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Effect of Mulch Types and Mineral Fertilizer Rates on Cabbage (*Brassica Oleracea* var. *Capitata*) Growth and Yield in the Highlands of Rwanda

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Authors' contributions

Authors CU, HR and JJL designed the study, and wrote the first draft of the manuscript. Author CU the performed the analyses and conducted literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Determine response of cabbage growth and yield to mulching and fertilizer application.
Study Design: Factorial arrangement (3 × 4) of mulching types (black plastic, wheat straw and bare soil) and four NPK fertilizer rates; 0, 60, 120 and 180 kg ha^{-1}, in a RCBD with three replicates.
Place and Duration of Study: Busogo sector Musanze District, Rwanda, from September 2016 to March 2017.
Methodology: Data on cabbage stem diameter, height, leaf area index (LAI), head diameter and weight was collected and subjected to ANOVA using SAS version 9.3. Mean separation was done using LSD at $P = .05$.
Results: Application of black plastic and wheat straw mulch significantly increased cabbage stem diameter, height, leaf area index (LAI), head diameter and weight compared to bare soil. Fertilizer rates of 60 and 120 $kgha^{-1}$ significantly increased cabbage growth and yields.
Conclusion: Application of wheat straw mulch is recommended in increasing cabbage growth

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and yields. It is cheaper than plastic mulch and contributes to soil organic matter increase. NPK fertilizer rate of 120 kg ha^{-1} is recommended to meet the nutrient demand of cabbage and increase yield.

Keywords: LAI; organic mulch; plastic mulch; stem diameter.

1. INTRODUCTION

Rwanda is a mountainous land locked sub-Saharan country with 26, 338 km^2 surface area, including rivers and lakes [1], 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 depends on agriculture for their livelihood. Cabbage is an important vegetable in small holder farms and has high demand, especially in urban centers. Economically cabbage can be profitable in reducing malnutrition [2] and can provide a source of income [3].

Low cabbage yields are obtained in the small holder farms in Rwanda. This is mainly due nitrogen (N), phosphorus (P) and potassium (K) deficiencies. Cabbage is a heavy nutrient feeder. To form full green heads it requires adequate supply of macronutrients N, P and K [3]. Nitrogen promotes leafy growth and green colour, phosphorus promotes root and flower growth while potassium is needed for overall plant health [4]. Deficiencies of these elements are attributable to nutrient mining, resulting from inadequate replenishment of nutrients lost through harvested products, nutrient leaching and soil erosion. Erosion affects half of the farm lands with resultant soil losses of between 2.6 to 21.5 t $ha^{-1}yr^{-1}$ reported [5]. Application of mulch combined with mineral fertilizer can improve soil fertility, cabbage growth and yields in the Rwanda highlands, and has not been exploited.

Mulching material is of two types; inorganic and organic. Organic mulches are applied beneath soil around crops, in layers of 5 cm or more, to improve fertility and health of soil, conserve moisture, reduce weeds and prevent soil erosion [6]. They add nutrients to the soil when they decompose and have low cost hence affordable by farmers. Wheat straw mulch provides light, fluffy mulch around vegetable and reduces rain drop intensity and is easy to apply. It is also quickly broken down, and can be turned into the soil each season and replenished [6]. Straw mulch reduces soil compaction, increases biotic activity [7] and acts as a soil temperature buffer [8]. 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 [9]. Inorganic mulches are man-made mulches. Synthetic mulches like plastic mulches are good in water and fertilizer management and weed control with low amount of herbicides application [10]. Black mulch keeps soil warm by heat retention and inhibits weeds growth by blocking out sunlight resulting in nutrient availability [11,12].

The objective was to determine effect of NPK fertilizer rates and mulch types on cabbage growth and yield in the Rwanda highlands.

2. MATERIALS AND METHODS

2.1 Site Description

Field experiments were conducted from September 2016 to March 2017 in Busogo sector, Musanze District, in the northern region of Rwanda, in two rainy seasons. The sector (1800 and 4200m asl) is geographically located at 1°33'26"S and 29°32'39"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°C and the average annual precipitation is 1420mm [13]. The site is occupied by volcanic soils, also called andisols due to volcanic eruptions. The region is surrounded by 5 of 8 volcanoes of Virunga chain [5]. There is dominance of hilly topography with elevated slopes. Soil erosion and landslides are high because the soils are fragile [14]. Four seasons are observed per year: two rainy seasons; February to June and September to December, and two dry seasons; occurring between June to September and December to February [15]. The main crops grown are potatoes, beans, wheat and maize.

