAT	45 DAT	60DAT	75 DAT
No mulch	0kg ha^{-1}	8.64^{ns}	16.01^{ns}	22.95^{ns}	26.89^{ns}	11.89^{a}	17.30^{abc}	22.70^{ab}	27.98^{ns}
	60kg ha^{-1}	8.02	14.99	18.94	24.94	10.10^{b}	15.00^{cd}	19.06^{d}	27.51
	120kg ha^{-1}	8.84	14.71	20.79	25.96	9.82^{c}	14.47^{d}	20.01^{cd}	24.82
	180kg ha^{-1}	8.41	15.73	20.58	26.51	7.73^{d}	11.07^{e}	16.34^{e}	23.70
Black plastic	0kg ha^{-1}	7.07	15.01	19.62	26.54	11.46^{ab}	17.95^{ab}	22.80^{ab}	31.19
	60kg ha^{-1}	7.61	16.07	22.70	28.35	10.76^{ab}	17.42^{abc}	22.80^{ab}	29.63
	120kg ha^{-1}	7.57	15.07	20.89	26.68	12.00^{a}	17.92^{ab}	23.38^{a}	28.97
	180kg ha^{-1}	5.86	13.50	20.29	26.63	9.95^{b}	16.53^{bcd}	20.47^{cd}	27.32
Wheat straw	0kg ha^{-1}	8.12	14.38	21.91	26.66	11.88^{a}	18.99^{a}	22.54^{ab}	28.45
	60kg ha^{-1}	8.57	16.31	24.08	26.34	11.63^{a}	18.32^{ab}	23.46^{a}	30.98
	120kg ha^{-1}	8.42	15.92	21.99	26.09	12.14^{a}	18.08^{ab}	22.00^{abc}	29.03
	180kg ha^{-1}	8.54	15.11	19.90	24.03	11.64^{a}	18.65^{ab}	23.49^{a}	30.93
LSD $_{(0.05)}$		2.011	3.176	3.851	3.818	1.520	2.449	2.473	3.348
CV (%)		14.97	12.37	10.77	8.61	8.26	8.64	6.80	7.00

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

4.1.3 Effect of mulch type, fertilizer rate and their interactions on cabbage leaf area

Effect of mulch type

There was a significant effect ($P<0.05$) of mulch type on cabbage leaf area in both seasons (Table 8). Wheat straw mulch had the highest leaf area than black plastic and bare soil at 30 (131.89 cm^2) and 60 DAT (596.66 cm^2) in season I. Both bare soil and wheat straw mulch had higher values than black plastic mulch at 45 DAT. Both wheat straw and black plastic mulches had higher leaf area than bare soil at 75 DAT in season I. In season II, both wheat straw and black plastic mulches had significantly higher leaf area than control (bare soil) Table 8).

Effect of fertilizer rate

Effect of fertilizer rate on cabbage leaf area was significant ($P<0.05$) in both seasons (Table 8). In season I application of 60 kg ha^{-1} at 30, 60 and 75 DAT and both 60 and 120 $kgha^{-1}$ at 45 DAT significantly increased leaf area. In season II application of 0, 60 and 120 kg ha^{-1} increased leaf area at 30, 60 and 75 DAT contrarily to 180 $kgha^{-1}$which decreased leaf area (Table 8). At 45 DAT in season II the values were significantly lower at application rates of 180 kg ha^{-1} compared to other rates.

Effect of interaction between mulch type and fertilizer rate

Effect of interaction was not significant ($P<0.05$) in both seasons but treatments combinations with 0 and 180$kgha^{-1}$ (F0 and F3) had the lowest mean leaf area (Table 9).

Table 8: Effect of mulch type and fertilizer rates on leaf area (cm^2) at different days after transplanting.

	Leaf area (cm^2)							
Treatments	**Season I**				**Season II**			
Mulch type	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	108.61^{b}	285.71^{a}	524.88^{b}	587.67^{b}	95.46^{b}	325.44^{b}	468.85^{b}	533.60^{b}
Black plastic	98.09^{b}	255.05^{b}	522.24^{b}	631.75^{a}	152.25^{a}	455.85^{a}	667.49^{a}	706.97^{a}
Wheat straw	131.89^{a}	287.30^{a}	596.66^{a}	640.57^{a}	155.80^{a}	486.22^{a}	710.89^{a}	711.60^{a}
LSD $_{(0.05)}$	14.320	23.149	33.757	35.491	21.146	69.497	69.897	79.676
CV (%)	14.99	9.91	7.28	6.76	18.57	19.43	13.41	14.46
NPK rate								
0kg ha^{-1}	97.83^{b}	261.28^{b}	547.13^{b}	582.88^{b}	156.51^{a}	470.56^{a}	673.87^{a}	662.54^{ns}
60kg ha^{-1}	135.20^{a}	304.70a	624.74^{a}	703.79^{a}	130.53^{b}c	421.80^{ab}	629.65^{a}	636.30
120kg ha^{-1}	111.25^{b}	279.21^{ab}	537.67^{b}	608.79^{b}	143.36^{ab}	451.88^{a}	628.39^{a}	671.97
180kg ha^{-1}	107.17^{b}	258.90^{b}	482.18^{c}	584.52^{b}	107.60^{c}	345.77^{b}	531.06^{b}	632.08
LSD $_{(0.05)}$	16.536	26.731	38.979	40.981	24.417	80.249	80.711	92.002
CV (%)	14.99	9.91	7.28	6.76	18.57	19.43	13.41	14.46

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 9: Effect of interaction between mulch types and fertilizer rates on leaf area (cm^2) at different days after transplanting.

		Leaf area (cm^2)							
Mulch type	**NPK rate**	Season I				Season II			
		30 DAT	45 DAT	60DAT	75 DAT	30 DAT	45 DAT	60DAT	75 DAT
No mulch	0kg ha^{-1}	93.92^{ns}	267.59^{ns}	515.20^{ns}	553.83^{ns}	134.09^{ns}	428.42^{ns}	587.96^{ns}	600.81^{ns}
	60kg ha^{-1}	121.66	291.31	591.29	682.12	91.91	304.46	461.38	487.20
	120kg ha^{-1}	101.74	298.52	482.33	549.66	96.28	363.48	451.95	513.25
	180kg ha^{-1}	117.13	285.41	510.72	565.08	59.55	205.40	374.10	533.13
Black plastic	0kg ha^{-1}	84.65	243.50	512.02	549.73	165.15	477.21	748.61	734.45
	60kg ha^{-1}	128.27	299.49	593.38	742.12	148.05	458.82	674.10	670.37
	120kg ha^{-1}	110.73	270.41	551.54	636.89	177.56	486.25	702.52	763.98
	180kg ha^{-1}	68.70	206.82	432.02	598.25	118.22	401.12	544.74	659.06
Wheat straw	0kg ha^{-1}	114.93	272.75	614.17	645.09	170.30	506.06	685.03	652.37
	60kg ha^{-1}	155.66	323.29	689.55	687.12	151.64	502.11	753.48	751.33
	120kg ha^{-1}	121.27	268.70	579.14	639.82	156.24	505.91	730.72	738.67
	180kg ha^{-1}	135.68	284.46	503.79	590.22	145.02	430.79	674.33	704.04
LSD $_{(0.05)}$		28.504	46.078	67.192	70.644	42.091	138.333	139.129	158.593
CV (%)		14.99	9.91	7.28	6.76	18.57	19.43	13.41	14.46

Key: DAT= days after transplanting ns: Means within column are not significantly different ($P < 0.05$).

4.1.4 Effect of mulch type, fertilizer rate and their interactions on number of leaves

Effect of mulch type

Mulch types had a significant effect ($P<0.05$) on number of leaves (Table 10). In season I; wheat straw mulch had the highest number of leaves i.e. 11.33, 18 and 18.08 at 30, 60 and 75 DAT, respectively but were not significantly different from black plastic mulch at the same periods (11.17, 17.58, and 17.75). Black plastic mulch had the highest mean (15.17) at 45 DAT in season I and the control which is bare soil had the lowest number of leaves at 45, 60 and 75 DAT. At 30 DAT the difference in number of leaves between bare soil and black plastic mulch was not statistically significant but were lower than wheat straw mulch. In season II; black plastic mulch had the highest means of 12.17 and 18.08 at 30 and 60 DAT, respectively. The means for black plastic were not different from straw mulch at 45 DAT but were higher than for bare soil. At 75 DAT in season II the number of leaves was not statistically significant among mulch treatments (Table 10).

Effect of fertilizer rates

Fertilizer application was significant ($P<0.05$) in both seasons (Table 10). In season I; highest means observed were 11.56 and 11.44 for 120 kg ha^{-1} (F2) and 0 kg ha^{-1} (F0), respectively at 30 DAT, 15.11 for 60 kg ha^{-1} (F1) at 45 DAT. The lowest values were 10.44 at 30 DAT observed at 180kg ha^{-1} ,14.11 and 14.00 using 120 and 180kg ha^{-1}, respectively) at 45 DAT. In season II significantly higher means were obtained with application rates of 0 and 120 kg ha^{-1} at 30 DAT; 0, 60 and 120 $kgha^{-1}$ at 45 DAT. The rate of 180$kgha^{-1}$ had the lowest means at 30 DAT and rates of 60 and 180 $kgha^{-1}$ the least at 45 DAT. (Table10).

Effect of interaction between mulch types and fertilizer rates

Interactions were significant ($P < 0.05$) at 30, 45 and 60 DAT in season I and were not significant in season II. In season I; higher values observed were 12.33, 16.33 and 19.00 respectively for wheat straw mulch combined with 0$kgha^{-1}$ (M2F0) at 30 DAT, black plastic mulch with 60$kgha^{-1}$ (M1F1) at 45 DAT and black plastic mulch with 120$kgha^{-1}$ (M1F2) at 60 DAT; For same DATs lowest values were 10.00, 13.33 and 16.00 respectively for bare soil with 60$kgha^{-1}$ (M0F1), bare soil with 120$kgha^{-1}$ (M0F2) and bare soil with 60$kgha^{-1}$ (M0F1) (Table11).

Table 10: Effect of mulch type and fertilizer rates on number of leaves at different days after transplanting.

	Number of leaves							
Treatments	**Season I**				**Season II**			
Mulch type	30DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	10.83^{b}	13.75^{c}	16.33^{b}	16.50^{b}	10.42^{b}	15.08^{b}	16.42^{b}	18.33^{ns}
Black plastic	11.17^{ab}	15.17^{a}	17.58^{a}	17.75^{a}	12.17^{a}	16.33^{a}	18.08^{a}	18.83
Wheat straw	11.33^{a}	14.42^{b}	18.00^{a}	18.08^{a}	11.08^{b}	15.83^{ab}	16.92^{b}	17.92
LSD $_{(0.05)}$	0.343	0.464	0.919	0.839	0.842	0.817	0.713	1.077
CV (%)	3.65	3.80	6.28	5.68	8.87	6.13	4.91	6.93
NPK rate								
0kg ha^{-1}	11.44^{a}	14.56^{b}	17.22^{ns}	17.44^{ns}	12.11^{a}	16.56^{a}	17.33^{ns}	17.67^{ns}
60kg ha^{-1}	11.00^{b}	15.11^{a}	17.56	18.00	11.11^{bc}	15.67^{ab}	17.44	18.78
120kg ha^{-1}	11.56^{a}	14.11^{bc}	17.56	16.78	11.44^{ab}	15.89^{a}	17.33	18.00
180kg ha^{-1}	10.44^{c}	14.00^{c}	16.89	17.56	10.22^{c}	14.89^{b}	16.44	19.00
LSD $_{(0.05)}$	0.396	0.536	1.062	0.969	0.973	0.944	0.824	1.244
CV (%)	3.65	3.80	6.28	5.68	8.87	6.13	4.91	6.93

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 11: Effect of interaction between mulch types and fertilizer rates on number of leaves at different days after transplanting.

		Number of leaves							
Mulch type	**NPK rate**	Season I				Season II			
		30 DAT	45 DAT	60DAT	75 DAT	30 DAT	45 DAT	60DAT	75 DAT
No mulch	0kg ha^{-1}	11.00^{cde}	14.00^{de}	17.33^{abc}	17.00^{ns}	12.00^{ns}	17.00^{ns}	17.33^{ns}	17.33^{ns}
	60kg ha^{-1}	10.00^{f}	13.67^{de}	16.00^{cd}	17.00	10.67	15.00	16.67	20.00
	120kg ha^{-1}	12.00^{ab}	13.33^{e}	15.33^{d}	15.67	10.33	14.67	16.00	17.67
	180kg ha^{-1}	10.33^{ef}	14.00^{de}	16.67^{bcd}	16.33	8.67	13.67	15.67	18.33
Black plastic	0kg ha^{-1}	11.00^{cde}	15.33^{b}	16.33^{bcd}	17.33	12.67	16.67	17.67	17.67
	60kg ha^{-1}	11.67^{abc}	16.33^{a}	17.67^{abc}	18.00	12.00	16.33	18.67	18.67
	120kg ha^{-1}	11.67^{abc}	15.00^{bc}	19.00^{a}	17.00	13.00	17.00	18.67	18.67
	180kg ha^{-1}	10.33^{ef}	14.00^{de}	17.33^{abc}	18.67	11.00	15.33	17.33	20.33
Wheat straw	0kg ha^{-1}	12.33^{a}	14.33^{cd}	18.00^{ab}	18.00	11.67	16.00	17.00	18.00
	60kg ha^{-1}	11.33^{bcd}	15.33^{b}	19.00^{a}	19.00	10.67	15.67	17.00	17.67
	120kg ha^{-1}	11.00^{cde}	14.00^{de}	18.33^{a}	17.67	11.00	16.00	17.33	17.67
	180kg ha^{-1}	10.67^{def}	14.00^{de}	16.67^{bcd}	17.67	11.00	15.67	16.33	18.33
LSD $_{(0.05)}$		0.683	0.924	1.830	1.670	1.677	1.627	1.420	2.144
CV (%)		3.65	3.80	6.28	5.68	8.87	6.13	4.91	6.93

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

4.1.5 Effect of mulch type, fertilizer rate and their interactions on Leaf Area Index (LAI)

Effect of mulch types

The effects mulch type on LAI was significant (P<0.05) in both seasons (Table 12). In season I, wheat straw mulch had significantly higher values (0.424 and 2.977) at 30 and 60 DAT respectively, than black plastic and bare soil. At 75 DAT LAI was significantly higher in wheat straw and black plastic mulch. In season I, black plastic mulch and bare soil means were not significantly different for all DAT. In season II, black plastic and wheat straw mulch had significantly higher means in all DAT. The control (bare soil) had the lowest mean LAI of 0.284, 1.374, 2.171 and 2.686 at 30, 45, 60 and 75 DAT, respectively (Table 12).

Effect of fertilizer rates

Effect of fertilizer rates on LAI was significant (P<0.05) in both seasons (Table 12). In season I, fertilizer rate of 60 kg ha^{-1} had significantly higher LAI values for all DAT. The values were 0.419, 1.284, 3.011 and 3.478 for 30, 45, 60 and 75 DAT, respectively. The means for other rates were not significantly different during these periods. In season II, application rates of 0 and 120 kg ha^{-1} at 30 DAT; 0, 60 and 120 at both 45 and 60 DAT, had significantly higher values. In season II, the least values were found in 60 and 180 kg ha^{-1} at 30 and 45 DAT and 180 kg ha^{-1} at 60 DAT (Table 12). At 75 DAT in season II, LAI did not differ significantly among fertilizer rates, but slightly higher values obtained for 180 kg ha^{-1}.

Effect of interaction between mulch types and fertilizer rates

The effect of interaction between mulch and fertilizer on LAI was significant in season I with wheat straw mulch and 60 $kgha^{-1}$ (M2F1) having highest value 0.483, 1.407 and 3.677 respectively at 30, 45 and 60 DAT (Table13).

Table 12: Effect of mulch types and fertilizer rates on leaf area index (LAI) at different days after transplanting.

	Leaf area index (LAI)							
Treatment	Season I				Season II			
Mulch type	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
No mulch	0.320^{b}	1.128	2.345^{b}	2.738^{b}	0.284^{b}	1.374^{b}	2.171^{b}	2.686^{b}
Black plastic	0.306^{b}	1.090	2.546^{b}	2.971^{ab}	0.518^{a}	2.101^{a}	3.369^{a}	3.685^{a}
Wheat straw	0.424^{a}	1.183	2.977^{a}	3.188^{a}	0.485^{a}	2.138^{a}	3.340^{a}	3.514^{a}
LSD $_{(0.05)}$	0.053	0.080	0.318	0.319	0.091	0.359	0.366	0.483
CV (%)	17.80	8.29	14.31	12.71	24.9	22.67	14.59	17.32
NPK rate								
0kg ha^{-1}	0.312^{b}	1.109^{b}	2.584^{b}	2.758^{b}	0.531^{a}	2.169^{a}	3.254^{a}	3.230^{ns}
60kg ha^{-1}	0.419^{a}	1.284^{a}	3.011^{a}	3.478^{a}	0.403^{bc}	1.846^{ab}	3.032^{a}	3.262
120kg ha^{-1}	0.344^{b}	1.092^{b}	2.542^{b}	2.763^{b}	0.460^{ab}	2.011^{a}	3.081^{a}	3.342
180kg ha^{-1}	0.324^{b}	1.048^{b}	2.352^{b}	2.864^{b}	0.322^{c}	1.458^{b}	2.472^{b}	3.346
LSD $_{(0.05)}$	0.061	0.092	0.367	0.368	0.105	0.415	0.422	0.558
CV (%)	17.80	8.29	14.31	12.71	24.9	22.67	14.59	17.32

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 13: Effect of interaction between mulch types and fertilizer rates on leaf area index (LAI) at different days after transplanting

		Leaf area index (LAI)							
Mulch type	**NPK rate**	Season I				Season II			
		30 DAT	45 DAT	60DAT	75 DAT	30 DAT	45 DAT	60DAT	75 DAT
No mulch	0kg ha^{-1}	0.287^{def}	1.187^{bc}	2.560^{bcd}	2.477^{ns}	0.447^{ns}	1.973^{ns}	2.833^{ns}	2.893^{ns}
	60kg ha^{-1}	0.347^{cde}	1.107^{c}	2.473^{bcd}	3.633	0.260	1.273	2.137	2.690
	120kg ha^{-1}	0.317^{de}	1.030^{c}	2.063^{d}	2.300	0.277	1.480	2.057	2.463
	180kg ha^{-1}	0.330^{cde}	1.187^{bc}	2.283^{cd}	2.543	0.153	0.770	1.657	2.697
Black plastic	0kg ha^{-1}	0.260^{ef}	1.100^{c}	2.127^{d}	2.603	0.587	2.270	3.693	3.607
	60kg ha^{-1}	0.427^{abc}	1.340^{ab}	2.883^{bc}	3.377	0.493	2.077	3.460	3.450
	120kg ha^{-1}	0.347^{cde}	1.130^{c}	2.817^{bc}	2.840	0.630	2.307	3.673	3.907
	180kg ha^{-1}	0.190^{f}	0.790^{d}	2.357^{cd}	3.063	0.363	1.750	2.650	3.777
Wheat straw	0kg ha^{-1}	0.390^{abcd}	1.040^{c}	3.067^{ab}	3.193	0.560	2.263	3.237	3.190
	60kg ha^{-1}	0.483^{a}	1.407^{a}	3.677^{a}	3.423	0.457	2.187	3.500	3.647
	120kg ha^{-1}	0.370^{bcd}	1.117^{c}	2.747^{bcd}	3.150	0.473	2.247	3.513	3.657
	180kg ha^{-1}	0.453^{ab}	1.167^{c}	2.417^{cd}	2.987	0.450	1.853	3.110	3.563
LSD $_{(0.05)}$		0.105	0.158	0.632	0.635	0.180	0.715	0.728	0.962
CV (%)		17.80	8.29	14.31	12.71	24.9	22.67	14.59	17.32

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different (P < 0.05). ns: Means within column are not significantly different (P < 0.05).