2.2 Treatments and Experimental Design

The treatments were a factorial arrangement (3 × 4) of three mulching types; Black plastic, wheat straw and bare soil, and four NPK fertilizer rates (0, 60, 120 and 180 kg ha^{-1}) in a randomized

complete block design, with three replicates. Each replicate had 12 treatments and the unit plot measured 3.6 m × 2.4 m. The distance between plots and blocks were 50 cm and 100 cm, respectively.

2.3 Agronomic Practices

The experimental field was cleared of vegetation, by slashing, four weeks before planting. Land was ploughed 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. NPK (17-17-17) fertilizer was applied once, just before transplanting, by banding and was mixed well with soil. Plastic mulch was placed on soil before transplanting, and transplanting holes were pocked on them. Well grown seedling from the nursery (>1.5 cm height) were transplanted, in all the plots, in both rainy seasons (seasons I and II), at spacing of 60 cm × 60 cm [2], to fit the plant population of 27,778 plants per hectare [16]. Straw mulch was placed around seedlings after transplanting, in layers of 5 cm thickness, in respective treatment. 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.

2.4 Soil Sampling and Analysis for Initial Characterization

Soil samples (0-30 cm) were collected from the experimental field before planting and application of treatments, using the zigzag method, in both rainy seasons. A composite sample was obtained using quartering method. The sample was well 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 samples, sieved through 0.5 (for N) and 2 mm mesh, were analyzed for initial properties using standard methods; pH by glass electrode method [17]; total nitrogen by Kjeldhal method [18]; available phosphorus by Mehlich III method (reading by UV/Vis) [19]; Exchangeable bases by Ammonium acetate saturation method [19] (reading by AAS); Organic carbon with loss by ignition [20] and soil texture by Hydrometer method [21]. The texture was loam, pH (H_2O) was medium in season I and low in season II, available phosphorus was high and total nitrogen medium in both seasons (Table 1). Exchangeable calcium, magnesium and potassium were medium. Soil organic matter, organic carbon and cation exchange capacity were medium in both seasons. The values were compared with those reported as high, medium and low by Landon [22].

2.5 Growth and Yield Measurements

Cabbage height, stem diameter, leaf area index and head size (diameter) were measured at early and late development stage i.e. at 30, 45, 60 and 75 days after transplanting (DAT). Height (cm) was measured by normal scale with a ruler. Stem diameter (mm) and head size (cm) were measured by normal scale with a venire caliper.

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

LAI = (Leaf area × number of leaves) / Spacing [23].

Cabbage head weight (g) was measured from 4 heads per plot at commercial maturity, using a weighing balance, and mean obtained.

Table 1. Initial soil properties

Parameter	Units	Season I	Season II	Parameter	Unit	Season I	Season II
pH(H_2O)	-	5.8	5.4	Ca^{2+}	$cmol_c/kg$	5.27	4.71
Available P	ppm	135	180	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
K^+	$cmol_c/kg$	0.66	0.60	TEA	$cmol_c/kg$	0.19	0.13

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

2.6 Data Analysis

Data for all the measured parameters were subjected to ANOVA using SAS version 9.3. Mean separation was done using LSD at 95% level of significance [24].

3. RESULTS AND DISCUSSION

3.1 Stem Diameter

Main and interaction effects of mulch types and fertilizer rates on cabbage stem diameter development were significant. In season I, at 30 days after transplanting (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 2). 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 2). Fertilizer rates had no significant effect 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 2). Interaction between mulch type and fertilizer rates did not show any significant stem diameter differences in all DAT in season, and at commercial maturity (75 DAT) in season II. 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 (Table 3).

Use of plastic and straw mulch was beneficial in retention of soil moisture and suppression of weeds [6]. This resulted in enhanced stem diameter development compared to the control (bare soil). 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 [25]. The results are in agreement with a study on effects of coloured plastic mulches and row covers on growth and yield of squash where the smallest stem diameter occurred in bare soil (27.2 mm) compared to black (29.3 mm), blue (29.5mm), red (28.8 mm), silver (29.8 mm) and white plastic films (29.4 mm) [26].