4.1.6 Effect of mulch type, fertilizer rate and their interactions on cabbage head diameter

Effect of mulch type

Effect of mulch types on head diameter was significant ($P<0.05$) in both seasons (Table 14). Bare soil had significantly lower means 12.20 and 19.35 cm in season I at 60 and 90 DAT, respectively and 8.11, 13.45 and 20.48 cm in season II at 60,75 and 90 DAT, respectively, compared to black plastic and wheat straw mulch (Table 14). In season I, cabbage head diameter in bare soil and wheat straw mulch was not statistically different at 75 DAT ($P<0.05$) (Table 14). During these periods (seasons I and II), the head diameter of cabbages from plots covered with wheat straw and black plastic mulch were not statistically different (Table 14).

Effect of fertilizer rates

Fertilizer rates significantly ($P<0.05$) influenced cabbage head diameter (Table 14). In season I application rates of 0 and 60kgha^{-1} at 75 DAT and 60 kg ha^{-1} at 90 DAT had the highest means. In season II, application of 0 and 120 kg ha^{-1} at 60 DAT, 0, 60 and 120kgha^{-1} at 75 DAT and 120 kgha^{-1} at 90 DAT had significantly higher means. Application of 180kgha^{-1} had the lowest means in both seasons (Table14).

Effect of interaction between mulch types and fertilizer rates

Interactions between mulch and fertilizer on head diameter were significant in both seasons. In season I at 60 DAT; higher means observed were (14.90, 14.79, 14.44 and 13.75cm) for black plastic with 120 kgha^{-1}(M1F2) , wheat straw with 0 kgha^{-1}(M2F0), wheat straw with 60 kgha^{-1} (M2F1) and black plastic with 60 kgha^{-1} (M1F1) respectively. In season II at 75DAT higher mean for head diameter were (20.39, 19.31 and 19.31cm) observed for black plastic with 120 kgha^{-1} (M1F2), black plastic with 60 kgha^{-1} (M1F1) and wheat straw with 60 kgha^{-1} (M2F1). At 90DAT in season II; higher value was 26.80cm for black plastic with 120 kgha^{-1} (M1F2) (Table15).

Table 14: Effect of mulch types and fertilizer rates on head diameter at different days after transplanting.

Head diameter (cm)						
Treatments	Season I			Season II		
Mulch type	60 DAT	75 DAT	90 DAT	60 DAT	75 DAT	90 DAT
No mulch	12.20^{b}	18.78^{b}	19.35^{b}	8.11^{b}	13.45^{b}	20.48^{b}
Black plastic	13.42^{a}	20.52^{a}	21.13^{a}	11.69^{a}	18.42^{a}	23.49^{a}
Wheat straw	13.34^{a}	19.75^{ab}	21.20^{a}	11.61^{a}	18.10^{a}	23.49^{a}
LSD $_{(0.05)}$	0.910	1.298	1.089	0.900	0.921	0.940
CV (%)	8.28	7.79	6.26	10.15	6.53	4.94
NPK rate						
0kg ha^{-1}	13.32^{ns}	19.78^{ab}	20.19^{b}	11.43^{a}	16.98^{a}	22.18^{b}
60kg ha^{-1}	13.16	21.26^{a}	22.00^{a}	10.26^{b}	17.05^{a}	22.34^{b}
120kg ha^{-1}	13.27	19.41^{b}	20.26^{b}	11.12^{ab}	17.76^{a}	23.53^{a}
180kg ha^{-1}	12.19	18.29^{b}	19.77^{b}	9.08^{c}	14.85^{b}	21.89^{b}
LSD $_{(0.05)}$	1.051	1.499	1.258	1.039	1.064	1.086
CV (%)	8.28	7.79	6.26	10.15	6.53	4.94

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 15: Effect of interaction between mulch types and fertilizer rates on head diameter (cm) at different days after transplanting

		Head diameter (cm)					
Mulch type	**NPK rate**	Season I			Season II		
		60 DAT	75 DAT	90 DAT	60 DAT	75 DAT	90DAT
No mulch	0kg ha^{-1}	12.67^{bcd}	19.54^{ns}	19.40^{ns}	9.71^{ns}	15.36^{de}	22.10^{cd}
	60kg ha^{-1}	11.28^{d}	20.80	20.46	8.29	12.54^{f}	19.88^{e}
	120kg ha^{-1}	12.64^{bcd}	18.08	19.42	7.58	14.99^{e}	20.37^{de}
	180kg ha^{-1}	12.22^{cd}	16.69	18.12	6.85	10.93^{f}	19.57^{e}
Black plastic	0kg ha^{-1}	12.51^{cd}	18.60	19.27	12.69	18.42^{bc}	22.03^{cd}
	60kg ha^{-1}	13.75^{abc}	22.32	23.01	10.85	19.31^{ab}	22.72^{bc}
	120kg ha^{-1}	14.90^{a}	20.55	20.72	13.59	20.39^{a}	26.80^{a}
	180kg ha^{-1}	12.51^{cd}	20.62	21.51	9.64	15.58^{de}	22.41^{c}
Wheat straw	0kg ha^{-1}	14.79^{a}	21.18	21.91	11.88	17.15^{cd}	22.40^{c}
	60kg ha^{-1}	14.44^{ab}	20.65	22.53	11.63	19.31^{ab}	24.44^{b}
	120kg ha^{-1}	12.28^{cd}	19.59	20.66	12.91	17.91^{bc}	23.42^{bc}
	180kg ha^{-1}	11.85^{d}	17.57	19.69	10.74	18.04^{bc}	23.69^{bc}
LSD $_{(0.05)}$		1.811	2.584	2.168	1.792	1.834	1.871
CV (%)		8.28	7.79	6.26	10.15	6.53	4.94

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

4.1.7 Effect of mulch type, fertilizer rate and their interactions on Rosette diameter

Effect of mulch types

Effect of mulch type on rosette diameter was not significant ($P<0.05$) in season I. At 60 and 75 DAT in season II; wheat straw and black plastic had significantly higher means than bare soil (Table16).

Effect of fertilizer rate

Effect of fertilizer rate was significant ($P<0.05$) in season I at 60 and 75 DAT and season II at 60 DAT. It was not significant at 75 DAT (Table 17). Application of 60 $kgha^{-1}$ (F1) had the highest values in season I at both sampling periods. Diameters obtained were 53.28 and 57.15 cm at 60 and 75 DAT, respectively. In season II application of 180 $kgha^{-1}$ had the lowest rosette diameter (51.34cm) at 60 DAT (Table16).

Effect of interactions between mulch types and fertilizer rates

Interactions were significant ($P<0.05$) at 75 DAT in both seasons and were not significant at 60DAT in both seasons. In season I; higher values recorded were 58.04, 57.04, 56.71, 56.69, 55.46 and 55.10 cm for bare soil and 60$kgha^{-1}$,wheat straw mulch and 0$kgha^{-1}$, wheat straw mulch and 60$kgha^{-1}$, black plastic and 60$kgha^{-1}$, black plastic and 180$kgha^{-1}$ and black plastic and 120$kgha^{-1}$ respectively at 75DAT. In season II; higher values of 64.77, 63.10, 62.57, 62.21, 61.28 and 60.27 cm were recorded for wheat straw mulch and 60$kgha^{-1}$, black plastic and 120$kgha^{-1}$, wheat straw and 120$kgha^{-1}$, black plastic and 60$kgha^{-1}$, black plastic and 0$kgha^{-1}$ and wheat straw mulch and 180$kgha^{-1}$ respectively at 75 DAT (Table17).

Table 16: Effect of mulch type and fertilizer rates on rosette diameter at different days after transplanting.

Rosette diameter (cm)				
Treatment	Season I		Season II	
Mulch type	60 DAT	75 DAT	60 DAT	75 DAT
No mulch	50.49^{ns}	52.81^{ns}	47.92^{b}	53.93^{b}
Black plastic	51.71	54.66	56.61^{a}	60.66^{a}
Wheat straw	50.55	54.72	57.41^{a}	61.83^{a}
LSD $_{(0.05)}$	2.100	1.791	2.043	2.531
CV (%)	4.87	3.91	4.47	5.08
NPK rate				
0kg ha^{-1}	50.42^{b}	53.39^{b}	55.54^{a}	59.50^{ns}
60kg ha^{-1}	53.28^{a}	57.15^{a}	54.79^{a}	59.45
120kg ha^{-1}	49.53^{b}	52.83^{b}	54.25^{a}	59.55
180kg ha^{-1}	50.45^{b}	52.88^{b}	51.34^{b}	56.72
LSD $_{(0.05)}$	2.425	2.068	2.359	2.922
CV (%)	4.87	3.91	4.47	5.08

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Table 17: Effect of interaction between mulch types and fertilizer rates on rosette diameter at different days after transplanting

		Rosette diameter (cm)			
Mulch type	NPK rate	Season I		Season II	
		60DAT	75 DAT	60DAT	75 DAT
No mulch	0kg ha^{-1}	49.13^{ns}	51.77^{cdef}	50.4^{ns}	57.52^{cde}
	60kg ha^{-1}	53.29	58.04^{a}	48.42	51.35^{f}
	120kg ha^{-1}	49.18	48.71^{f}	46.60	52.98^{ef}
	180kg ha^{-1}	50.37	52.73^{bcde}	46.24	53.86^{ef}
Black plastic	0kg ha^{-1}	50.01	51.37^{def}	58.65	61.28^{abc}
	60kg ha^{-1}	55.09	56.69^{a}	56.43	62.21^{abc}
	120kg ha^{-1}	50.15	55.10^{abc}	59.27^{a}	63.10^{ab}
	180kg ha^{-1}	51.61	55.46^{ab}	52.08	56.04^{def}
Wheat straw	0kg ha^{-1}	52.13	57.04^{a}	57.55	59.72^{bcd}
	60kg ha^{-1}	51.44	56.71^{a}	59.51	64.77^{a}
	120kg ha^{-1}	49.25	54.69^{abcd}	56.88	62.57^{ab}
	180kg ha^{-1}	49.37	50.44^{ef}	55.69	60.27^{abcd}
LSD $_{(0.05)}$		4.180	3.564	4.066	5.038
CV (%)		4.87	3.91	4.47	5.08

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different (P < 0.05). ns: Means within column are not significantly different (P < 0.05).

4.1.8 Effect of mulch type, fertilizer rate and their interactions on cabbage yield (weight per cabbage head)

Effect of mulch types

The effect of mulch type was significant (P<0.05) on cabbage yield (Table 18). Wheat straw and black plastic mulch had significantly higher mean weight per cabbage head and bare soil the least in both seasons (Table 18). The means for wheat straw were significantly higher than for black plastic mulch in season I. The values for season I were 3462.50g for wheat straw mulch, 3075.00g for black plastic and 2723.60g for bare soil (Table 18). For season II the head weight per plant were 4215.90g, 4203.40g and 2639.40g for black plastic, wheat straw mulch and bare soil, respectively. There was no significant difference in yield between the plastic and wheat straw mulch types in season II (Table18).

Effect of fertilizer rates

Fertilizer rate effect on means weight of cabbage heads were significant ($P<0.05$) (Table 18). In season I; application of 60kgha^{-1} (F1) had the highest mean weight per cabbage head (3399.20g) whereas in season II it was 120kgha^{-1} (F2) with 3994.90g obtained (Table18).

Effect of interaction between mulch types and fertilizer rates

Interactions effects were significant only in season II. Highest values for head weight per plant observed were 4850.44g and 4542.67g for black plastic mulch and 120kgha^{-1} (M1F2) and for wheat straw mulch and 120kgha^{-1} (M2F2) respectively (Table19).

Table 18: Effect of mulch type and fertilizer rates on head weight per cabbage at commercial maturity (90DAT)

Treatment	**Head weight (g per pant)**	
Mulch type	Season I	Season II
No mulch	2723.60^{c}	2639.40^{b}
Black plastic	3075.00^{b}	4215.90^{a}
Wheat straw	3462.50^{a}	4203.40^{a}
LSD $_{(0.05)}$	255.660	259.510
CV (%)	9.78	8.32
NPK rate		
0kg ha^{-1}	2898.40^{b}	3590.30^{b}
60kg ha^{-1}	3399.20^{a}	3600.20^{b}
120kg ha^{-1}	3063.90^{b}	3994.90^{a}
180kg ha^{-1}	2986.60^{b}	3559.40^{b}
LSD $_{(0.05)}$	295.210	299.66
CV (%)	9.78	8.32

Key: Means with the same letter within columns are not significantly different ($P < 0.05$).

Table 19: Effect of interaction between mulch and fertilizer on head weight at commercial maturity

		Head weight (g per plant)	
Mulch type	**NPK rate**	Season I	Season II
No mulch	0kg ha^{-1}	2416.00^{ns}	3004.17^{d}
	60kg ha^{-1}	2958.33	2404.17^{e}
	120kg ha^{-1}	2675.00	2591.67^{de}
	180kg ha^{-1}	2845.00	2557.50^{de}
Black plastic	0kg ha^{-1}	2816.67	3987.50^{c}
	60kg ha^{-1}	3579.17	4154.67^{bc}
	120kg ha^{-1}	2839.50	4850.44^{a}
	180kg ha^{-1}	3064.67	3870.83^{c}
Wheat straw	0kg ha^{-1}	3462.50	3779.17^{c}
	60kg ha^{-1}	3660.17	4241.67^{bc}
	120kg ha^{-1}	3677.17	4542.67^{ab}
	180kg ha^{-1}	3050.00	4250.00^{bc}
LSD $_{(0.05)}$		508.876	516.555
CV (%)		9.78	8.32

Key: Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

4.2 Effect of mulch type, fertilizer rate and their interactions on N, P and K uptake by cabbage

4.2.1 Effect of mulch type, fertilizer rate and their interactions on N uptake by cabbage

Effect of mulch type

Effect of mulch type was significant on N uptake in both seasons. Black plastic mulch had significantly higher nitrogen uptake (49.78 $kgha^{-1}$) compared to wheat straw mulch and bare soil, in season I (Table 20). In season II, wheat straw (74.49 kg ha^{-1}) and black plastic (63.54 $kgha^{-1}$) had higher nitrogen uptake compared to the control (45.42 $kgha^{-1}$) (Table 20).

Effect of fertilizer rate

Effect of fertilizer rates was not significant on N uptake in both seasons. N uptake was slightly higher (46.35 kg N ha^{-1}) and (65.40kg N ha^{-1}) respectively in in season I and II with application rate of 120 kg ha^{-1} and slightly lower for application of 180 kg ha^{-1} (37.84 kg N $ha^{-1}$and 56.36 kg N ha^{-1}) respectively in season I and II (Table 20).

Table 20: Means for the effect of mulch type and fertilizer rate on nitrogen uptake before heading (60DAT)

Nitrogen uptake (kg ha^{-1})					
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	36.09^{b}	45.42^{b}	0kg ha^{-1}	44.02^{ns}	61.37^{ns}
Black plastic	49.78^{a}	63.54^{a}	60kg ha^{-1}	40.07	61.47
Wheat straw	40.34^{b}	74.49^{a}	120kg ha^{-1}	46.35	65.40
			180kg ha^{-1}	37.84	56.36
LSD $_{(0.05)}$	7.374	11.422	LSD $_{(0.05)}$	8.514	13.190
CV (%)	20.70	22.06	CV (%)	20.70	22.06

Key: Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Effect of interaction between mulch types and fertilizer rates

Effect of interaction between mulch types and fertilizer rates on N uptake was significant in season I and not significant in season II. Application of 60kg ha^{-1} significantly increased nitrogen uptake for wheat straw mulch and decreased uptake for black plastic mulch and bare soil , in season I. Application of 120$kgha^{-1}$ increased nitrogen uptake for all types of mulch while application of 180$kgha^{-1}$ decreased nitrogen uptake for black plastic and wheat straw mulch and increased nitrogen uptake for bare soil (Fig 3a). In season II; application of 60 kgha^{-1} increased nitrogen uptake for wheat straw mulch and decreased uptake for black plastic mulch and bare soil; application of 120 kgha^{-1} increased uptake for bare soil and black plastic mulch while it decreased uptake for wheat straw mulch; application of 180 kgha^{-1} decreased nitrogen uptake for both mulch types and bare soil (Fig3b)

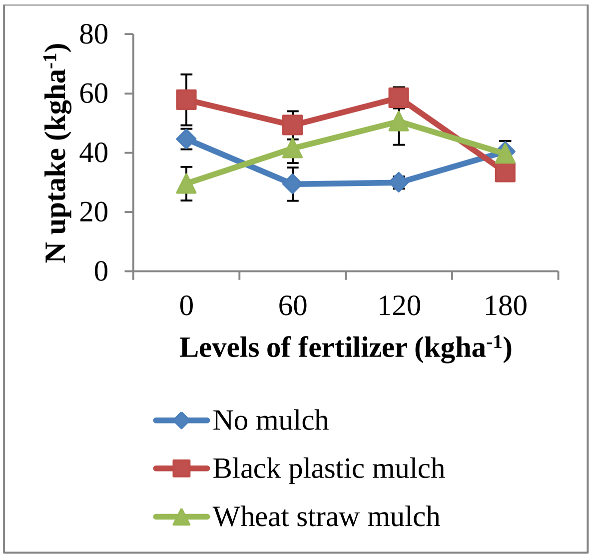


Figure 3a

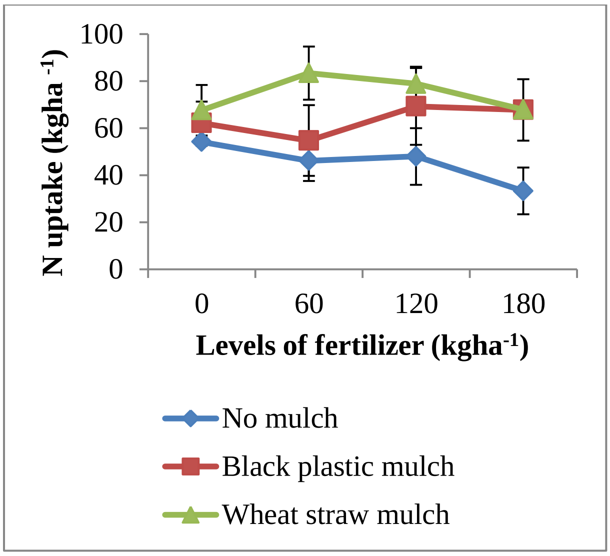


Figure 3b

Figure 3 a and b: Effect of interaction between mulch type and fertilizer rate on nitrogen uptake before cabbage heading (60 DAT) in season I and II.