Cabbage requires adequate availability of plant nutrients for growth [27] hence the response in diameter development to fertilizer application. Jayamangkala [28] also found higher values on growth parameters of *Brassica oleracea* L. var. italica for the plots treated with mineral fertilizer than control. The highest rate (180 $kgha^{-1}$) seemed to have caused stunted growth, due to nutrient toxicity. The initial soil available phosphorus level was sufficient before fertilizer addition (Table 1). 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 [29]. The stem diameter values measured at 30 and 75 DAT were similar to those obtained by Pérez [30] in the study on Morphophysiological indicators of cabbage (*Brassica oleracea* L .var. *capitata*) planted inside and outside a greenhouse.

Little rainfall received in first two weeks after transplanting of seedlings in season I may have caused non-significant effect of mulch and fertilizer on stem diameter at 45, 60 and 75 DAT. The transplanted seedlings were therefore starved of water which may have affected nutrient uptake [31]. Cabbage requires adequate availability of soil water and plant nutrients for optimum growth [27].

3.2 Cabbage Height

Main effects of mulch type and fertilizer rate on cabbage height were significant, in both seasons. In season I at 30 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 (23.48 cm) and bare soil (22.30 cm) had significantly higher means. The latter's mean was not significantly different from black plastic mulch (21.50 cm) (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. Both black plastic and wheat straw mulch had significantly higher means than bare soil at 75 DAT (Table 4).

In season I, significantly higher means were obtained using fertilizer rates of 60 $kgha^{-1}$ and 120 kg ha^{-1} (23.90 and 22.99 cm) at 45 DAT, 60 $kgha^{-1}$ rate at 60 DAT (30.86) and 0 and 60 $kgha^{-1}$ at 75 DAT (30.16 and 31.56), than 180$kgha^{-1}$.(20.91, 27.13, 27.69 cm at 45, 60 and 75 DAT). 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 180$kgha^{-1}$ which had means of

15.05, 23.90 and 27.88 at the respective dates (Table 4). At 60 DAT, there were no significant differences in cabbage height in 60, 120 and 180 kgha^{-1} fertilizer rates.

The interactive effect of mulch and fertilizer on cabbage height was not significant (Table 5). The lowest mean in season I was, however, observed in black plastic mulch in combination with 180kgha^{-1} and, bare soil with 180 kgha^{-1} in season II (Table 5).

Noticeable height increases observed with wheat straw mulch application was because of ability of the organic mulch to retain moisture and keep soil wet which enhanced better water use efficiency by seedlings. In addition, the mulch suppressed weeds reducing competition for resources. Mulching in general has a positive effect on height, leaf numbers and size, shoot diameter and dry matter [32]. Black plastic mulch equally retained moisture by reducing evapotranspiration loss, increased soil temperature and reduced weeds which promoted cabbages growth noted at 75 DAP, compared to bare soil. Similarly, Locascio et al. [33] reported that black plastic mulch significantly increased plant height compared to other mulch colours. An experiment conducted on edible lily (*Lilium davidii* var. unicolor) bulb and yield responses to potassium fertilizer and plastic film revealed a significant increase for seedling height, leaf area and dry matter [34].

Cabbage is a heavy nutrient feeder hence the observed response to fertilizer application. To form full green heads it requires adequate N, P and K supply. N promotes leafy growth and green colour, phosphorus supports root and flower growth and potassium ensures overall plant health [4]. Cabbages well supplied with these nutrients attain height ranges of 30 to 38 cm. Even though the interaction effect of mulch and fertilizer on cabbage height was not significant, the means obtained (Table 5) fall within the ranges mentioned above. The loamy texture and pH at experimental site (Table 1) was also favourable for cabbage growth. Optimum growth occurs in loamy or sandy loamy soils and pH ranging between 5.5 and 6.8 [16].

3.3 Leaf Area Index (LAI)

The main effects of fertilizer rates and mulch type on LAI were significant, in both seasons. In season I, wheat straw mulch had significantly highest values (0.424, 1.183, 2.977 and 3.188) at 30, 45, 60 and 75 DAT respectively. 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, in season I (Table 6).