Key: Bars represent standard errors.

4.2.2 Effect of mulch type, fertilizer rate and their interactions on P uptake

Effect of mulch type

Effect of mulch type on P uptake was not significant in both seasons ($P<0.05$). Plots covered with wheat straw mulch had slightly higher P uptake (20.44 and35.70 kgha^{-1}) in season I and II, respectively compared to black plastic mulch and bare soil (Table 21).

Effect of fertilizer rate

Effect of fertilizer rate was significant in both seasons ($P<0.05$). Application of 120 and 60 kg ha^{-1} increased P uptake (25.23 and 22.89 kg ha^{-1}) in season I, compared to bare soil. Application of 120 kg ha^{-1} and the control had significantly higher phosphorus uptake (41.66 and 38.17 kgha^{-1}) in season II (Table 21).

Table 21: Means for the effect of mulch types and fertilizer rates on phosphorus uptake before heading (60 DAT)

		Phosphorus uptake (kg ha^{-1})			
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	19.78^{ns}	34.42^{ns}	0kg ha^{-1}	16.62^{b}	38.17^{a}
Black plastic	19.82	34.59	60kg ha^{-1}	22.89^{a}	31.03^{b}
Wheat straw	20.44	35.70	120kg ha^{-1}	25.23^{a}	41.66^{a}
			180kg ha^{-1}	15.33^{b}	28.75^{b}
LSD $_{(0.05)}$	4.731	5.743	LSD $_{(0.05)}$	5.463	6.631
CV (%)	27.92	19.43	CV (%)	27.92	19.43

Key: Means with the same letter within columns are not significantly different (P < 0.05). ns: Means within column are not significantly different (P < 0.05).

Effect of interaction between mulch types and fertilizer rates

Interaction effects were not significant in both seasons (Fig 4a and b). Application of 60 kgha^{-1} increased uptake for every type of mulch. Application of 120 kgha^{-1} increased uptake for wheat straw mulch and 180kgha^{-1} decreased uptake for all mulch types in season I (Fig 4a). Application of 60 and 180kgha^{-1} decreased P uptake and application of 120 increased P uptakes for all mulch types in season II (Fig 4b).

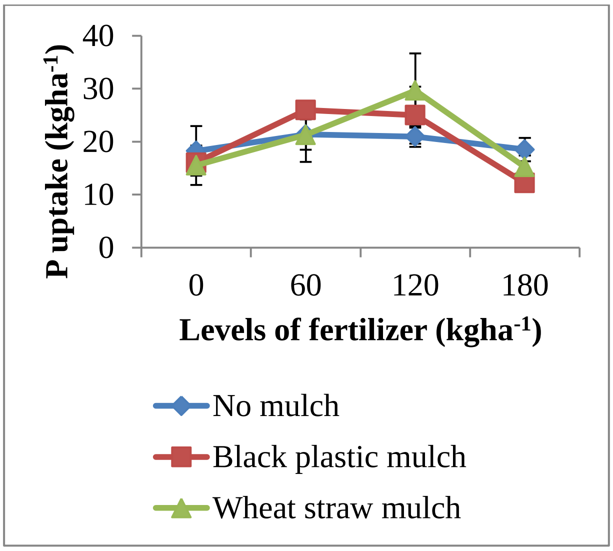


Figure 4a

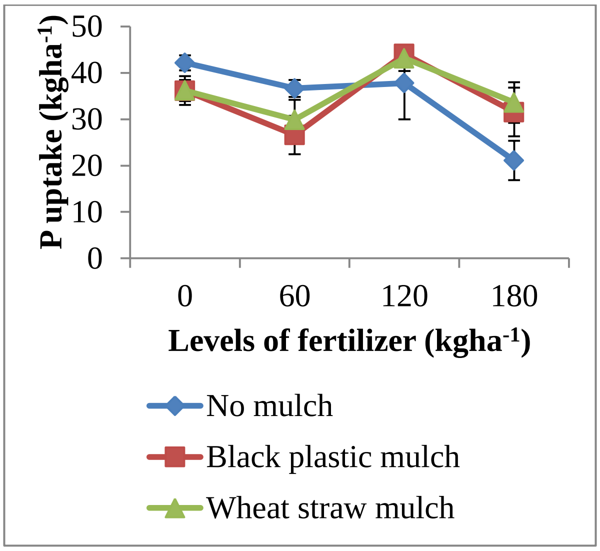


Figure 4b

Figure 4 a and b: Effect of interaction between mulch type and fertilizer rate on phosphorus uptake before heading in season I and II (60DAT)

Key: Bars represent standard errors.

4.2.3 Effect of mulch type, fertilizer rate and their interactions on K uptake

Effect of mulch types

Effect of mulch types on potassium uptake was significant in Season II but was not significant in season I. In season II, black plastic mulch and wheat straw mulch had significantly higher K uptake (66.35 and 61.55 kg ha^{-1}) than bare soil (41.59 kg ha^{-1}).

Effect of fertilizer rate

Effect of fertilizer rate on potassium uptake was significant in season I and II. In season I, application rates of 60 and 120 $kgha^{-1}$ had significantly higher K uptake (72.27 and 65.30 kg ha^{-1}) than application of 0 and 180 $kgha^{-1}$ (52.95 and 50.99 $kgha^{-1}$). In season II, fertilizer application at 120 kg ha^{-1} had higher K uptake (64.63 kg ha^{-1}) compared to 60 kg ha^{-1} (55.58) and 180 kg ha^{-1} (46.71) (Table22).

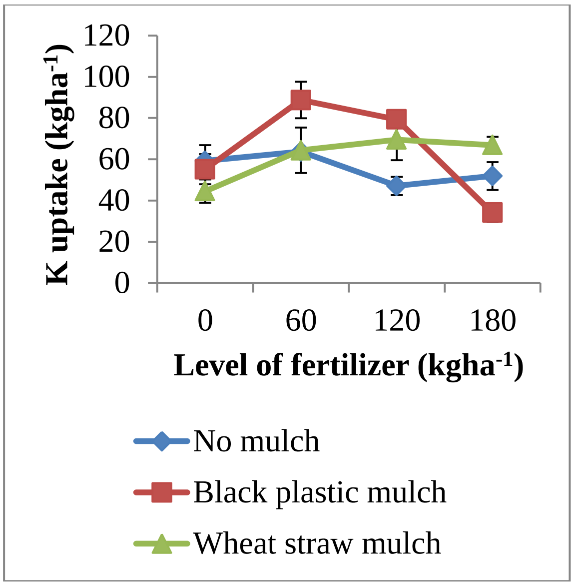
Table 22: Means for the effect of mulch type and fertilizer rates on potassium uptake before heading (60 DAT).

		Potassium uptake (kg ha^{-1})			
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	55.46^{ns}	41.59^{b}	0kg ha^{-1}	52.95^{b}	59.07^{ab}
Black plastic	64.30	66.35^{a}	60kg ha^{-1}	72.27^{a}	55.58^{b}
Wheat straw	61.34	61.55^{a}	120kg ha^{-1}	65.30^{a}	64.63^{a}
			180kg ha^{-1}	50.99^{b}	46.71^{c}
LSD $_{(0.05)}$	10.263	7.512	LSD $_{(0.05)}$	11.850	8.674
CV (%)	20.08	15.71	CV (%)	20.08	15.71

Key: Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Effect of interaction between mulch types and fertilizer rates

Effect of interaction between mulch types and fertilizer rate was significant in both seasons. In season I; fertilizer application at 60$kgha^{-1}$ had significantly higher K uptake for black plastic mulch compared to wheat straw and bare soil. Application of 120$kgha^{-1}$ had significantly higher K uptake for wheat straw and black plastic mulch and lower uptake for bare soil. There was a significant difference among mulch types at application of 180$kgha^{-1}$ where black plastic had lower K uptake and wheat straw mulch higher uptake (Fig. 5a). In season II; fertilizer application at 120$kgha^{-1}$ showed a significant difference among mulch types; black plastic had higher K uptake followed by wheat straw mulch and lower uptake was observed for bare soil. Application of 180$kgha^{-1}$ had higher K uptake for black and wheat straw mulch and significantly lower K uptake for bare soil (Fig. 5b).



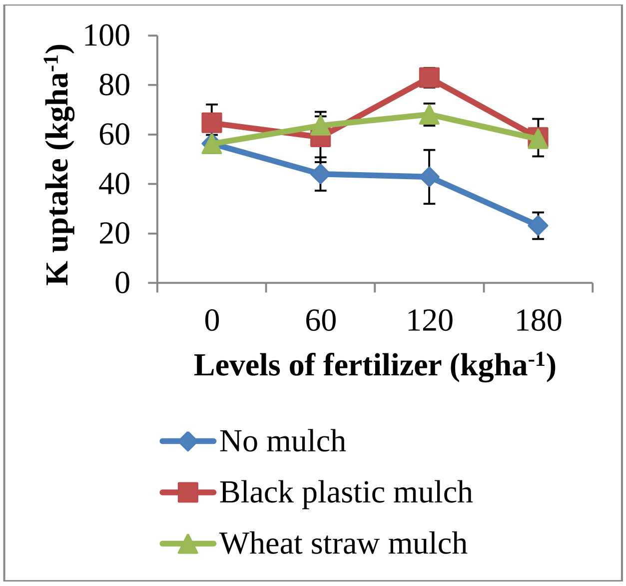


Figure 5a **Figure 5b**

Figure 5 a and b. Effect of interaction between mulch type and fertilizer rate on potassium uptake before cabbage heading in season I and II (60 DAT).

Key: Bars represent standard errors.

4.2.4 Correlation between nutrient uptake and cabbage yield

There was a positive correlation between nitrogen, phosphorus and potassium uptake (kgha^{-1}) and cabbage yield (fresh head weight in kgha^{-1}) in season I and II (Table 23). There was a strong significant correlation between potassium and nitrogen uptake in cabbages but also a significant weak correlation between potassium and phosphorus uptake (Table 23).

Table 23: Correlation coefficients of nutrient uptake and yield of white cabbage grown within different mulch types, levels of fertilizer application and seasons.

	Nitrogen	Phosphorus	Potassium	Yield
Nitrogen	1.0000	0.5213***	0.5433***	0.5352***
Phosphorus		1.0000	0.3169**	0.4341***
Potassium			1.0000	0.4851***
Yield				1.0000

Key: * *= significant at P<0.01 and *** = significant at P<0.001.

4.3. Effect of mulch type, fertilizer rate and their interactions on Soil moisture, available P, exchangeable K and total N

4.3.1 Effect of mulch type, fertilizer rate and their interactions on Soil moisture

Effect of mulch types

Effect of mulch type on soil moisture was significant ($P < 0.05$) in both seasons (Table 24). Black plastic and wheat straw mulches recorded the highest soil moisture content and bare soil the lowest at 60 and 90 DAT in season I. In season II at 90DAT wheat straw mulch had the significantly higher soil moisture content (Table 24).

Effect of fertilizer rates

Effect of fertilizer rate was significant ($P<0.05$) on soil moisture in season II at 30 and 90 DAT (Table 24). The fertilizer rate of 120 kg ha^{-1} at 30 DAT and 180 kg ha^{-1} at 90 DAT had highest soil moisture in season II (Table 24).

Table 24: Means for the effect of mulch type and fertilizer rates on soil moisture content

Soil Moisture (%)						
Treatment	Season I			Season II		
Mulch type	30DAT	60DAT	90DAT	30DAT	60DAT	90DAT
No mulch	26.25^{ns}	12.25^{b}	9.89^{c}	25.01^{ns}	29.11^{ns}	33.50^{a}
Black plastic	24.62	19.21^{a}	16.30^{a}	27.54	29.93	33.83^{a}
Wheat straw	26.30	17.22^{a}	13.00^{b}	28.31	26.16	29.15^{b}
LSD $_{(0.05)}$	3.884	3.085	2.935	3.371	4.208	3.844
CV (%)	17.83	22.46	26.54	14.77	17.50	14.12
NPK rate						
0kg ha^{-1}	23.92^{ns}	14.13^{ns}	12.18^{ns}	24.72^{b}	25.17^{ns}	30.53^{b}
60kg ha^{-1}	25.15	16.43	12.16	26.09^{b}	29.41	30.75^{b}
120kg ha^{-1}	28.68	17.12	12.50	30.50^{a}	29.84	31.27^{b}
180kg ha^{-1}	25.13	17.21	15.41	26.51^{b}	29.19	36.08^{a}
LSD $_{(0.05)}$	4.485	3.562	3.389	3.893	4.859	4.438
CV (%)	17.83	22.46	26.54	14.77	17.50	14.12

Key: DAT= days after transplanting. Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Effect of interaction between mulch and fertilizer

Effect of interaction between mulch and fertilizer on soil moisture was not significant in both seasons (Figure 6 a and b).

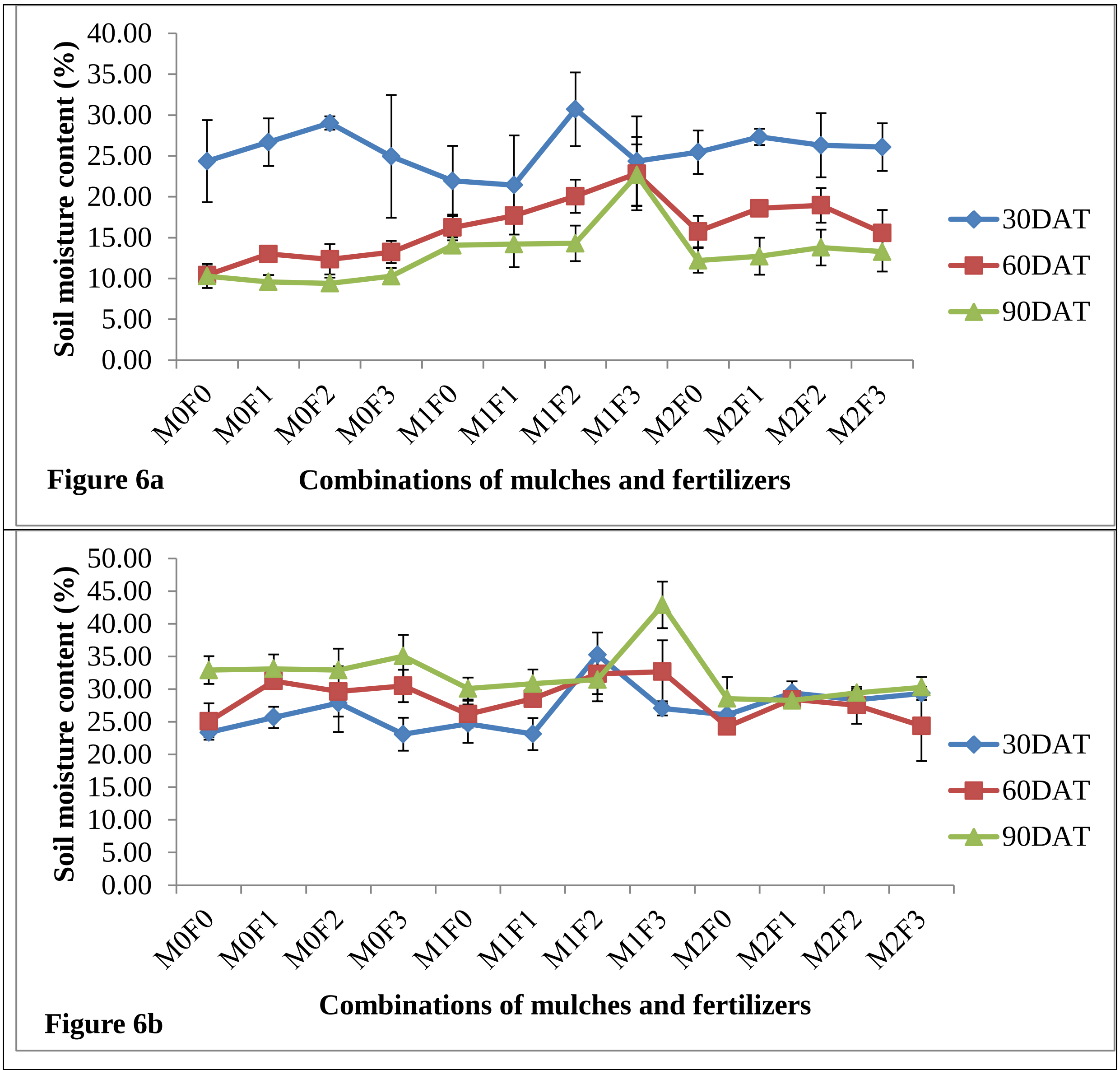


Figure 6 a and b: Effect of interaction between mulch and fertilizer on soil moisture content in Season I and II.

Key: M0: Bare soil, M1: Black plastic mulch, M2: Wheat straw mulch; F0: 0kgha^{-1} NPK; F1: 60kgha^{-1} NPK; F2: 120kgha^{-1} NPK; F3: 180kgha^{-1} NPK. Bars represent standard errors.

4.3.2 Effect of mulch type, fertilizer rate and their interactions on soil available P after harvesting

Effect of mulch types

Mulch type effect on soil available P was significant (P<0.05) in both seasons (Table 25). After harvesting for season I, soil available P was higher under black plastic (103.94 ppm) and bare soil (102.43 ppm) compared to wheat straw mulch (91.53ppm) (Table 25). Soil available P was higher under black plastic mulch (140.20ppm) than bare soil (132.72ppm) in season II. Means for black plastic were not significantly different from wheat straw mulch (Table 25).

Effect of fertilizer rate

Fertilizer rate effect was significant (P<0.05) in seasons I and II (Table 25). Fertilized plots had higher available P compared to the control in season I. Soil fertilized at 180 kgha^{-1} had higher available P (147.01ppm) followed by application of 120 and 60 kgha^{-1} and the control had least available P (124.23ppm) in season II (Table 25).

Table 25: Means for soil available P after harvesting

Available P (ppm)					
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	102.43^{a}	132.72^{b}	0kg ha^{-1}	88.62^{b}	124.23^{c}
Black plastic	103.94^{a}	140.20^{a}	60kg ha^{-1}	100.97^{a}	133.49^{b}
Wheat straw	91.53^{b}	133.92^{ab}	120kg ha^{-1}	106.34^{a}	137.72^{b}
			180kg ha^{-1}	101.28^{a}	147.01^{a}
LSD $_{(0.05)}$	8.104	6.372	LSD $_{(0.05)}$	9.358	7.357
CV (%)	9.64	5.55	CV (%)	9.64	5.55

Key: Means with the same letter within columns are not significantly different (P < 0.05).

Effect of interaction between mulch types and fertilizer rates

After season I harvesting; there was no noticeable interactions effect on soil available P but after harvesting for season II significant difference was observed with soil treated by black plastic mulch and fertilizer rate of 120 and 180 kgha^{-1} (M1F2 and M1F3) having higher available P than other combinations (Fig7).

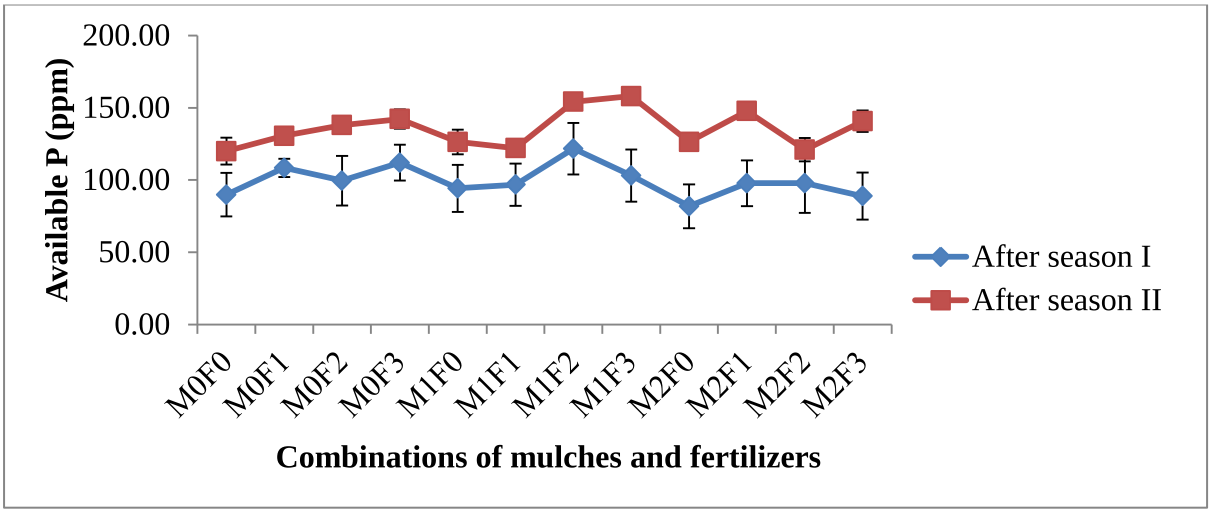


Figure 7: Effect of interactions between mulch type and fertilizer rate on soil available P after harvesting.

Key: M0: Bare soil, M1: Black plastic mulch, M2: Wheat straw mulch; F0: 0kgha^{-1} NPK; F1: 60kgha^{-1} NPK; F2: 120kgha^{-1} NPK; F3: 180kgha^{-1} NPK. Bars represent standard errors

4.3.3 Effect of mulch type, fertilizer rate and their interactions on soil exchangeable K after harvesting

Effect of mulch types

Effect of mulch type on soil exchangeable K after harvesting of cabbages was not significant (P<0.05) in both seasons (Table 26 and Appendix 15).

Effect of fertilizer rate

Fertilizer rate effect on soil exchangeable K after harvesting, was significant in both season I and II. After season I the control (0 kgha^{-1}) had low exchangeable K (0.24 Cmol$_c$kg^{-1}) compared to other treatments. Contrarily after season II the control had significantly higher exchangeable K (0.25 Cmol$_c$kg^{-1}) compared to other treatments (Table 26).

Table 26: Means for soil exchangeable K after harvesting

		Exchangeable K (Cmol$_c$ kg^{-1})			
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	0.30^{ns}	0.20^{ns}	0kg ha^{-1}	0.24^{b}	0.25^{a}
Black plastic	0.29	0.21	60kg ha^{-1}	0.30^{a}	0.20^{b}
Wheat straw	0.29	0.21	120kg ha^{-1}	0.33^{a}	0.18^{b}
			180kg ha^{-1}	0.30^{a}	0.19^{b}
LSD $_{(0.05)}$	0.035	0.023	LSD $_{(0.05)}$	0.041	0.026
CV (%)	14.30	13.07	CV (%)	14.30	13.07

Key: Means with the same letter within columns are not significantly different (P < 0.05). ns: Means within column are not significantly different (P < 0.05).

Effect of interaction between mulch types and fertilizer rates

Interaction effect between mulch types and fertilizer rates was significant on soil exchangeable K after both seasons (Appendix 15). After season I harvesting; black plastic mulch combined with 120kgha^{-1} (M1F2) had high exchangeable K 0.37Cmol$_c$kg^{-1} compared to other combinations. After season II; wheat straw mulch with 0kgha^{-1} (M2F0) had higher mean (0.26Cmol$_c$kg^{-1}) and bare soil with 120kgha^{-1} (M0F2) the lowest (0.17Cmol$_c$kg^{-1}) (Fig8).

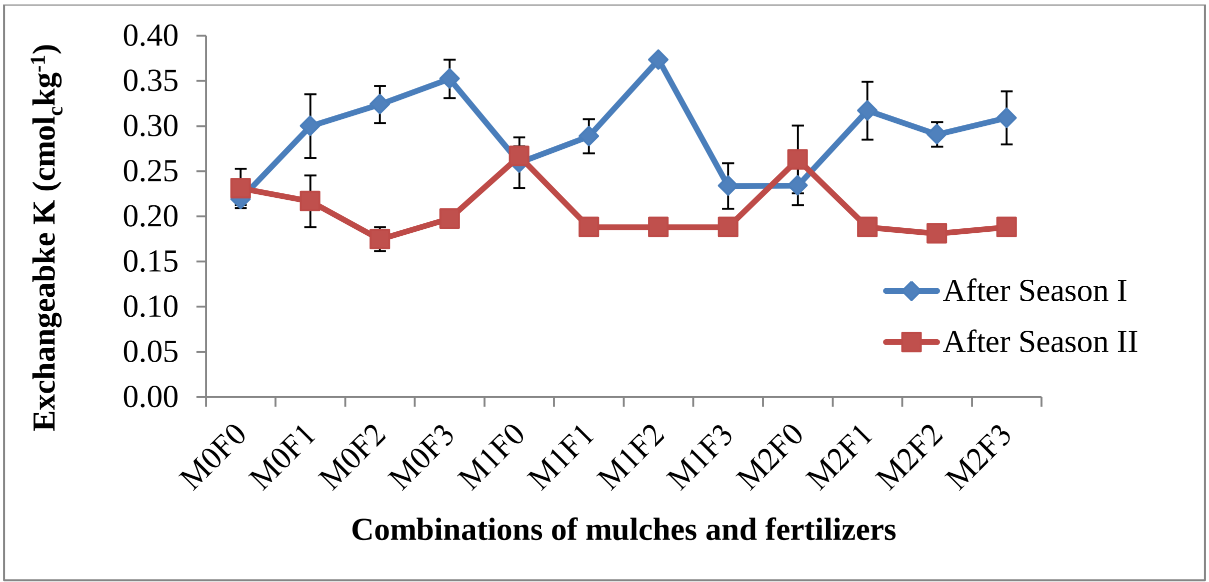


Figure 8: Effect of interactions between mulch type and fertilizer rate on soil exchangeable K after harvesting.

Key: M0: Bare soil, M1: Black plastic mulch, M2: Wheat straw mulch; F0: 0kgha^{-1} NPK; F1: 60kgha^{-1} NPK; F2: 120kgha^{-1} NPK; F3: 180kgha^{-1} NPK. Bars represent standard errors.

4.3.4 Effect of mulch type, fertilizer rate and their interactions on Soil total N after harvesting

Effect of mulch types

Effect of mulch type was significant ($P<0.05$) on soil total N only after season II harvesting. Bare soil (0.40%) and black plastic mulch (0.37%) had significantly higher values (Table27).

Effect of fertilizer rate

Effect of fertilizer rate on soil total N after harvesting was not significant ($P<0.05$) for both seasons I and II (Table 27 and Appendix 20).

Table 27: Means for soil total Nitrogen after harvesting

		Total N (%)			
Mulch type	Season I	Season II	**NPK rate**	Season I	Season II
No mulch	0.36^{ns}	0.40^{a}	0kg ha^{-1}	0.33^{ns}	0.37^{ns}
Black plastic	0.33	0.37^{ab}	60kg ha^{-1}	0.33	0.35
Wheat straw	0.37	0.33^{b}	120kg ha^{-1}	0.38	0.37
			180kg ha^{-1}	0.37	0.37
LSD $_{(0.05)}$	0.041	0.047	LSD $_{(0.05)}$	0.047	0.054
CV (%)	13.54	15.15	CV (%)	13.54	15.15

Key: Means with the same letter within columns are not significantly different ($P < 0.05$). ns: Means within column are not significantly different ($P < 0.05$).

Effect of interaction between mulch types and fertilizer rates

Interaction effect was significant after harvesting for season I and not significant for season II. After season I harvesting, plots with wheat straw mulch with fertilizer application rates of 120 and 180kgha^{-1} had 0.43 and 0.40%, respectively and bare soil with 120kgha^{-1} had 0.43%. The values were significantly higher compared to other treatments and bare soil with 60 kg ha^{-1} had the lowest value (0.29%). For season II there was no significant difference among treatments (Figure9).

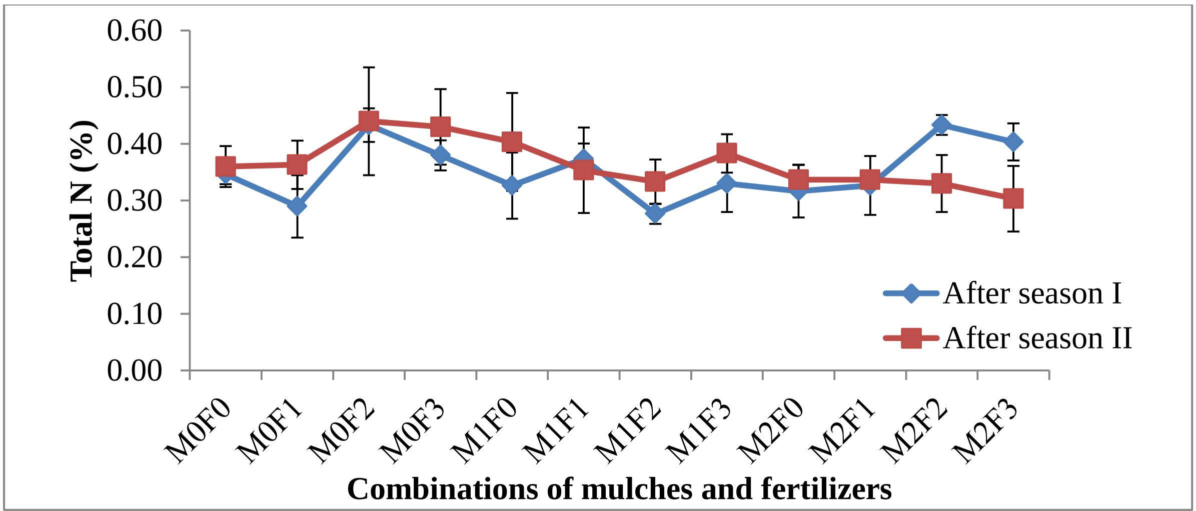


Figure 9: Effect of interactions between mulch type and fertilizer rate on soil total N after harvesting.

Key: M0: Bare soil, M1: Black plastic mulch, M2: Wheat straw mulch; F0: 0kgha^{-1} NPK; F1: 60kgha^{-1} NPK; F2: 120kgha^{-1} NPK; F3: 180kgha^{-1} NPK. Bars represent standard errors.

CHAPTER FIVE
DISCUSSION

5.1 Effect of mulch type, fertilizer rate and their interactions on growth and yield of cabbage

5.1.1 Effect of mulch type on growth and yield of cabbage

Application of wheat straw mulch and black plastic mulch significantly increased the growth and yield of cabbage than bare soil in season I and II. This may have been due to the ability of mulch to retain moisture in soil and increase the plants' water use efficiency (Yaghi and Noum, 2013). During sunny days, black plastic mulch prevents loss of water by evaporation, reduce temperature fluctuations and promote productivity (Gary *et al*., 2014).Water is essential for plant development. Water regulates plant development by performing three basic functions; mediates environmental effects on growth and metabolism, correlates the growth of different parts of the plant, and integrates growth and metabolic activity at the cellular level (Geraldo and Henrique, 2007). Plants leaves as vascular plant parts help plant to suck up water and dissolved nutrients from the soil to support the plant's growth (McIntyre, 1987).

Black plastic mulch additionally increases soil temperature and reduces weeds (Locascio *et al*., 2005; Gordon *et al*., 2010), and this promoted cabbage growth compared to bare soil. The organic mulch cover also suppressed weed growth thereby reducing competition for water and nutrients. N enrichment by mineralization of wheat straw mulch also contributed to the growth and yield increase of cabbage (Liang *et al*., 2002; Trdan *et al*., 2008; Traunfeld and Nibali, 2013).

Results of this study agree with findings by Decoteau *et al*. (1986) and Yang *et al*. (2015); which showed that mulching in general has a positive effect on plant height, leaf numbers and size, shoot diameter and dry matter. Little rainfall received in first two weeks after transplanting of seedlings in season I may have caused non-significant effect of mulch on stem diameter at 45, 60 and 75 DAT and rosette diameter at 60 DAT. The transplanted seedlings were starved of water to favour seedlings nutrient uptake (Olaniyi and Ojetayo, 2011).

5.1.2 Effect of fertilizer rate on growth and yield of cabbage

NPK fertilizer rates of 60 and 120 kg ha^{-1} were optimal for the growth and yield of cabbage compared to 0 and 180 kg ha^{-1}, irrespective of season. N, P and K are essential macronutrients for crop growth (Nina *et al*., 2012). N promotes leafy growth and green colour, phosphorus is required for root and flower growth and potassium for overall plant health (Nina *et al*., 2012). To form full green heads, cabbages require adequate supply of these macronutrients (Kelly and Murekezi, 2000; Maniriho and Bizoza, 2013). A study on the effect of fertilizer types on the growth and yield of two cabbage varieties reported that NPK fertilizer was important in increasing cabbage yield (Van Averbeke, 2007; Olaniyi and Ojetayo, 2011). Jayamangkala (2015) also found higher values on growth parameters of *Brassica oleracea L* .var. *italica* in the plots treated with mineral fertilizer than control.

The stem diameter values measured at 30 and 75 DAT were similar to those obtained by Pérez *et al*. (2015) in the study on cabbage planted inside and outside a greenhouse. The response of LAI to increased fertilizer was due to supply of N which enhanced leaf expansion (Van Keulen and Stol, 1991).

Effect of fertilizer rate on number of leaves at 60 and 75 DAT and head diameter at 60 DAT in season I head diameter was not significant. Similarly in season II, parameters such as height, stem diameter, leaf area, leaf area index and rosette diameter at 75 DAT were not significantly different. This was because these periods coincided with the start of head formation and vertical growth had ceased. The cabbages were fast approaching commercial maturity and some leaves were not visible because of head compaction. This is in addition to the likely loss of some leaves during weed control.

The observed decline in growth parameters and yield beyond fertilizer rate of 120 kgha^{-1} was due nutrient toxicity. The initial soil available phosphorus level before application of treatments, as shown in Table 1, was sufficient. As the concentration of nutrient increases from deficiency to an optimal point, the relative growth of a plant increases and then a decline occurs due to nutrient toxicity (Nyle, 1984). At 75 DAT in season II, fertilizer rate of 180kgha^{-1} had higher LAI because cabbages in this treatment had not fully headed continuing to show many visible leaves. This was unlike cabbages in other fertilizer rates that had already started forming full heads. Nutrients toxicity caused stunted growth and thereby delayed head formation (Nyle, 1984).

5.1.3 Effect of interactions between mulch type and fertilizer rate on growth and yield of cabbage

Effect of interaction between mulch and fertilizer on growth parameters and yield were significant in both or one season. Wheat straw and black plastic mulch combined mainly with fertilizer at rate of 60 and 120 kgha^{-1} had higher means compared to other used combinations. Cabbage stem diameter, head diameter, rosette diameter and weight require high levels of essential nutrientincluding NPK during growth. The mulch type used is a probable cause that can facilitate either release or binding of nutrients from their complex states to active form so as to be available for uptake by the plant. Wheat straw mulch ability to initiate mineralization that liberates more nitrogen to be available during cabbage growth may be the cause of higher value recorded compared to plastic mulch and bare soil. Lower means observed in stem diameter, head diameter, rosette diameter and weight for bare soil and fertilizer at rate of 180kgha^{-1} could be due nitrogen leaching since its water soluble and toxicity caused by fertilizer rate that is over the critical range. Cabbage expansion (diameter) and weight has been found to be greatly influenced by nitrogen uptake (Van Keulen and Stol, 1991).

5.2 Effect of interactions between mulch type and fertilizer rate on N, P and K uptake by cabbage

5.2.1 Effect of mulch type on N, P and K uptake by cabbage

The higher NPK uptake in plants with mulch compared to bare soil may have been due to the fact that mulches have a nutrient use efficiency effect. The results agrees with a study on use of row covers on white cabbages where the control (uncovered) gave lowest fresh matter head yield compared to those covered plots (Wien, 1993; Übelhör, 2014).

5.2.2 Effect of fertilizer rate on N, P and K uptake by cabbage

The higher P and K uptake recorded with fertilizer application rates of 60 and 120 kg ha^{-1} in both seasons was because NPK fertilizer is water soluble hence increased availability for uptake (Vitosh, 1996). The results confirm with those of Shabani *et al.* (2015), who showed that, in both irrigated and dry farming conditions, all fertilizer treatments increased macro-and micro-nutrients uptake of annual medic crop over the control. For N uptake even though there was no significant difference, the highest mean N uptake was also observed on application rate of 120kgha^{-1} followed by 60kgha^{-1} and control. The application at 180kgha^{-1} had the lowest mean and it is an indication that fertilizer rate has reached a toxic range.