Table 2. Main effects of mulch type and fertilizer rate on cabbage stem diameter (mm)

Treatment	Stem diameter (mm)							
	Season I				Season II			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Mulch type								
M0	8.48^{a}	15.36^{a}	20.82^{a}	26.07^{a}	9.89^{c}	14.46^{b}	19.53^{b}	26.00^{b}
M1	7.02^{b}	14.91^{a}	20.88^{a}	27.05^{a}	11.05^{b}	17.46^{a}	22.36^{a}	29.28^{a}
M2	8.41^{a}	15.43^{a}	21.97^{a}	25.78^{a}	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
Fertilizer rate								
F0	7.94^{a}	15.13^{a}	21.50^{a}	26.69^{a}	11.74^{a}	18.08^{a}	22.68^{a}	29.21^{ab}
F1	8.07^{a}	15.79^{a}	21.91^{a}	26.54^{a}	10.83^{b}	16.91^{a}	21.78^{a}	29.37^{a}
F2	8.28^{a}	15.24^{a}	21.23^{a}	26.25^{a}	11.32^{ab}	16.82^{ab}	21.80^{a}	27.61^{ab}
F3	7.60^{a}	14.78^{a}	20.25^{a}	25.72^{a}	9.77^{c}	15.42^{b}	20.10^{b}	27.32^{b}
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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}.; DAT= Days after transplanting.

Means with the same letter within columns are not significantly different (P =.05)

Table 3. Effect of interaction between mulch type and fertilizer rate on cabbage stem diameter (mm) (means ± Std. error)

Treatment	Stem diameter (mm)							
	Season I				Season II			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
M0F0	8.64 ± 0.98	16.01 ± 0.94	22.95 ± 1.58	26.89 ± 1.40	11.89 ± 0.03	17.30 ± 0.33	22.70 ± 0.38	27.98 ± 0.70
M0F1	8.02 ± 0.21	14.99 ± 0.35	18.94 ± 0.38	24.94 ± 0.81	10.10 ± 0.67	15.00 ± 1.31	19.06 ± 0.77	27.51 ± 1.08
M0F2	8.84 ± 0.33	14.71 ± 0.59	20.79 ± 1.11	25.96 ± 1.50	9.82 ± 0.41	14.47 ± 1.34	20.01 ± 0.96	24.82 ± 1.27
M0F3	8.41 ± 0.49	15.73 ± 1.50	20.58 ± 1.39	26.51 ± 1.38	7.73 ± 0.75	11.07 ± 1.18	16.34 ± 1.36	23.70 ± 1.36
M1F0	7.07 ± 0.22	15.01 ± 0.68	19.62 ± 1.28	26.54 ± 1.34	11.46 ± 0.96	17.95 ± 1.19	22.80 ± 1.45	31.19 ± 0.99
M1F1	7.61 ± 0.15	16.07 ± 0.83	22.70 ± 1.03	28.35 ± 1.42	10.76 ± 0.48	17.42 ± 1.29	22.80 ± 1.26	29.63 ± 0.97
M1F2	7.57 ± 0.25	15.07 ± 0.70	20.89 ± 0.99	26.68 ± 1.98	12.00 ± 0.77	17.92 ± 1.03	23.38 ± 0.44	28.97 ± 1.34
M1F3	5.86 ± 0.94	13.50 ± 0.65	20.29 ± 2.14	26.63 ± 0.82	9.95 ± 0.15	16.53 ± 0.94	20.47 ± 1.16	27.32 ± 1.00
M2F0	8.12 ± 0.89	14.38 ± 0.37	21.91 ± 0.60	26.66 ± 1.15	11.88 ± 0.40	18.99 ± 0.56	22.54 ± 0.16	28.45 ± 1.54
M2F1	8.57 ± 0.48	16.31 ± 0.40	24.08 ± 1.18	26.34 ± 2.55	11.63 ± 0.35	18.32 ± 0.24	23.46 ± 0.53	30.98 ± 0.27
M2F2	8.42 ± 0.62	15.92 ± 0.96	21.99 ± 1.04	26.09 ± 2.23	12.14 ± 0.43	18.08 ± 0.56	22.00 ± 0.70	29.03 ± 1.57
M2F3	8.54 ± 1.58	15.11 ± 2.73	19.90 ± 1.58	24.03 ± 2.85	11.64 ± 0.16	18.65 ± 0.95	23.49 ± 0.49	30.93 ± 0.66
$LSD_{(0.05)}$	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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}; DAT= days after transplanting. Means with the same letter within columns are not significantly different (P =.05)

Table 4. Main effect of mulch type and fertilizer rate on cabbage height (cm)