5.2.3 Effect of interactions between mulch type and fertilizer rate on N, P and K uptake by cabbage

Plant treated with black plastic and wheat straw mulch with fertilizer rate of 120kgha^{-1} had higher N uptake. For phosphorus and potassium uptake; fertilizer application rate of 60kgha^{-1} and 120kgha^{-1} increased uptake with all types of mulch. Ashrafuzzaman *et al.*

(2011) reported that under black plastic mulch weeds were suppressed which favored nutrient uptake. Straw mulch reduces soil compaction and increase biotic activity which promote mineralization and increase nutrient availability and uptake (Ingle, 1981) and it acts as soil temperature buffering so that changes in the soil hydrothermal regime for straw mulch can increase the density and spread of roots and increase nutrient uptake (Trdan *et al*., 2008). In both seasons the rate of 180kgha^{-1} decreased P uptake with black plastic and wheat straw mulch but increased uptake with bare soil in season I; these confirm with Deenik *et al*. (2006) who mentioned that when P concentrations are high in the soil additions of more P fertilizer do not necessarily contribute to improved yields and that addition may be an unnecessary cost, reducing the farmer's profit margin.

5.2.4 Correlation of nutrient uptake and yield

There was significant positive correlation between N, P and K nutrient uptake in cabbage and yield indicates that the nutrients did their role in enhancing cabbage growth. Cabbage is a heavy feeder. The loamy soil texture and moisture under mulch may have favoured nutrients availability from their complex status and migration toward the crop for uptake (Cauley *et al*., 2009).

5.3 Effect of mulch type, fertilizer rate and their interactions on soil moisture, available P, K and total N contents

5.3.1 Effect of mulch type on soil moisture during growth and available P, K and total N contents after harvesting

Higher moisture retention in season I at 60 and 90 DAT and season II at 90 DAT under black plastic mulch was caused by reduction in evapotranspiration losses (Lalitha *et al*., 2010). Mulches generate higher soil temperature and soil moisture retention over the control (Ashrafuzzaman, *et al*., 2011).

Soil available P content after harvesting in both seasons, was higher under black plastic mulch than wheat straw mulch and control. Those may be due to the ability of black plastic mulch to modify soil structure favouring nutrients migration. This is in agreement with the study on effect of plastic mulch on soil properties and crop growth that revealed that under plastic mulch, properties of soil such as temperature, moisture, bulk density, aggregate stability and available nutrient including phosphorus were improved (Lalitha *et al*., 2010).

Soil under wheat straw mulch had higher total N content compared to black plastic and bare soil in season I. This may have been because of the wide C:N ratio of the wheat straw. Cereals have wide C:N ratio and can temporarily tie up soil nitrogen levels as they decay and can reduce loss of nitrate, sulfate, calcium, magnesium and potassium (Traunfeld and Nibali, 2013 Liang *et al*., 2002).

5.3.2 Effect of fertilizer rate on soil moisture during growth and available P, K and total N contents after harvesting of cabbage

In season II, plots with fertilizer application rate of 120 kg ha^{-1} at 30 DAT and 180 kg ha^{-1} at 90 DAT had the highest moisture compared to other rates. This could be due to cover from cabbage leaves which were wide compared to other rates.

Soil available P and K after harvesting in both seasons were significantly lower in the control (bare soil) compared to other fertilizer treatments. Soil total N content after harvesting in season I was greater in plots treated with 120kgha^{-1}. Fertilizer addition filled the gap between absorbed and leached nutrients. The noticeable decline in N, P and K content after harvesting compared to the initial soil properties was due to uptake and shows the importance of NPK fertilizer addition in soil fertility maintenance (Kulhánek *et al*., 2014).

5.3.3 Effect of interactions between mulch type and fertilizer rate on soil moisture during growth and available P, K and total N contents after harvesting

The absence of interaction effect of the mulch type and rate of NPK fertilizer application on the soil moisture during growth may be caused by rain times that occurred before sampling where nearly all plots had same characteristics.

The higher soil total N, soil available P and soil exchangeable K after harvesting were recorded mainly under plots covered with black plastic and wheat straw mulch and fertilizer at rate of 120kgha^{-1}. Those were due to mulches ability to reduced leaching, addition from mineralization of wheat straw and sufficient fertilizer rate used (Pot and Guide, 2015; Rohwer, 2015) N, P and K decrease after harvesting was due to leaching and uptake of nutrients during growth (Appendix 21).

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The study on "effect of mulch type and NPK (17-17-17) rates on soil nutrient availability, nutrients uptake, growth and yield of cabbage (*Brassica oleracea* var. *capitata*) in the volcanic highlands zone of Rwanda" revealed that:

1. Application of the black plastic and wheat straw mulch and fertilizer rates of 60 and 120kgha^{-1} influenced positively plant growth and yield because of capacity of mulch to retain moisture for increased nutrient uptake.
2. Mulching increased N and K uptake comparatively to the control while fertilizer application at rate of 120kgha^{-1} favoured P uptake due to nutrients release from complex to available form.
3. Black plastic and wheat straw mulches generated higher soil moisture compared to the control. Increase in fertilizer rate increased soil P and K availability. Wheat straw mulch and bare soil with 120kgha^{-1} favoured higher values for soil total N after season I harvesting.

6.2 RECOMMENDATIONS

1. Wheat straw mulch in combination with NPK (17-17-17) at rate of 120kg ha^{-1} is recommended as it is locally available and environment friendly and increasing cabbage growth and yield.
2. To conduct soil analysis including microbiological parameters in other agro ecological zones of Rwanda to have an updated soil fertility status for better fertilizer recommendation based on nutrients present.
3. To use other forms of fertilizers and organic mulches to come up with the most affordable and increasing production and favouring soil nutrients retention.

REFERENCES

ADFSC (2015). Growing cabbage for profit and sustainability 2014- 2015 season guidelines. Abu Dhabi farmers' Service Center; *Open field vegetable production guide* pp 1- 8.

Anon (2014). Tillage and residue management. Retrieved from: http://www.viagroforestry.org/files/2014/09/Vi_SALM-Training-Manual_Chapter-7-to-11.pdf Accessed on May 14, 2016.

Ashrafuzzaman, M., Abdul Halim, M., Ismail, M. R., Shahidullah, S.M. and Alamgir, H. M. (2011). Effect of Plastic Mulch on Growth and Yield of Chilli (*Capsicum annuum* L.). *Brazilian archives of biology and technology* 54,321 – 330.

Augusto S., Nereu, G. P., Diego, J.Z., Alencar, F. G., Luana S. M. R., Thiago, T. S.a, André, R. S., M. (2014). Effect of plant spacing on growth, development and yield of cassava in a subtropical environment. *Journal of Crop Production and Management* 73, 407 – 4015.

Bhardwaj, R. (2013). Effect of mulching on crop production under rainfed condition - a review. *Agricultural Reviews* 34, 188 – 197.

Bidogeza, J. C., Paul, B. M., de Graaff, J. and Lansink, A. O. (2015). Potential Impact of Alternative Agricultural Technologies to Ensure Food Security and Raise Income of Farm Households in Rwanda. *Forum for Development Studies* 42, 133-157

Broschat, T. K. (2007). Effects of mulch type and fertilizer placement on weed growth and soil pH and nutrient content. *Horticultural Technology* 17, 174-177.

Castillo, V.M., Martinez, M. M. and Albaladejo, J. (1997). Runoff and soil loss response to vegetation removal in semi-arid environment. *Soil Science Society of America* 61, 1116 – 1121.

Cauley, A., Jones, C. and Jacobson, J. (2009). Plant Nutrient Functions and Deficiency and Toxicity Symptoms. *Nutrient management module No.9* Pp1-16.

Climate-data.Org (2012). Retrieved from: http://en.climate-data.org/location/323937/. Accessed on 22nd May, 2016.

Cody, Z., Urs, K. and Richard, C. (2009). Population Growth and Fertilizer Use: Ecological and Economic Consequences in Santa Cruz del Quiché, Guatemala. *Society and Natural Resources* 23, 1-13.

Cotching, B. (2009). (Book). *Soil Health for Farming in Tasmania*. pp124. *National Library of Australia Cataloguing-in-Publication entry. Bibliography*. ISBN: 978-0-646-50764-4.

Cregg, B. M. and Robert, S. (2009). Weed Control and Organic Mulches Affect Physiology and Growth of Landscape Shrubs. *Horticultural Science* 44,1419–1424.

Decoteau, D. R., Daniels, D.D., Kasperbauer, M.J. and Hunt, P. G. (1986). Coloured plastic mulches and tomato morphogenesis. *Proceedings of national agricultural plastics congress,* 19, 240 – 248.

Deenik, J., Hamasaki, R., Shimabuku, R., Nakamoto, S. and Uchida, R. (2006). Phosphorus Fertilizer Management for Head Cabbage. *Soil and Crop Management* pp 1 – 6.

Djigal, D., Saj, S., Rabary, B., Blanchart, E. and Villenave, C. (2012). Mulch type affects soil biological functioning and crop yield of conservation agriculture systems in a long-term experiment in Madagascar. *Soil and Tillage Research* 118, 11 – 21

El- Shaikh and Fouda, T. (2008). Effect of Different Mulching Types on Soil Temperature and Cucumper Production under Libyan Conditions. *Misr Journal of Agricultural Engineering* 25, 160- 175.

Estefan, G., Rolf, S., and John, R. (2013). *Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region*: Third edition. *ICARDA*.

Fao.org. (2017) http://www.fao.org/docrep/X0490E/x0490e0b.htm#crop%20coefficients visited on 01st May 2017.

Farias-Larios, J. and Orozco-Santos, M. (1997). Effect of polyethylene mulch color on aphid populations, soil temperature, fruit quality, and yield of watermelon under tropical conditions, *New Zealand Journal of Crop and Horticultural Science* 25, 369 - 374.

Farias-Larios, J., Orozco, M., Guzman, S., Aguilar, S. (1994): Soil temperature and moisture under different plastic mulches and their relation to growth and yield cucumber in a tropical region. *Gartenbauwissenschaft* 59, 249-252.

FitzPatrick, E.A. (1986). An introduction to Soil Science. *Longman group U. K.* 22, 2 – 246.

Gary, W. W., Angela, M. H., Melissa, C., and Marvin, L. (2014).The Management of Tree Root Systems in Urban and Suburban Settings: A Review of Soil Influence on Root Growth. *Arboriculture & Urban Forestry* 40, 193 – 217.

Geraldo, C. and Henrique, P. S. (2007). Plant Water Relations: Absorption, Transport and Control Mechanisms .*The University of Passo Fundo and Embrapa Grape & Wine Brazil,* pp.105-132.

Gobron, N. (2000). Leaf Area Index (LAI). http://www.fao.org/3/a-i0197e/i0197e15.pdf visited on 20th April, 2017

Gomez, K. A. and Gomez, A. A. (1984).Statistical procedures for agricultural research, 2ndEdition. *John Willey and Sons, New York* pp304 – 308.

Gordon, G. G., Foshee, W. G., Reed, S. T., Brown, J. E. and Vinson, E. L. (2010).The effects of colored plastic mulches and row covers on the growth and yield of okra. *International Journal of vegetable science* 20, 224-233.

Hochmuth, G., Maynard, D., Vavrina, C., Hanlon, E. Simonne, E. (2012). Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida. pp 48.

Hooda R.S., Singh J., Malik V.S., Batra V.K. (1999). Influence of direct seeding, transplanting time and mulching of tomato yield. *Vegetable Science* 26, 140-142.

IDNR - Iowa Department of Natural Resources (2006). Iowa Construction Site Erosion Control Manual pp 1- 5.

Ingle, A. (1981). Comparison of mulches in their effect on weed germination, soil nutrient status, soil physical conditions and worm population. *Horticultural Research Center Levin, New Zealand*. Final Report Experiment. No. 46/07.

Ipromo Course (2015). *Soil Erosion*. Food security in mountain areas Extraordinary Potential by Silvia Stanchi PhD – University of Torino (DISAFA – NatRISK), pp49. (http://eusoils.jrc.ec.europa.eu/library/themes/erosion/). Visited on 5th August, 2016.

Isaac, B. (2006). Manual for Vegetable Production in Botswana Horticultural Research Program. *Department of Agricultural Research. Private bag 0033, Gaborone, Botswana* pp7-9.

Jayamangkala, N, Sutigoolabud, P., Inthasan, J., Sakhonwasee, S. (2015). The effect of organic fertilizers on growth and yield of broccoli (*Brassica oleracea* L . var . italica Plenck cv . Top Green). *Journal of organic systems* 10, 9-14.

Jiang, L., Dami, I. and Doohan, D. (2016). Effects of Mulching on Soil Temperature, Scion Rooting, and Soil Moisture of Mounded Grapevines, *International Journal of Fruit Science* 16, 182-190

Kabirigi, M., Musana, B., Ngetich, F., Mugwe, J., Mukuralinda, A. and Nabahungu, N. L. (2015). Applicability of conservation agriculture for climate change adaptation in Rwanda's situation. *Journal of Soil Science and Environmental Management* 6, 241-248.

Kagabo, M. D. (2013). Participatory integrated watershed management in the north-western highlands of Rwanda. *PhD thesis, Wageningen University, The Netherlands.* Available at http://library.wur.nl/WebQuery/edepot/254923. pp 104.

Kanyanjua, S. M. and Ayaga, G. O. (2006). A guide to Choice of Mineral Fertilizers in Kenya Technical Note Series. Kenya Agricultural Research Institute KARI, Technical Note No. 17

Kelly, V. and Murekezi, A. 2000. Fertilizer Response and Profitability in Rwanda: A Synthesis of Findings from MINAGRI Studies conducted by the Food Security Research Project and the FAO Soil Fertility Initiative. *Kigali: Food Security Research, MINAGRI.*

Kelly, V. and Nasseem, A. (1999). Fertilizer Use in Sub - Saharan Africa: Types and Amounts. *Encyclopedia of life support system (EOLSS)*. Volume II.

Kenneth, V. R. (2013). Evaluation of Three Cabbage (*Brassica oleraceae* var. *capitata* L.) Varieties Grown for the Fresh Market. *Gladstone Agricultural Centre Crops Research Report No.15*, 2, 32 – 44.

Kołota, E. and Chohura, P. (2015). Control of Head size and Nutritional value of Cabbage by Plant population and Nitrogen fertilization. *Acta Institute* 14, 75 – 85.

Kroetsch, D., and Wang, C. (2008). Particle Size Distribution. In M. R. Carter, and E. G. Gregorich, Soil Sampling and Methods of Analysis. *New York: Taylor and Francis*.

Kulhánek, M., Balík, J., Černý,J., Vašák, F.,. Shejbalová, Š. (2014). Influence of long-term fertilizer application on changes of the content of Mehlich-3 estimated soil macronutrients.*Plant Soil Environment* 60, 151 – 157.

Lalitha M., Kasthuri T. V., Balakrishnan N. and Mostafa M. (2010). Effect of plastic mulch on soil properties and crop growth - a review. *Agricultural research communication centre*. 31, 145 -149.

Land, L. (2015). Science notes Land series L35 Runoff control measures for erosion control in cropping land. pp1-4.

Landon, J. R. (ed) (1991). Booker Tropical Soil Manual; John Wiley and SonsInc.; New York

Liang, Y. L., Zhang, C. E. and Guo, D. W. (2002). Mulch types and their benefit in cropland ecosystems on the loess plateau in china, *Journal of Plant Nutrition* 25, 945 - 955.

Linda C. S. (2007). Impact of Mulches on Landscape Plants and the Environment. *Journal of Environmental Horticulture* 25, 239- 249.

Linjian J., Imed D. and Douglas D. (2016). Effects of Mulching on Soil Temperature, Rooting, and Soil Moisture of Mounded Grapevines. *International Journal of Fruit Science* 16, 182-190.

Locascio, S. J., Gilreath, J. P., Olson, S., Hutchinson, C. M., Chase, C. A. (2005). Red and black mulch color affects production of Florida strawberries. *Horticultural Science* 40, 69 – 71.

Luis, S. Z. and Byizigiro, V. (2012). Rapid risk and capacities assessment and livelihoods profiling in Nyabihu, Musanze and Burera districts affected by floods and landslides. *IOM – MIDIMAR.*

Maniriho and Bizoza (2013): Financial benefit – cost Analysis of agricultural Production in Musanze District. Book available at (http://www.sciencepub.net/academia.3). 5, 30-39.

McIntyre, G.I. . (1987). The role of water in the regulation of plant development. *Canadian Journal of Botany* 65, 1287-1298.

Minirena (2007). Building capacity for sustainable land use and management in Rwanda. pp 1-114.

Nabahungu, N. L. (2013). Rwandan soil health status for sustainable food security and economic growth. http://www.fao.org/fileadmin/user_upload/GSP/docs/South_east_partnership/Rwanda.pdf visited on 21st July, 2016

Navar, J. and Synnot, T. J (2000). Surface runoff, Soil erosion, and Land use in North Eastern Mexico. *Terra volumen*, 18, (). 247 – 253.

Nina, K. M., Martina, Š., Vesna, Z., Sonja, L. and Marina, P. (2012). Quality of white cabbage yield and potential risk of ground water Nitrogen pollution, as affected by Nitrogen fertilization and irrigation practices. *Journal of the Science of Food and Agriculture* 92, 92 – 98.

NRCS (2002). Straw Mulching. *Natural Resources Conservation Service* 2600, 1-4.

Nyle C. Brady (1984). The Nature and Properties of Soils. Tenth edition. Pp18.

Okalebo, J. R., Kenneth, L., and Gathua, W. (2002). Laboratory Methods of Soil and Plant Analysis :a working manual. *Nairobi - Kenya: SACRED Africa*.

Olaniyi, J.O. and Ojetayo, A.E. (2011). Effect of fertilizer types on the growth and yield of two cabbage varieties. *Journal of Animal and Plant Sciences* 12, 1573 – 1582.

Omotayo, O. E. and Chukwuka, K. S. (2009). Soil fertility restoration techniques in sub-Saharan Africa using organic resources. *African Journal of Agricultural Research* 4, 144 – 150.

Onduso, J. (2011). Cabbage Growing Tips for a Good Head Start. *Seed Time* 35, 1-5.

Pearcy, R., Ehleringer, J. Mooney, H. and Rundel, P. (1989). Plant physiological ecology: field methods and instrumentation. New York, NY: Chapman and Hall

Pérez, R. A., Brito, J.D., Guerra, Y., Odríguez, R., and Soria, S. (2015). Morphophysiological Indicators of Cabbage (*Brassica olerace*a L . var . capitata) Planted Inside and Outside

Greenhouse , under Ecuadorian Amazon Conditions. *Journal of Agriculture and Ecology Research International* 3, 160-167.