Treatment	Height (cm)							
	Season I				Season II			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Mulch type								
M0	15.89^{b}	22.30^{ab}	29.30^{a}	29.11^{a}	13.99^{c}	22.80^{c}	25.66^{c}	27.20^{b}
M1	14.14^{b}	21.50^{b}	27.75^{a}	29.87^{a}	17.69^{b}	27.11^{b}	30.66^{b}	31.05^{a}
M2	19.01^{a}	23.48^{a}	29.35^{a}	29.45^{a}	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
Fertilizer rate								
F0	16.63^{a}	21.92^{bc}	29.19^{ab}	30.16^{ab}	18.97^{a}	28.98^{a}	31.63^{a}	30.48^{a}
F1	16.97^{a}	23.90^{a}	30.86^{a}	31.56^{a}	16.45^{bc}	26.89^{b}	29.67^{ab}	29.87^{a}
F2	16.93^{a}	22.99^{ab}	28.03^{b}	28.49^{bc}	17.22^{b}	26.49^{b}	29.63^{ab}	29.80^{a}
F3	14.85^{a}	20.91^{c}	27.13^{b}	27.69^{c}	15.05^{c}	23.90^{c}	27.88^{b}	29.95^{a}
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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}.; DAT= Days after transplanting.

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

In season I, 60 kg ha^{-1} fertilizer rate had significantly higher LAI values. In season II, application rates of 0 and 120 kg ha^{-1} at 30 and 45 DAT, and 0, 60 and 120 kg ha^{-1} at 60 DAT, had significantly higher LAI values than the highest fertilizer rate (180 kg ha^{-1} (Table 6). LAI did not differ significantly with fertilizer rates used at 75 DAT; however, means were slightly with application rate of 180 kg ha^{-1}. The effect of interaction between mulch and fertilizer on LAI was significant in season I. Combination of wheat straw mulch and 60 kg ha^{-1} fertilizer rate had highest values of 0.483, 1.407 and 3.677 respectively at 30, 45 and 60 DAT (Table 7).

Increased LAI by wheat straw mulch was due to conservation of water in addition to N enrichment by mineralization of the straw. Water is essential for plant development. The leaves help plants suck up water and dissolved nutrients from the soil to support the plant's growth. As plants grow taller they gain access to energy from light. Wheat straw mulch adds organic matter to the soil and conserves water [6,9]. Plastic mulches are also good in water and fertilizer management and increasing production [10]. The response of LAI to fertilizer was because N enhances leaf expansion [35]. At 75 DAT in season II, fertilizer rate of 180kgha^{-1} had higher LAI because while others were forming full heads; it had not fully headed and had many visible leaves. Nutrients toxicity with use of highest rate (180 kg ha^{-1}) caused stunted growth and thereby delayed head formation [29].

3.4 Head Diameter

The main and interaction effects of mulch type and fertilizer rates on head diameter were significant. Bare soil had significantly lower means of 12.20, 18.78, 19.35 cm in season I 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. Head diameter of cabbages from plots covered with wheat straw and black plastic mulch were not statistically different (Table 8).

In season I, application rates of 0 (13.32 cm), 60 (13.16 cm) and 120 (13.27 cm) kgha^{-1} had the significantly higher mean head diameter at 60 DAT. Application of 60 kgha^{-1} had the significantly highest means (21.26 and 22.00 cm) at 75 and 90 DAT than other rates. In season II, application of 0 and 120 kgha^{-1} had the highest means of 11.43 and 11.12 cm, respectively at 60DAT. Application of 0, 60 and 120 kgha^{-1} had significantly higher means at 75 DAT, and 120 kgha^{-1} 90 DAT (Table 8). For interactions, black plastic mulch combined with 120 kg ha^{-1} (14.90 cm) at 30 DAT in season I, black plastic mulch and 60 kgha^{-1} (19.31 cm) at 75DAT in season II and black plastic mulch with 120 kgha^{-1} (26.80 cm) in season II had significantly higher head diameter values(Table 9).