Peterburgski, AV. (1986). Practical Guidance on Agro-chemistry. *Kolos Publ*., Moscow.

Philip, J. (2013). Erosion control in cropping lands. Science notes Land series L13. School Science Review 95, 11-16.

Pot,G. and Guide, G. (2015). Book. Grow Space where people grow. *Greensmart grow guide* 2015.

Rohwer, C. (2015). Fertilizer, plastic mulch treatments benefit tomato yield. Retrieved from https://phys.org/news/2016-10-fertilizer-plastic-mulch-treatme-nts-benefit.html on 17th July 2017.

Russo, V. M., Cartwright, B. and Webber, C. L. (1997). Mulching Effects on Erosion of Soil Beds and on Yield of Autumn and Spring Planted Vegetables, *Biological Agriculture and Horticulture* 14, 85-93.

Rutherford, P. M., McGill, W. B., Arocena, J. M., and Figueiredo, C. T. (2008). Total Nitrogen. In M. R. Carter, and E. G. Gregorich, Soil Sampling and Methods of Analysis. *New York: Taylor and Francis*, pp. 239-249.

Rutunga, V., Janssen, H. B., Mantel, S. and Janssens M. (2007). Soil use and management strategy for raising food and cash output in Rwanda. *Journal of Food, Agriculture and Environment* 5, 434–441.

Rwanda, G. (2014). National Horticulture Policy and Strategic Implementation Plan. *European Union* 2014/339622

Sajib, K., Dash, P., Adhikary, B. and Abdul, M. (2015). Yield Performance of Cabbage under Different Combinations of Manures and Fertilizers. *World Journal of Agricultural sciences* 11, 411 – 422.

Shabani, Gh., Ardakani, M. R., Chaichi, M. R, Friedel, J. K. and Khavazi, K. (2015). Effect of Different Fertilizing Treatments on Nutrient Uptake in Annual Medic (*Medicago scutellata* cv. Robinson) under Irrigated and Dry Farming Systems. *Agricultural Science and Technology* 17, 299 – 310.

Sommer, R., Bossio, D., Desta, L., Dimes, J., Kihara, J., Koala, S., Mango, N., Rodriguez, D., Thierfelder, C. and Winowiecki, L. (2013). *Profitable and Sustainable Nutrient Management Systems for East and Southern African Smallholder Farming Systems – Challenges and Opportunities*, pp91.

Steven M. (2012). Biodegradable Mulch Film Made From Bioplastics Petition. *Biodegradable Products Institute*, pp299.

Traunfeld J., Nibali E. (2013). Fertilizing guidelines included by plant group. *University of Maryland*, pp1 – 8.

Trdan, S., Žnidarčič, D., Kač, M. and Vidrih, M. (2008).Yield of early white cabbage grown under mulch and non-mulch conditions with low populations of onion thrips (Thripstabaci Lindeman). *International Journal of Pest Management* 54, 309 – 318.

Übelhör, A., Gruber, S., Schlayer, M. and Claupein, W. (2014). Influence of row covers on soil loss and plant growth in white cabbage cultivation. *Plant Soil Environment* 60, 407- 4012

USDA-NRCS (2013): Michigan Technical Note USDA – Natural Resources Conservation Service. Mulching materials for Control of Soil erosion, pp 1- 6.

Van averbeke, W., Juma, K.A. and Tshikalange, T.E. (2007). Yield response of African leafy vegetables to nitrogen, phosphorus and potassium: the case of *Brassica rapa* L. subsp. chinensis and *Solanum retroflexum* Dun. Water SA 33, 355-362.

Van Keulen, H. and Stol, W. 1991. Quantitative aspects of nitrogen nutrition in crops. *Fertilizer research*. 27: 151-160.

Verdoodt, A. and Van Ranst, E. (2003). Land evaluation for agricultural production in the tropics. A large-scale land suitability classification for Rwanda. *Laboratory of Soil Science, Ghent University*.

Vitosh, M. L. (1996). N-P-K FERTILIZERS, types, uses and characteristics. *Michigan State University Extension. Extension Bulletin* E-896.

WDI, 2016. World Bank's catalog: World development indicators - Agriculture and rural development.

Wien, H. C. (1993), Polythene mulch stimulates really roots growth and nutrient uptake of transplanted tomatoes. *Journal of American Society of Horticultural Sciences*, 118, 562–568.

Yaghi, T. and Noum, F. 2013. Cucumber (*Cucumis sativus*, L.) water use effciency (WUE) under plastic mulch and drip irrigation. *Agricultural water management* 128, 149-157.

Yang, N., Sun, Z. X., Feng, L. S., Zheng, M. Z., Chi, D. C., Meng, W. Z., Hou, Z. Y., Bai, W. and Li, K.Y. (2015). Plastic Film Mulching for Water-Efficient. *Agricultural Applications and Degradable Films Materials Development Research, Materials and Manufacturing Processes*, 30, 143-154.

Yang, Y.H., Zong, J.W., Huang, P., Zhao, G.Q., Liang, Y.H. (2015b). Growth of edible lily (Lilium davidii var. unicolor) and bulb yield responses to potassium fertilizer and plastic film mulching. *Journal of horticultural science and biotechnology* 90, 115 - 120.

Zaniewicz, B., Franczuk, J., Kosterna, E. (2009). Direct and secondary effects of soil mulching with straw on fresh mass and number of weeds, vegetable yield. *Polish Journal of Environmental Studies* 18, 1185-1190.

Ziadi, N. and Sen, T. T. (2008). Mehlich 3- Extractable Elements. In M. R. Carter, and E. R. Gregorich, Soil Sampling and Methods of Analysis. *New York: Taylor and Francis*, pp. 81-87.

Zoe, D. and Jesus, B.H. (2012). Fertilizer Subsidies in Sub - Saharan Africa. *ESA working paper* No 12.

APPENDICES

Appendix 1: Analysis of variance (ANOVA) for growth and yield parameters

		Mean Squares							
		Season I				Season II			
Source of variation	**Df**	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**
Stem diameter									
Mulch	2	8.09*	0.95ns	5.09ns	5.30ns	11.40***	52.95***	38.95***	51.63***
Fertilizer	3	0.72ns	1.58ns	4.45ns	1.66ns	6.49***	10.69**	10.46**	10.19ns
Mulch ×Fertilizer	6	0.89ns	2.57ns	8.85ns	3.52ns	2.39*	5.47*	8.41**	7.74ns
R2		0.49	0.29	0.41	0.55	0.77	0.81	0.78	0.68
CV		14.97	12.37	10.77	8.61	8.26	8.64	6.80	7.00
Height									
Mulch	2	72.93***	11.89ns	9.96ns	1.74ns	83.15***	149.37***	160.38***	73.54***
Fertilizer	3	9.19ns	15.12*	23.25*	26.97**	23.96***	39.22***	21.19*	0.85ns
Mulch ×Fertilizer	6	1.97ns	3.98ns	4.96ns	3.05ns	2.52ns	5.06ns	4.46ns	6.07ns
R2		0.64	0.54	0.45	0.54	0.82	0.84	0.81	0.60
CV		13.31	8.83	9.48	7.14	9.44	7.58	7.17	8.30
Leaf Area									
Mulch	2	3589.31***	3964.12*	21395.40***	9635.38*	13758.49***	87555.11***	199857.92***	123527.15***
Fertilizer	3	2278.93***	4029.02**	30989.15***	29346.63***	3907.63**	27183.24*	32710.69*	3439.86ns
Mulch ×Fertilizer	6	660.88ns	1513.08ns	3779.15ns	3726.83ns	607.03ns	4105.01ns	8962.34ns	8580.12ns
R2		0.74	0.66	0.85	0.79	0.77	0.69	0.79	0.62
CV		14.99	9.91	7.28	6.76	18.57	19.43	13.41	14.46

ns: non-significant, *: Significant $p \leq 0.05$, **: Significant $p \leq 0.01$, ***: Significant $p \leq 0.001$.

ANOVA cont'd

		Mean Squares							
		Season I				Season II			
Source of variation	**Df**	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**
		Number of leaves							
Mulch	2	0.78*	6.03***	9.03**	8.36**	9.36**	4.75*	8.78***	2.53ns
Fertilizer	3	2.30***	2.30**	0.92ns	2.30ns	5.56**	4.25*	1.95ns	3.58ns
Mulch × Fertilizer	6	1.41***	0.99*	3.92*	0.88ns	1.47ns	1.64ns	0.81ns	2.31ns
R2		0.86	0.83	0.65	0.66	0.67	0.65	0.70	0.58
CV		3.65	3.80	6.28	5.68	8.87	6.13	4.91	6.93
		Leaf Area Index (LAI)							
Mulch	2	0.05***	0.03ns	1.25***	0.61*	0.19***	2.22***	5.61***	3.43***
Fertilizer	3	0.02**	0.10***	0.70**	1.07**	0.07**	0.84*	1.03**	0.03ns
Mulch × Fertilizer	6	0.01*	0.07***	0.36*	0.23ns	0.01ns	0.11ns	0.26ns	0.16ns
R2		0.74	0.82	0.69	0.67	0.73	0.70	0.81	0.57
CV		17.8	8.29	14.31	12.71	24.90	22.67	14.59	17.32

ns: non-significant, *: Significant $p \leq 0.05$, **: Significant $p \leq 0.01$, ***: Significant $p \leq 0.001$.

ANOVA cont'd

		Mean squares					
		Season I			Season II		
Source of variation	**df**	**60 DAT**	**75 DAT**	**90 DAT**	**60 DAT**	**75 DAT**	**90 DAT**
			Rosette diameter				
Mulch	2	5.71ns	14.06ns		332.26***	218.35***	
Fertilizer	3	23.90*	38.62***		30.37**	17.38ns	
Mulch × Fertilizer	6	5.36ns	24.99**		10.06ns	24.62*	
R2		0.62	0.79		0.88	0.78	
CV		4.87	3.91		4.47	5.08	
			Head diameter				
Mulch	2	5.56*	9.15*	13.10**	50.24***	92.79***	36.16***
Fertilizer	3	2.58ns	13.49**	8.75**	9.96***	14.27***	4.69*
Mulch × Fertilizer	6	4.65**	5.30ns	3.08ns	2.59ns	7.06***	8.07***
R2		0.70	0.67	0.66	0.87	0.92	0.83
CV		8.28	7.79	6.26	10.15	6.53	4.94
			Weight				
Mulch	2			1639107.80***			9863118.96***
Fertilizer	3			431040.23*			383943.74*
Mulch × Fertilizer	6			183787.24ns			344887.89*
R2				0.78			0.92
CV				9.78			8.32

ns: non-significant, *: Significant p ≤ 0.05, **: Significant p ≤ 0.01, ***: Significant p ≤ 0.001.

Appendix 2: Analysis of variance for dry matter and nutrient uptake

		Mean squares	
		Season I	Season II
Source of variation	**Df**	**60 DAT**	**60 DAT**
		Dry matter	
Mulch	2	303208.40*	2770913.65***
Fertilizer	3	539876.92***	421816.52*
Mulch × Fertilizer	6	379465.92***	494574.41**
R^2		0.78	0.84
CV		13.42	14.08
		N Uptake	
Mulch	2	589.01**	2585.97***
Fertilizer	3	132.33ns	123.39ns
Mulch × Fertilizer	6	336.80**	213.48ns
R^2		0.69	0.73
CV		20.7	22.06
		P Uptake	
Mulch	2	1.66ns	5.80ns
Fertilizer	3	206.73**	327.56**
Mulch × Fertilizer	6	37.71ns	92.58ns
R^2		0.63	0.63
CV		27.92	19.43
		K Uptake	
Mulch	2	245.10ns	2067.86***
Fertilizer	3	926.69**	508.47**
Mulch × Fertilizer	6	722.29**	265.90*
R^2		0.70	0.83
CV		20.08	15.71

ns: non-significant, *: Significant $p \leq 0.05$, **: Significant $p \leq 0.01$, ***: Significant $p \leq 0.001$

Appendix 3: Analysis of variance for soil moisture content at different DAT

Mean squares for Moisture Content							
		Season I			Season II		
Source of variation	**Df**	**30 DAT**	**60 DAT**	**90 DAT**	**30 DAT**	**60 DAT**	**90 DAT**
Mulch	2	11.00ns	154.29***	123.49***	35.92ns	47.35ns	81.94*
Fertilizer	3	38.04ns	18.57ns	22.19ns	55.49*	42.48ns	62.57*
Mulch × Fertilizer	6	15.74ns	10.58ns	16.97ns	26.98ns	12.03ns	26.97ns
R^2		0.71	0.60	0.63	0.55	0.42	0.53
CV		17.83	22.46	26.54	14.77	17.50	14.12

ns: non-significant, *: Significant $p \leq 0.05$, **: Significant $p \leq 0.01$, ***: Significant $p \leq 0.001$

Appendix 4: Analysis of variance for soil available P, K and total N content after harvesting

Mean squares for Soil after harvesting			
Source of variation	**Df**	**Season I**	**Season II**
		Soil available P	
Mulch	2	550.20**	193.51*
Fertilizer	3	510.69**	804.97***
Mulch × Fertilizer	6	212.24ns	489.18***
R^2		0.91	0.85
CV		9.64	5.55
		Soil exchangeable K	
Mulch	2	0.0005ns	0.00003ns
Fertilizer	3	0.0135**	0.00951**
Mulch × Fertilizer	6	0.0058*	0.00072*
R^2		0.67	0.69
CV		14.30	13.07
		Soil total N	
Mulch	2	0.006ns	0.016*
Fertilizer	3	0.007ns	0.001ns
Mulch × Fertilizer	6	0.009**	0.004ns

R^2	0.75	0.77
CV	13.54	15.15

ns: non-significant, *: Significant $p \leq 0.05$, **: Significant $p \leq 0.01$, ***: Significant $p \leq 0.001$

Appendix 5: Soil pH, available P and K and total N before and after harvesting

	Before planting		After harvesting	
Parameters	Season I	Season II	Season I	Season II
pH H_2O	5.8	5.4	5.8	6.1
TN(%)	0.32	0.45	0.35	0.36
Available P (ppm)	135	180	99	136
Exchangeable K ($Cmol_c$/kg)	0.66	0.60	0.29	0.21

Appendix 6: Soil and plant tissues analysis results interpretation norms

			Range		
Soil analysis	**Very low**	**Low**	**Medium**	**High**	**Very High**
pH		<5.5	5.5 – 7.0	>7.0	
Organic Matter (%)		<4.0	4.0 – 10.0	>10.0	
Total N (%)	<0.1	0.1 -0.2	0.2 – 0.5	0.5 – 1.0	>1.0
Available P (ppm)		<5.0	5.0 – 15.0	>15.0	
K^+ (meq/100g)		<0.2	0.2 – 0.6	>0.6	
Ca^{2+} (meq/100g)		<4.0	4.0 – 10.0	>10.0	
Mg^{2+} (meq/100g)		<0.5	0.5 – 4.0	>4.0	
CEC (meq/100g)	<5.0	5.0 – 15.0	15.0 – 25.0	>25.0 - 40.0	>40.0
Plant tissues analysis					
Total N (%)		<3.5	3.5 – 5.0	>5.0	
Total P (%)		<0.35	0.35 – 0.80	>0.80	
Total K (%)		<3.0	3.0 – 5.0	>5.0	

Source: Horneck *et al*., 2011; Landon, 1991. (meq/100g) = $Cmol_c$/kg * Z; where Z is the charge of element.

Appendix 7: Raw data for height at different DAT

			Height (cm)							
			Season1				Season2			
M	B	F	30	45	60	75	30	45	60	75
M0	1	0	16.04	21.49	32.63	30.25	18.00	27.95	31.30	27.18
M0	1	1	16.98	22.24	30.08	29.50	13.71	21.46	24.00	26.63
M0	1	2	14.88	21.08	27.13	26.50	12.43	19.49	23.93	27.28
M0	1	3	15.29	20.41	26.13	28.38	11.91	19.49	26.23	31.05
M1	1	0	16.34	23.55	29.38	32.00	16.96	27.24	31.45	31.50
M1	1	1	16.99	26.44	31.58	33.63	16.53	24.63	27.85	27.13
M1	1	2	15.39	22.99	29.55	28.50	17.84	24.68	30.50	31.83
M1	1	3	13.09	19.44	27.78	28.75	15.63	21.84	28.16	26.40
M2	1	0	18.00	21.76	27.88	30.13	19.41	30.08	31.66	31.68
M2	1	1	17.53	23.15	28.38	29.38	20.18	31.60	33.58	30.03
M2	1	2	18.21	24.85	27.13	28.55	20.55	32.20	35.90	33.23
M2	1	3	17.89	23.70	26.75	23.75	17.11	26.50	30.43	29.25
M0	2	0	15.45	20.30	25.95	26.00	15.63	24.65	27.13	25.58
M0	2	1	15.31	21.95	29.65	28.73	13.30	22.99	25.33	28.25
M0	2	2	18.05	24.46	30.98	30.55	12.95	22.45	24.88	24.08
M0	2	3	17.79	24.40	27.63	29.00	12.98	20.36	23.80	26.88
M1	2	0	15.43	20.73	26.90	27.65	18.93	29.39	33.14	29.25
M1	2	1	14.09	22.89	30.83	31.10	18.53	30.08	33.26	31.73
M1	2	2	14.01	20.88	25.50	28.38	19.31	29.76	32.75	34.75
M1	2	3	13.01	18.23	26.08	27.50	16.01	25.10	29.38	32.30
M2	2	0	18.06	22.14	31.03	30.63	22.10	32.09	32.74	29.73
M2	2	1	19.39	24.93	29.63	31.43	15.09	27.95	35.11	33.25
M2	2	2	17.08	22.41	27.85	29.00	19.00	27.91	28.24	27.93
M2	2	3	14.28	17.90	25.40	28.00	17.81	29.09	33.01	32.80
M0	3	0	16.13	22.84	29.85	28.53	17.06	26.95	29.00	30.30
M0	3	1	15.06	25.58	35.50	36.50	15.06	24.30	26.65	24.30
M0	3	2	15.58	20.88	24.68	28.35	14.56	24.51	25.51	26.88
M0	3	3	14.11	21.94	31.40	26.98	10.31	18.96	20.21	28.00
M1	3	0	11.47	19.56	24.65	32.68	22.90	33.40	33.68	35.53
M1	3	1	14.94	22.84	29.85	32.28	16.88	28.86	29.50	33.65
M1	3	2	14.90	23.44	29.38	29.33	18.91	27.33	30.91	30.53
M1	3	3	10.03	17.05	21.50	26.60	13.88	23.03	27.33	28.05
M2	3	0	22.75	24.88	34.40	33.55	19.73	29.10	34.58	33.53
M2	3	1	22.45	25.06	32.20	31.53	18.81	30.13	31.79	33.88
M2	3	2	24.31	25.89	30.03	27.25	19.39	30.11	34.06	31.68
M2	3	3	18.14	25.11	31.53	30.25	19.84	30.71	32.33	34.85

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 8: Raw data for stem diameter at different DAT

			Stem diameter (mm)							
			Season I				Season II			
M	B	F	30	45	60	75	30	45	60	75
M0	1	0	10.60	17.83	26.10	26.85	11.93	17.10	23.36	28.40
M0	1	1	8.41	15.45	18.85	24.03	8.76	12.42	18.05	25.38
M0	1	2	8.43	13.89	19.28	22.98	9.36	12.54	18.45	24.11
M0	1	3	7.84	13.60	17.98	23.85	8.03	11.73	16.80	25.72
M1	1	0	7.10	14.18	22.18	24.88	9.71	16.03	19.99	31.38
M1	1	1	7.43	17.73	22.90	27.08	9.86	15.07	20.63	28.31
M1	1	2	8.01	15.93	20.30	22.95	10.46	15.91	22.95	30.12
M1	1	3	6.68	14.46	23.08	25.63	9.66	14.66	18.74	26.63
M2	1	0	9.90	14.70	21.08	25.60	11.75	17.99	22.74	31.38
M2	1	1	8.09	15.83	22.80	21.25	12.22	18.72	23.12	30.60
M2	1	2	8.63	17.14	23.65	24.55	12.79	18.93	22.87	32.05
M2	1	3	11.59	20.03	19.40	21.05	11.87	17.34	22.62	31.41
M0	2	0	7.51	14.71	21.08	24.48	11.83	16.86	22.69	26.61
M0	2	1	7.98	14.31	18.33	24.23	10.75	15.90	20.57	28.24
M0	2	2	8.58	15.85	22.95	27.73	9.45	13.82	19.82	23.07
M0	2	3	9.39	18.63	22.75	28.45	8.86	12.71	18.43	24.27
M1	2	0	7.43	16.36	18.50	29.20	11.65	17.70	23.56	29.40
M1	2	1	7.91	15.19	20.82	26.80	11.49	19.52	24.98	31.52
M1	2	2	7.16	13.68	19.55	27.40	12.84	18.53	24.26	30.49
M1	2	3	6.90	13.79	21.70	28.25	10.13	17.52	22.66	29.28
M2	2	0	7.15	13.63	21.58	25.43	12.62	19.93	22.67	27.83
M2	2	1	9.53	17.11	26.45	29.10	11.02	17.90	22.76	31.51
M2	2	2	7.26	14.03	20.08	23.25	12.31	17.01	20.62	26.76
M2	2	3	6.30	10.59	17.45	21.30	11.33	18.11	23.56	31.75
M0	3	0	7.81	15.49	21.68	29.33	11.92	17.94	22.05	28.94
M0	3	1	7.68	15.21	19.65	26.55	10.79	16.68	18.57	28.90
M0	3	2	9.50	14.40	20.15	27.18	10.64	17.05	21.77	27.29
M0	3	3	8.00	14.96	21.00	27.23	6.30	8.78	13.79	21.11
M1	3	0	6.67	14.49	18.18	25.53	13.03	20.12	24.85	32.80
M1	3	1	7.48	15.29	24.38	31.18	10.94	17.68	22.79	29.05
M1	3	2	7.53	15.60	22.83	29.70	12.71	19.33	22.92	26.29
M1	3	3	3.99	12.25	16.08	26.00	10.07	17.42	20.00	26.04
M2	3	0	7.31	14.80	23.08	28.95	11.26	19.06	22.22	26.14
M2	3	1	8.08	16.00	23.00	28.68	11.65	18.33	24.51	30.82
M2	3	2	9.38	16.60	22.25	30.48	11.33	18.29	22.51	28.29
M2	3	3	7.73	14.70	22.85	29.73	11.71	20.50	24.30	29.63

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 9: Raw data for leaf area at different DAT

			Leaf area							
			Season I				Season II			
M	B	F	30	45	60	75	30	45	60	75
M0	1	0	93.79	279.37	510.18	563.98	139.35	412.49	639.30	615.88
M0	1	1	124.26	293.81	541.07	692.89	66.71	239.65	378.66	414.83
M0	1	2	96.38	282.00	462.27	551.42	78.71	389.85	363.42	499.95
M0	1	3	117.92	308.34	462.78	533.72	52.30	210.75	406.25	574.82
M1	1	0	83.40	263.91	504.84	593.11	112.62	229.08	616.49	654.24
M1	1	1	144.36	344.00	613.51	754.71	130.58	351.80	552.03	550.04
M1	1	2	98.09	297.86	513.60	662.67	143.22	369.22	646.84	741.23
M1	1	3	83.36	223.57	407.48	675.92	107.62	404.45	506.11	569.24
M2	1	0	106.38	265.41	568.03	668.05	182.28	477.07	646.95	722.40
M2	1	1	142.29	327.65	619.39	644.63	188.28	504.75	734.55	642.40
M2	1	2	119.82	269.91	515.66	587.01	157.96	546.41	862.78	825.29
M2	1	3	156.10	279.73	494.92	522.19	127.53	364.86	654.46	739.67
M0	2	0	90.84	222.92	443.20	532.08	121.48	426.59	543.42	519.63
M0	2	1	94.64	299.71	572.90	631.73	105.55	323.92	478.02	512.87
M0	2	2	109.12	303.67	472.00	543.11	93.85	293.89	440.15	437.46
M0	2	3	118.82	293.11	533.55	568.86	84.31	262.12	447.31	568.98
M1	2	0	91.25	260.10	525.39	517.95	167.08	539.66	795.85	673.37
M1	2	1	113.42	286.77	587.22	739.88	173.00	580.50	799.98	777.54
M1	2	2	97.60	240.73	530.05	582.15	193.04	553.04	797.99	841.22
M1	2	3	82.69	207.10	423.93	539.85	144.33	447.74	605.30	792.56
M2	2	0	115.63	231.86	564.61	583.00	185.30	573.68	674.89	623.63
M2	2	1	175.39	312.42	703.95	672.01	123.17	493.80	800.88	857.68
M2	2	2	101.77	240.05	523.01	632.86	153.40	472.61	606.32	584.93
M2	2	3	116.32	264.49	455.94	561.98	151.75	474.92	700.14	675.12
M0	3	0	97.13	300.48	592.22	565.44	141.43	446.19	581.15	666.91
M0	3	1	146.08	280.42	659.90	721.73	103.47	349.82	527.45	533.91
M0	3	2	99.72	309.89	512.71	554.46	116.27	406.70	552.28	602.34
M0	3	3	114.65	254.78	535.83	592.66	42.03	143.32	268.74	455.60
M1	3	0	79.29	206.48	505.84	538.12	215.74	662.88	833.48	875.74
M1	3	1	127.03	267.69	579.42	731.76	140.58	444.16	670.29	683.53
M1	3	2	136.51	272.65	610.97	665.84	196.43	536.49	662.72	709.49
M1	3	3	40.05	189.79	464.64	578.99	102.71	351.18	522.82	615.39
M2	3	0	122.79	320.98	709.87	684.23	143.31	467.42	733.26	611.08
M2	3	1	149.29	329.80	745.32	744.73	143.46	507.79	725.02	753.90
M2	3	2	142.21	296.14	698.74	699.60	157.37	498.70	723.05	805.80
M2	3	3	134.63	309.17	560.51	686.49	155.78	452.59	668.38	697.34

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 10: Raw data for number of leaves at different DAT

			Number of leaves							
			Season I				Season II			
M	B	F	30	45	60	75	30	45	60	75
M0	1	0	11	15	18	17	13	17	16	15
M0	1	1	10	14	15	16	12	15	17	20
M0	1	2	12	13	15	16	10	14	15	17
M0	1	3	10	14	17	15	8	13	15	17
M1	1	0	11	16	16	17	12	16	17	17
M1	1	1	12	16	18	17	12	16	18	18
M1	1	2	12	15	20	16	13	15	19	18
M1	1	3	10	14	19	17	10	13	16	18
M2	1	0	12	15	19	18	12	16	15	17
M2	1	1	11	15	19	18	12	16	17	17
M2	1	2	11	14	18	17	11	16	18	17
M2	1	3	11	14	18	16	11	15	15	17
M0	2	0	10	13	17	18	11	17	18	19
M0	2	1	10	13	16	17	9	14	16	21
M0	2	2	12	13	17	16	10	15	17	18
M0	2	3	10	14	17	17	10	14	17	19
M1	2	0	11	15	17	19	13	16	18	18
M1	2	1	11	16	17	18	12	16	19	18
M1	2	2	11	15	20	18	13	18	19	20
M1	2	3	10	13	16	19	12	17	19	24
M2	2	0	12	13	17	18	13	17	18	17
M2	2	1	11	15	20	21	9	15	17	17
M2	2	2	10	13	19	17	11	17	17	17
M2	2	3	10	13	15	19	11	16	17	19
M0	3	0	12	14	17	16	12	17	18	18
M0	3	1	10	14	17	18	11	16	17	19
M0	3	2	12	14	14	15	11	15	16	18
M0	3	3	11	14	16	17	8	14	15	19
M1	3	0	11	15	16	16	13	18	18	18
M1	3	1	12	17	18	19	12	17	19	20
M1	3	2	12	15	17	17	13	18	18	18
M1	3	3	11	15	17	20	11	16	17	19
M2	3	0	13	15	18	18	10	15	18	20
M2	3	1	12	16	18	18	11	16	17	19
M2	3	2	12	15	18	19	11	15	17	19
M2	3	3	11	15	17	18	11	16	17	19

M = Mulch, B = Block, F = Fertilizer, 0 = $0 kgha^{-1}$, 1= $60 kgha^{-1}$, 2 = $120 kgha^{-1}$, 3 = $180 kgha^{-1}$.

Appendix 11: Raw data for leaf area index at different DAT

			Leaf area index							
			Season I				Season II			
M	B	F	30	45	60	75	30	45	60	75
M0	1	0	0.29	1.32	3.05	2.65	0.50	1.89	2.84	2.61
M0	1	1	0.35	1.13	1.93	3.19	0.21	0.99	1.75	2.33
M0	1	2	0.31	1.08	1.93	2.49	0.22	1.50	1.55	2.33
M0	1	3	0.34	1.23	1.66	2.22	0.12	0.73	1.66	2.71
M1	1	0	0.25	1.15	2.21	2.72	0.37	1.03	2.95	3.13
M1	1	1	0.45	1.48	3.02	3.56	0.42	1.53	2.80	2.71
M1	1	2	0.32	1.25	2.75	2.99	0.51	1.58	3.39	3.71
M1	1	3	0.21	0.86	2.49	3.24	0.29	1.50	2.30	2.85
M2	1	0	0.35	1.12	3.04	3.29	0.63	2.12	2.74	3.36
M2	1	1	0.43	1.27	3.34	3.24	0.63	2.21	3.37	3.03
M2	1	2	0.36	1.05	2.08	2.81	0.48	2.43	4.19	3.90
M2	1	3	0.58	1.18	2.41	2.65	0.39	1.47	2.75	3.44
M0	2	0	0.26	1.04	2.12	2.27	0.37	1.97	2.77	2.78
M0	2	1	0.27	1.09	2.47	2.94	0.27	1.29	2.17	2.92
M0	2	2	0.34	0.96	2.60	2.38	0.27	1.20	2.11	2.13
M0	2	3	0.34	1.11	2.85	2.61	0.24	1.04	2.16	3.04
M1	2	0	0.29	1.09	2.41	2.70	0.59	2.40	3.90	3.37
M1	2	1	0.34	1.10	2.69	3.34	0.58	2.60	4.14	3.94
M1	2	2	0.28	1.02	2.81	2.94	0.70	2.71	4.27	4.56
M1	2	3	0.23	0.77	2.44	2.77	0.48	2.16	3.13	5.23
M2	2	0	0.39	0.86	2.71	2.92	0.64	2.71	3.30	2.90
M2	2	1	0.52	1.51	3.96	3.31	0.32	2.06	3.78	3.93
M2	2	2	0.28	1.09	2.69	2.90	0.48	2.18	2.91	2.76
M2	2	3	0.36	1.06	2.15	2.93	0.47	2.11	3.38	3.52
M0	3	0	0.31	1.20	2.51	2.51	0.47	2.06	2.89	3.29
M0	3	1	0.42	1.10	3.02	4.77	0.30	1.54	2.49	2.82
M0	3	2	0.30	1.05	1.66	2.03	0.34	1.74	2.51	2.93
M0	3	3	0.31	1.22	2.34	2.80	0.10	0.54	1.15	2.34
M1	3	0	0.24	1.06	1.76	2.39	0.80	3.38	4.23	4.32
M1	3	1	0.49	1.44	2.94	3.23	0.48	2.10	3.44	3.70
M1	3	2	0.44	1.12	2.89	2.59	0.68	2.63	3.36	3.45
M1	3	3	0.13	0.74	2.14	3.18	0.32	1.59	2.52	3.25
M2	3	0	0.43	1.14	3.45	3.37	0.41	1.96	3.67	3.31
M2	3	1	0.50	1.44	3.73	3.72	0.42	2.29	3.35	3.98
M2	3	2	0.47	1.21	2.86	3.74	0.46	2.13	3.44	4.31
M2	3	3	0.42	1.26	2.69	3.38	0.49	1.98	3.20	3.73

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 12: Raw data for head diameter at different DAT

			Head diameter (cm)					
			Season I			Season II		
M	B	F	60	75	90	60	75	90
M0	1	0	13.50	20.25	20.46	9.19	19.23	22.68
M0	1	1	11.13	19.05	19.73	7.24	13.45	20.03
M0	1	2	11.68	16.25	18.13	5.86	11.70	18.18
M0	1	3	11.30	15.50	16.55	6.53	14.48	20.28
M1	1	0	12.43	18.06	18.00	10.36	17.23	20.30
M1	1	1	14.44	24.10	24.03	8.16	18.25	22.05
M1	1	2	14.38	19.72	22.30	11.66	22.57	27.87
M1	1	3	13.50	19.20	22.63	7.84	14.40	21.23
M2	1	0	14.13	20.00	22.70	10.68	19.33	23.48
M2	1	1	13.65	18.05	21.69	11.76	19.63	23.73
M2	1	2	12.35	17.43	20.60	12.05	21.45	22.83
M2	1	3	12.50	17.03	19.10	10.03	18.43	24.05
M0	2	0	10.43	18.08	18.65	10.10	13.88	21.93
M0	2	1	10.78	22.43	19.58	7.56	8.03	20.10
M0	2	2	12.95	19.61	21.13	7.46	15.23	20.55
M0	2	3	12.73	17.22	19.28	7.15	11.30	20.28
M1	2	0	13.58	23.35	20.35	13.25	17.75	22.83
M1	2	1	12.33	21.90	23.45	11.53	19.70	26.35
M1	2	2	13.78	21.01	19.60	14.71	20.10	26.75
M1	2	3	11.53	23.10	20.85	10.84	16.40	24.80
M2	2	0	13.35	20.40	20.28	13.74	17.23	21.18
M2	2	1	14.60	22.13	23.00	10.45	19.75	24.80
M2	2	2	10.40	18.25	19.50	12.21	16.80	22.78
M2	2	3	11.04	17.77	18.83	10.76	18.55	22.83
M0	3	0	14.08	20.30	19.10	9.85	15.28	21.70
M0	3	1	11.93	20.93	22.08	10.06	15.95	19.50
M0	3	2	13.28	18.38	19.00	9.43	16.95	22.90
M0	3	3	12.63	17.36	18.54	6.88	5.70	14.88
M1	3	0	11.53	18.40	19.45	14.45	20.55	22.95
M1	3	1	14.48	20.95	21.55	12.86	19.98	22.10
M1	3	2	16.55	20.93	20.25	14.41	18.50	23.73
M1	3	3	12.49	19.55	21.04	10.25	15.93	21.20
M2	3	0	16.88	23.15	22.75	11.23	14.90	22.55
M2	3	1	15.08	21.78	22.90	12.69	18.55	24.78
M2	3	2	14.10	23.08	21.87	12.30	17.53	24.65
M2	3	3	12.00	17.91	21.15	11.44	17.13	24.18

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 13: Raw data for Rosette diameter at different DAT

			Rosette diameter			
			Season I		Season II	
M	B	F	60	75	60	75
M0	1	0	49.22	52.61	45.81	57.68
M0	1	1	50.02	57.12	44.33	49.75
M0	1	2	48.02	53.22	43.40	49.43
M0	1	3	46.35	52.30	44.98	55.00
M1	1	0	50.10	52.48	55.94	57.98
M1	1	1	54.55	59.63	55.31	57.83
M1	1	2	50.37	58.45	58.06	61.73
M1	1	3	51.45	57.93	50.24	52.70
M2	1	0	51.18	58.38	54.45	59.55
M2	1	1	46.83	54.23	56.38	62.18
M2	1	2	47.80	53.73	53.69	60.33
M2	1	3	48.35	49.83	49.49	59.73
M0	2	0	49.23	50.70	52.03	55.23
M0	2	1	50.38	58.38	49.84	51.58
M0	2	2	48.04	49.38	47.41	54.90
M0	2	3	52.60	54.25	48.31	53.75
M1	2	0	49.15	50.30	56.50	59.15
M1	2	1	56.83	53.95	59.16	67.53
M1	2	2	49.20	49.90	62.93	67.83
M1	2	3	51.63	53.15	55.50	61.70
M2	2	0	47.98	52.98	58.05	61.30
M2	2	1	51.35	54.20	63.78	68.68
M2	2	2	46.40	52.23	57.71	62.45
M2	2	3	46.51	48.08	60.60	58.35
M0	3	0	48.93	52.00	53.40	59.65
M0	3	1	59.48	61.58	51.10	52.73
M0	3	2	51.48	49.03	48.99	54.60
M0	3	3	52.15	54.65	45.44	52.82
M1	3	0	50.77	51.33	63.50	66.70
M1	3	1	53.90	56.50	54.81	61.28
M1	3	2	50.88	56.95	56.83	59.75
M1	3	3	51.74	55.30	50.50	53.73
M2	3	0	57.23	59.75	60.15	58.30
M2	3	1	56.15	61.70	58.38	63.45
M2	3	2	53.55	58.10	59.23	64.93
M2	3	3	53.25	53.42	56.99	62.72

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 14: Raw data for yield at commercial maturity (head weight)