Table 5. Effect of interaction between mulch type and fertilizer rate on cabbage height (cm) (means ± Std. error)

Treatment	Height (cm)							
	Season I				Season I			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
M0F0	15.87 ± 0.21	21.54 ± 0.73	29.48 ± 1.94	28.26 ± 1.23	16.90 ± 0.69	26.52 ± 0.98	29.14 ± 1.21	27.69 ± 1.39
M0F1	15.78 ± 0.60	23.26 ± 1.16	31.74 ± 1.88	31.58 ± 2.47	14.02 ± 0.53	22.92 ± 0.82	25.33 ± 0.76	26.39 ± 1.15
M0F2	16.17 ± 0.96	22.14 ± 1.16	27.60 ± 1.83	28.47 ± 1.17	13.31 ± 0.64	22.15 ± 1.46	24.77 ± 0.46	26.08 ± 1.01
M0F3	15.73 ± 1.08	22.25 ± 1.16	28.39 ± 1.57	28.12 ± 0.60	11.73 ± 0.78	19.60 ± 0.41	23.41 ± 1.75	28.64 ± 1.25
M1F0	14.41 ± 1.49	21.28 ± 1.18	26.98 ± 1.37	30.78 ± 1.58	19.60 ± 1.75	30.01 ± 1.81	32.76 ± 0.67	32.09 ± 1.84
M1F1	15.34 ± 0.86	24.06 ± 1.19	30.75 ± 0.50	32.34 ± 0.73	17.31 ± 0.62	27.86 ± 1.65	30.20 ± 1.60	30.84 ± 1.93
M1F2	14.77 ± 0.40	22.44 ± 0.79	28.14 ± 1.32	28.74 ± 0.30	18.69 ± 0.44	27.26 ± 1.47	31.39 ± 0.69	32.37 ± 1.25
M1F3	12.04 ± 1.01	18.24 ± 0.69	25.12 ± 1.88	27.62 ± 0.62	15.17 ± 0.66	23.32 ± 0.95	28.29 ± 0.60	28.92 ± 1.76
M2F0	19.60 ± 1.57	22.93 ± 0.98	31.10 ± 1.88	31.44 ± 1.07	20.41 ± 0.85	30.42 ± 0.88	32.99 ± 0.85	31.65 ± 1.10
M2F1	19.79 ± 1.43	24.38 ± 0.62	30.07 ± 1.12	30.78 ± 0.70	18.03 ± 1.52	29.89 ± 1.06	33.49 ± 0.96	32.39 ± 1.19
M2F2	19.87 ± 2.25	24.38 ± 1.03	28.34 ± 0.87	28.27 ± 0.52	19.65 ± 0.47	30.07 ± 1.24	32.73 ± 2.31	30.95 ± 1.57
M2F3	16.77 ± 1.25	22.24 ± 2.21	27.89 ± 1.86	27.33 ± 1.91	18.25 ± 0.82	28.77 ± 1.23	31.92 ± 0.77	32.30 ± 1.64
$LSD_{(0.05)}$	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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}. DAT= Days after transplanting.

Table 6. Main effects of mulch type and fertilizer rate on leaf area index (LAI)

Treatment	Leaf area index							
	Season I				Season I			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
Mulch type								
M0	0.320^{b}	1.128^{ab}	2.345^{b}	2.738^{b}	0.284^{b}	1.374^{b}	2.171^{b}	2.686^{b}
M1	0.306^{b}	1.090^{b}	2.546^{b}	2.971^{ab}	0.518^{a}	2.101^{a}	3.369^{a}	3.685^{a}
M2	0.424^{a}	1.183^{a}	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
Fertilizer rate								
F0	0.312^{b}	1.109^{b}	2.584^{b}	2.758^{b}	0.531^{a}	2.169^{a}	3.254^{a}	3.230^{a}
F1	0.419^{a}	1.284^{a}	3.011^{a}	3.478^{a}	0.403^{bc}	1.846^{ab}	3.032^{a}	3.262^{a}
F2	0.344^{b}	1.092^{b}	2.542^{b}	2.763^{b}	0.460^{ab}	2.011^{a}	3.081^{a}	3.342^{a}
F3	0.324^{b}	1.048^{b}	2.352^{b}	2.864^{b}	0.322^{c}	1.458^{b}	2.472^{b}	3.346^{a}
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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}.; DAT= days after transplanting.
Means with the same letter within columns are not significantly different (P = .05)

The fact that mulches have nutrient use efficiency effect, improved nutrient uptake occurred. This played an important role in head development. 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 covered plots [36]. Response to fertilizer was because of the role of the macronutrients N, P and K in the plant's life cycle. N is a constituent of nucleic acids, proteins and hormones; P is essential component of nucleic acids, phospholipids, ATP and K a cofactor in protein synthesis and water balance. The results are in agreement with the study on the effect of fertilizer types on the growth and yield of two cabbage varieties, which reported that NPK fertilizer was important in increasing cabbage yield [31].