			Fresh weight (g/plant)		Fresh weight ($kgha^{-1}$)	
Mulch	Block	Fertilizer	Season I	Season II	Season I	Season II
M0	1	0	2373.00	3125.00	65916.67	86805.56
M0	1	1	2300.00	2075.00	63888.89	57638.89
M0	1	2	2312.50	2225.00	64236.11	61805.56
M0	1	3	2435.00	2337.00	67638.89	64916.67
M1	1	0	2450.00	3875.00	68055.56	107638.89
M1	1	1	3650.00	4070.00	101388.89	113055.56
M1	1	2	2781.00	4983.33	77250.00	138425.93
M1	1	3	3125.00	3687.50	86805.56	102430.56
M2	1	0	2962.50	4050.00	82291.67	112500.00
M2	1	1	3243.00	3987.50	90083.33	110763.89
M2	1	2	3487.50	4612.50	96875.00	128125.00
M2	1	3	2825.00	3925.00	78472.22	109027.78
M0	2	0	2175.00	2837.50	60416.67	78819.44
M0	2	1	3162.50	2475.00	87847.22	68750.00
M0	2	2	3100.00	2400.00	86111.11	66666.67
M0	2	3	3125.00	2862.50	86805.56	79513.89
M1	2	0	3250.00	3562.50	90277.78	98958.33
M1	2	1	3800.00	4124.00	105555.56	114555.56
M1	2	2	2637.50	4743.00	73263.89	131750.00
M1	2	3	2941.00	4350.00	81694.44	120833.33
M2	2	0	3337.50	3312.50	92708.33	92013.89
M2	2	1	3800.00	4200.00	105555.56	116666.67
M2	2	2	3679.00	4253.00	102194.44	118138.89
M2	2	3	2825.00	4075.00	78472.22	113194.44
M0	3	0	2700.00	3050.00	75000.00	84722.22
M0	3	1	3412.50	2662.50	94791.67	73958.33
M0	3	2	2612.50	3150.00	72569.44	87500.00
M0	3	3	2975.00	2473.00	82638.89	68694.44
M1	3	0	2750.00	4525.00	76388.89	125694.44
M1	3	1	3287.50	4300.00	91319.44	119444.44
M1	3	2	3100.00	4825.00	86111.11	134027.78
M1	3	3	3128.00	3575.00	86888.89	99305.56
M2	3	0	4087.50	3975.00	113541.67	110416.67
M2	3	1	3937.50	4537.50	109375.00	126041.67
M2	3	2	3865.00	4762.50	107361.11	132291.67
M2	3	3	3500.00	4750.00	97222.22	131944.44

Appendix 15: Raw data for dry matter before heading at 60DAT

			Dry matter (Kgha^{-1})	
Mulch	Block	Fertilizer	Season I	Season II
M0	1	0	1607.44	2436.48
M0	1	1	2082.32	1459.14
M0	1	2	1422.07	1118.97
M0	1	3	1594.54	927.41
M1	1	0	2168.87	2086.60
M1	1	1	2740.81	1879.46
M1	1	2	2578.46	2486.71
M1	1	3	1369.88	2099.19
M2	1	0	1316.50	2129.24
M2	1	1	1841.42	2799.58
M2	1	2	2138.77	2486.81
M2	1	3	2023.19	2286.25
M0	2	0	1668.72	2153.70
M0	2	1	1672.57	2177.46
M0	2	2	1728.06	1335.24
M0	2	3	1677.57	1496.24
M1	2	0	2045.63	3006.54
M1	2	1	2353.96	2726.67
M1	2	2	2192.92	3457.78
M1	2	3	1242.93	2675.09
M2	2	0	1583.51	2497.78
M2	2	1	1567.39	3151.60
M2	2	2	1741.77	2838.82
M2	2	3	1533.47	2524.39
M0	3	0	1893.46	2250.94
M0	3	1	1834.34	1591.04
M0	3	2	1261.40	2220.17
M0	3	3	1473.05	714.86
M1	3	0	1606.05	2260.28
M1	3	1	2061.53	1394.29
M1	3	2	2469.23	2739.02
M1	3	3	899.20	2067.59
M2	3	0	1504.81	2402.78
M2	3	1	2210.31	2778.82
M2	3	2	2408.01	2466.04
M2	3	3	1876.18	2266.18

Appendix 16: Raw data for nitrogen concentration in tissues and uptake before heading at 60DAT

			N $_{total}$ (%)		N $_{Uptake}$ (Kgha^{-1})	
Mulch	Block	Fertilizer	Season I	Season II	Season I	Season II
M0	1	0	2.63	2.24	42.31	54.58
M0	1	1	1.86	2.30	38.73	33.56
M0	1	2	1.96	2.80	27.87	31.33
M0	1	3	2.38	3.08	37.95	28.56
M1	1	0	3.07	2.39	66.50	49.87
M1	1	1	2.10	2.52	57.56	47.36
M1	1	2	2.54	1.96	65.49	48.74
M1	1	3	2.70	2.80	36.99	58.78
M2	1	0	1.39	2.24	18.25	47.69
M2	1	1	2.56	2.52	47.18	70.55
M2	1	2	2.39	2.66	51.20	66.15
M2	1	3	1.82	2.94	36.82	67.22
M0	2	0	2.41	2.38	40.18	51.26
M0	2	1	1.81	2.88	30.27	62.71
M0	2	2	1.97	3.08	34.04	41.13
M0	2	3	2.14	3.50	35.82	52.37
M1	2	0	3.25	2.66	66.44	79.97
M1	2	1	1.75	3.07	41.19	83.71
M1	2	2	2.45	2.94	53.73	101.66
M1	2	3	2.60	3.50	32.37	93.63
M2	2	0	2.17	3.39	34.36	84.67
M2	2	1	2.01	3.36	31.55	105.89
M2	2	2	2.10	3.21	36.58	91.13
M2	2	3	2.72	2.52	41.65	63.61
M0	3	0	2.71	2.52	51.35	56.72
M0	3	1	1.05	2.66	19.26	42.32
M0	3	2	2.21	3.22	27.88	71.49
M0	3	3	3.22	2.66	47.43	19.02
M1	3	0	2.53	2.52	40.70	56.96
M1	3	1	2.38	2.38	49.06	33.18
M1	3	2	2.28	2.10	56.35	57.52
M1	3	3	3.44	2.47	30.97	51.07
M2	3	0	2.40	2.94	36.13	70.64
M2	3	1	2.07	2.66	45.80	73.92
M2	3	2	2.66	3.22	64.05	79.41
M2	3	3	2.16	3.22	40.53	72.97

Appendix 17: Raw data for phosphorus concentration in tissues and uptake before heading at 60DAT

			P_{total} (%)		P_{Uptake} ($Kgha^{-1}$)	
Mulch	Block	Fertilizer	Season I	Season II	Season I	Season II
M0	1	0	1.04	1.85	16.75	45.14
M0	1	1	1.04	2.38	21.70	34.71
M0	1	2	1.43	2.38	20.29	26.62
M0	1	3	1.43	2.41	22.75	22.35
M1	1	0	0.66	1.85	14.26	38.66
M1	1	1	1.04	1.85	28.57	34.82
M1	1	2	0.66	1.85	16.96	46.07
M1	1	3	1.04	1.85	14.28	38.89
M2	1	0	0.66	1.85	8.66	39.45
M2	1	1	0.87	1.33	16.02	37.13
M2	1	2	1.13	1.85	24.17	46.07
M2	1	3	0.66	1.85	13.31	42.36
M0	2	0	0.66	1.84	10.98	39.63
M0	2	1	0.97	1.85	16.22	40.34
M0	2	2	1.43	2.54	24.66	33.92
M0	2	3	1.04	1.85	17.49	27.72
M1	2	0	0.84	1.33	17.18	39.88
M1	2	1	0.97	0.80	22.83	21.81
M1	2	2	1.04	1.31	22.86	45.30
M1	2	3	1.04	0.80	12.96	21.40
M2	2	0	1.04	1.49	16.51	37.22
M2	2	1	1.04	0.96	16.34	30.26
M2	2	2	1.22	1.33	21.25	37.65
M2	2	3	0.84	1.14	12.88	28.78
M0	3	0	1.43	1.85	27.02	41.70
M0	3	1	1.43	2.19	26.17	34.84
M0	3	2	1.43	2.38	18.00	52.82
M0	3	3	1.04	1.85	15.35	13.24
M1	3	0	1.04	1.33	16.74	29.98
M1	3	1	1.29	1.66	26.59	23.15
M1	3	2	1.43	1.49	35.23	40.81
M1	3	3	1.04	1.66	9.37	34.32
M2	3	0	1.43	1.33	21.47	31.87
M2	3	1	1.43	0.80	31.54	22.23
M2	3	2	1.81	1.85	43.62	45.69
M2	3	3	1.04	1.31	19.56	29.69

Appendix 18: Raw data for potassium concentration in tissues and uptake before heading at 60DAT

			K_{total} (%)		K_{Uptake} ($Kgha^{-1}$)	
Mulch	Block	Fertilizer	Season I	Season II	Season I	Season II
M0	1	0	2.95	2.41	47.36	58.65
M0	1	1	3.05	2.24	63.42	32.62
M0	1	2	2.92	2.76	41.58	30.90
M0	1	3	2.87	2.30	45.72	21.37
M1	1	0	2.82	2.52	61.19	52.64
M1	1	1	3.71	2.73	101.60	51.35
M1	1	2	2.97	3.07	76.61	76.37
M1	1	3	3.01	2.46	41.20	51.59
M2	1	0	2.53	2.33	33.36	49.55
M2	1	1	2.97	2.10	54.66	58.67
M2	1	2	2.74	2.47	58.68	61.54
M2	1	3	3.54	2.30	71.62	52.50
M0	2	0	3.38	2.54	56.43	54.66
M0	2	1	3.61	2.57	60.46	56.06
M0	2	2	3.22	2.48	55.70	33.08
M0	2	3	3.90	2.22	65.45	33.27
M1	2	0	3.11	2.61	63.62	78.48
M1	2	1	3.95	2.90	92.98	79.13
M1	2	2	3.54	2.60	77.66	89.92
M1	2	3	2.86	2.76	35.52	73.96
M2	2	0	3.26	2.28	51.62	56.86
M2	2	1	3.31	2.25	51.95	70.83
M2	2	2	3.47	2.70	60.45	76.67
M2	2	3	3.85	2.45	59.04	61.76
M0	3	0	3.89	2.47	73.74	55.59
M0	3	1	3.66	2.73	67.19	43.46
M0	3	2	3.48	2.91	43.90	64.59
M0	3	3	3.02	2.08	44.56	14.87
M1	3	0	2.53	2.78	40.69	62.90
M1	3	1	3.48	3.34	71.70	46.55
M1	3	2	3.39	3.01	83.65	82.56
M1	3	3	2.86	2.45	25.72	50.70
M2	3	0	3.23	2.59	48.58	62.26
M2	3	1	3.91	2.21	86.48	61.52
M2	3	2	3.72	2.68	89.49	66.08
M2	3	3	3.74	2.66	70.10	60.35

Appendix 19: Raw data for soil moisture content under mulches at different DAT

			Soil moisture content					
			Season I			Season II		
M	B	F	30	60	90	30	60	90
M0	1	0	34.13	10.06	8.84	23.97	22.92	32.76
M0	1	1	31.94	13.13	8.53	22.44	29.92	31.61
M0	1	2	28.00	15.08	10.44	19.67	34.36	38.69
M0	1	3	38.94	11.53	9.83	27.36	26.27	36.43
M1	1	0	26.25	18.97	12.57	21.49	28.38	29.76
M1	1	1	31.94	18.00	13.88	26.15	26.93	32.86
M1	1	2	35.44	19.91	10.82	29.01	29.78	25.62
M1	1	3	35.00	15.56	15.21	28.66	23.28	36.01
M2	1	0	30.63	19.51	14.02	27.09	26.56	33.45
M2	1	1	29.31	19.92	11.41	25.93	27.11	27.23
M2	1	2	34.13	19.54	11.83	30.19	26.60	28.23
M2	1	3	31.06	10.03	14.02	27.48	13.65	33.45
M0	2	0	21.44	8.75	13.23	21.97	21.70	36.66
M0	2	1	26.25	12.25	8.98	26.90	30.38	30.28
M0	2	2	28.44	13.13	9.72	29.14	32.55	32.67
M0	2	3	22.75	12.25	8.85	23.31	30.38	28.87
M1	2	0	26.25	13.56	13.75	30.60	22.05	33.14
M1	2	1	21.44	17.54	9.50	24.99	28.52	26.52
M1	2	2	35.00	23.67	13.75	40.80	38.48	37.12
M1	2	3	21.44	21.88	26.88	24.99	35.57	47.91
M2	2	0	21.88	14.63	13.41	25.62	22.57	22.29
M2	2	1	26.25	18.28	17.11	30.74	28.21	28.46
M2	2	2	21.88	15.03	18.18	25.62	23.19	30.21
M2	2	3	26.25	19.18	17.06	30.75	29.59	28.36
M0	3	0	17.50	12.41	8.80	24.17	30.55	29.33
M0	3	1	21.88	13.63	11.25	27.71	33.46	37.47
M0	3	2	30.63	8.82	8.04	34.80	22.01	27.38
M0	3	3	13.13	15.90	12.15	18.64	34.86	39.87
M1	3	0	13.35	16.19	15.84	22.08	28.11	27.37
M1	3	1	10.94	17.50	19.19	18.27	30.14	33.15
M1	3	2	21.72	16.63	18.33	35.96	28.78	31.66
M1	3	3	16.63	31.06	25.92	27.53	39.18	44.78
M2	3	0	23.89	13.13	9.19	25.51	23.67	29.97
M2	3	1	26.43	17.58	9.63	31.65	30.02	29.15
M2	3	2	22.91	22.31	11.38	29.30	32.82	29.87
M2	3	3	20.94	17.50	8.75	29.87	29.89	29.08

M = Mulch, B = Block, F = Fertilizer, 0 = 0kgha^{-1}, 1= 60kgha^{-1}, 2 = 120kgha^{-1}, 3 = 180kgha^{-1}.

Appendix 20: Raw data for soil available P after harvesting

		P available (ppm)		
M	B	F	Season I	Season II
M0	1	0	67.61	117.82
M0	1	1	99.52	124.23
M0	1	2	67.61	135.80
M0	1	3	88.88	142.21
M1	1	0	72.93	117.82
M1	1	1	70.12	124.23
M1	1	2	88.88	157.17
M1	1	3	67.61	156.28
M2	1	0	51.65	124.23
M2	1	1	67.61	137.05
M2	1	2	56.97	127.26
M2	1	3	56.97	126.59
M0	2	0	83.56	105.00
M0	2	1	104.84	124.23
M0	2	2	104.84	130.64
M0	2	3	115.48	130.64
M1	2	0	83.56	117.82
M1	2	1	99.37	117.82
M1	2	2	125.97	149.16
M1	2	3	115.48	149.16
M2	2	0	99.52	124.23
M2	2	1	104.84	156.28
M2	2	2	115.48	105.00
M2	2	3	99.37	143.46
M0	3	0	118.44	137.05
M0	3	1	120.80	143.46
M0	3	2	126.12	147.55
M0	3	3	131.44	153.96
M1	3	0	126.12	143.46
M1	3	1	120.80	124.23
M1	3	2	150.35	156.28
M1	3	3	126.12	168.92
M2	3	0	94.20	130.64
M2	3	1	120.80	149.87
M2	3	2	120.80	130.64
M2	3	3	110.16	151.83

Appendix 21: Raw data for soil exchangeable K after harvesting

			K $_{exchangeable}$ ($cmol_c kg^{-1}$)	
M	B	F	Season I	Season II
M0	1	0	0.228	0.259
M0	1	1	0.236	0.274
M0	1	2	0.289	0.188
M0	1	3	0.358	0.188
M1	1	0	0.311	0.265
M1	1	1	0.285	0.188
M1	1	2	0.369	0.188
M1	1	3	0.186	0.188
M2	1	0	0.191	0.303
M2	1	1	0.378	0.188
M2	1	2	0.289	0.188
M2	1	3	0.326	0.188
M0	2	0	0.207	0.246
M0	2	1	0.307	0.188
M0	2	2	0.323	0.148
M0	2	3	0.386	0.216
M1	2	0	0.252	0.249
M1	2	1	0.258	0.188
M1	2	2	0.370	0.188
M1	2	3	0.272	0.188
M2	2	0	0.259	0.188
M2	2	1	0.303	0.188
M2	2	2	0.315	0.167
M2	2	3	0.252	0.188
M0	3	0	0.222	0.188
M0	3	1	0.357	0.188
M0	3	2	0.360	0.188
M0	3	3	0.313	0.188
M1	3	0	0.215	0.286
M1	3	1	0.323	0.188
M1	3	2	0.381	0.188
M1	3	3	0.243	0.188
M2	3	0	0.252	0.298
M2	3	1	0.270	0.188
M2	3	2	0.268	0.188
M2	3	3	0.349	0.188

M = Mulch, B = Block, F = Fertilizer, 0 = 0$kgha^{-1}$, 1= 60$kgha^{-1}$, 2 = 120$kgha^{-1}$, 3 = 180$kgha^{-1}$.

Appendix 22: Raw data for soil total nitrogen after harvesting

			N_{total} (%)	
Mulch	Block	Fertilizer	Season I	Season II
M0	1	0	0.34	0.29
M0	1	1	0.18	0.28
M0	1	2	0.39	0.27
M0	1	3	0.34	0.34
M1	1	0	0.21	0.28
M1	1	1	0.32	0.25
M1	1	2	0.25	0.31
M1	1	3	0.27	0.36
M2	1	0	0.27	0.29
M2	1	1	0.24	0.31
M2	1	2	0.40	0.27
M2	1	3	0.34	0.29
M0	2	0	0.32	0.41
M0	2	1	0.35	0.42
M0	2	2	0.42	0.60
M0	2	3	0.37	0.66
M1	2	0	0.38	0.57
M1	2	1	0.39	0.50
M1	2	2	0.31	0.41
M1	2	3	0.29	0.45
M2	2	0	0.41	0.38
M2	2	1	0.42	0.35
M2	2	2	0.46	0.43
M2	2	3	0.45	0.41
M0	3	0	0.38	0.48
M0	3	1	0.34	0.50
M0	3	2	0.49	0.45
M0	3	3	0.43	0.39
M1	3	0	0.39	0.36
M1	3	1	0.41	0.31
M1	3	2	0.27	0.28
M1	3	3	0.43	0.34
M2	3	0	0.27	0.34
M2	3	1	0.32	0.35
M2	3	2	0.44	0.29
M2	3	3	0.42	0.21

Appendix 23: Pictures for field work

a. **Cabbage field**

b. **Kjeldhal distillation and titration**

c. **AAS reading**