3.5 Cabbage Head Weight (Yield)

Main and interaction effects of mulch type and fertilizer rate on head weight were significant (Tables 10, 11). Wheat straw mulch had significantly higher mean cabbage head weight while bare soil had the lowest. The values for season I were 3462.50 g for wheat straw mulch, 3075.00 g for black plastic and 2723.60 g for bare soil (Table 10).

For season II, head weight per plant was significantly higher with use of black plastic (4215.90 g) and wheat straw (4203.40 g) mulches than bare (2639.40 g). Application of 60 and 120 kgha^{-1} fertilizer rates had significantly higher means in season I (3399.20 g) and II (3994.90 g), respectively (Table 10). Interactions effects between black plastic mulch with 120kgha^{-1} on head weight were significant in season II (4850.44 g). The lowest value was obtained for bare soil combined with 60kgha^{-1} (2404.17 g) (Table 11).

Increase in head weight by mulching may have been due to the beneficial effect of mulch in water and moisture conservation, nutrient use efficiency and weeds suppression. This is in addition to organic matter increase and mineralization of wheat straw mulch. These results are in agreement with Trdan et al. [8] who reported increased cabbage head weight in mulched plots than non-mulched plots. Results obtained confirms those of Olaniyi and Ojetayo [31], where effect of fertilizers on cabbage yield was significant, and Yang et al. [34] who found a significant effect on yield for plastic mulch film and potassium fertilizer for edible lily and bulb yield.

Table 7. Effect of interaction between mulch type and fertilizer rate on leaf area index (LAI) (means ± Std. error)

Treatment	Leaf Area Index							
	Season I				Season II			
	30 DAT	45 DAT	60 DAT	75 DAT	30 DAT	45 DAT	60 DAT	75 DAT
M0F0	0.287 ± 0.01	1.187 ± 0.08	2.560 ± 0.27	2.477 ± 0.11	0.447 ± 0.04	1.973 ± 0.05	2.833 ± 0.03	2.893 ± 0.20
M0F1	0.347 ± 0.04	1.107 ± 0.01	2.473 ± 0.31	3.633 ± 0.57	0.260 ± 0.03	1.273 ± 0.16	2.137 ± 0.21	2.690 ± 0.18
M0F2	0.317 ± 0.01	1.030 ± 0.04	2.063 ± 0.28	2.300 ± 0.14	0.277 ± 0.03	1.480 ± 0.16	2.057 ± 0.28	2.463 ± 0.24
M0F3	0.330 ± 0.01	1.187 ± 0.04	2.283 ± 0.34	2.543 ± 0.17	0.153 ± 0.04	0.770 ± 0.15	1.657 ± 0.29	2.697 ± 0.20
M1F0	0.260 ± 0.02	1.100 ± 0.03	2.127 ± 0.19	2.603 ± 0.11	0.587 ± 0.12	2.270 ± 0.68	3.693 ± 0.38	3.607 ± 0.36
M1F1	0.427 ± 0.04	1.340 ± 0.12	2.883 ± 0.10	3.377 ± 0.10	0.493 ± 0.05	2.077 ± 0.31	3.460 ± 0.39	3.450 ± 0.38
M1F2	0.347 ± 0.05	1.130 ± 0.07	2.817 ± 0.04	2.840 ± 0.13	0.630 ± 0.06	2.307 ± 0.36	3.673 ± 0.30	3.907 ± 0.34
M1F3	0.190 ± 0.03	0.790 ± 0.04	2.357 ± 0.11	3.063 ± 0.15	0.363 ± 0.06	1.750 ± 0.21	2.650 ± 0.25	3.777 ± 0.74
M2F0	0.390 ± 0.02	1.040 ± 0.09	3.067 ± 0.21	3.193 ± 0.14	0.560 ± 0.08	2.263 ± 0.23	3.237 ± 0.27	3.190 ± 0.15
M2F1	0.483 ± 0.03	1.407 ± 0.07	3.677 ± 0.18	3.423 ± 0.15	0.457 ± 0.09	2.187 ± 0.07	3.500 ± 0.14	3.647 ± 0.31
M2F2	0.370 ± 0.06	1.117 ± 0.05	2.747 ± 0.06	3.150 ± 0.30	0.473 ± 0.01	2.247 ± 0.09	3.513 ± 0.37	3.657 ± 0.46
M2F3	0.453 ± 0.07	1.167 ± 0.06	2.417 ± 0.16	2.987 ± 0.21	0.450 ± 0.03	1.853 ± 0.20	3.110 ± 0.19	3.563 ± 0.09
$LSD_{(0.05)}$	1.105	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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}, DAT= Days after transplanting

Table 8. Main effects of mulch type and fertilizer rates on head diameter

Treatments	Head diameter (cm)					
	Season I			Season II		
	60 DAT	75 DAT	90 DAT	60 DAT	75 DAT	90 DAT
Mulch type						
M0	12.20^{b}	18.78^{b}	19.35^{b}	8.11^{b}	13.45^{b}	20.48^{b}
M1	13.42^{a}	20.52^{a}	21.13^{a}	11.69^{a}	18.42^{a}	23.49^{a}
M2	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
Fertilizer rate						
F0	13.32^{a}	19.78^{ab}	20.19^{b}	11.43^{a}	16.98^{a}	22.18^{b}
F1	13.16^{ab}	21.26^{a}	22.00^{a}	10.26^{b}	17.05^{a}	22.34^{b}
F2	13.27^{a}	19.41^{b}	20.26^{b}	11.12^{ab}	17.76^{a}	23.53^{a}
F3	12.19^{b}	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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}.; DAT= days after transplanting. Means with the same letter within columns are not significantly different (P=.05)

Table 9. Effect of interaction between mulch type and fertilizer rate on head diameter (means± Std. error)

Treatment	Head diameter (cm)					
	Season I			Season II		
	60DAT	75DAT	90DAT	60DAT	75DAT	90DAT
M0F0	12.67 ± 1.13	19.54 ± 0.73	19.40 ± 0.54	9.71 ± 0.27	15.36 ± 0.88	22.10 ± 0.30
M0F1	11.28 ± 0.34	20.80 ± 0.98	20.46 ± 0.81	8.29 ± 0.89	12.54 ± 0.46	19.88 ± 0.19
M0F2	12.64 ± 0.49	18.08 ± 0.98	19.42 ± 0.89	7.58 ± 1.03	14.99 ± 0.34	20.37 ± 0.10
M0F3	12.22 ± 0.46	16.69 ± 0.60	18.12 ± 0.82	6.85 ± 0.18	10.93 ± 0.37	19.57 ± 0.71
M1F0	12.51 ± 0.59	18.60 ± 0.39	19.27 ± 0.68	12.69 ± 1.21	18.42 ± 0.46	22.03 ± 0.86
M1F1	13.75 ± 0.71	22.32 ± 0.93	23.01 ± 0.75	10.85 ± 1.40	19.31 ± 0.54	22.72 ± 0.65
M1F2	14.90 ± 0.84	20.55 ± 0.42	20.72 ± 0.81	13.59 ± 0.97	20.39 ± 1.18	26.80 ± 0.60
M1F3	12.51 ± 0.57	20.62 ± 1.25	21.51 ± 0.56	9.64 ± 0.92	15.58 ± 0.60	22.41 ± 1.20
M2F0	14.79 ± 1.07	21.18 ± 0.99	21.91 ± 0.82	11.88 ± 0.94	17.15 ± 1.28	22.40 ± 0.67
M2F1	14.44 ± 0.42	20.65 ± 1.31	22.53 ± 0.42	11.63 ± 0.65	19.31 ± 0.38	24.44 ± 0.35
M2F2	12.28 ± 1.07	19.59 ± 1.76	20.66 ± 0.68	12.91 ± 0.07	17.91 ± 0.77	23.42 ± 0.62
M2F3	11.85 ± 0.43	17.57 ± 0.27	19.69 ± 0.73	10.74 ± 0.41	18.04 ± 0.45	23.69 ± 0.43
$LSD_{(0.05)}$	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: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}

Table 10. Main effects of mulch type and fertilizer rates on cabbage head weight (g) at commercial maturity

Treatment	Head weight (g)	
	Season I	Season II
Mulch type		
M0	2723.60[c]	2639.40[b]
M1	3075.00[b]	4215.90[a]
M2	3462.50[a]	4203.40[a]
LSD $_{(0.05)}$	255.660	259.510
CV (%)	9.78	8.32
Fertilizer rate		
F0	2898.40[b]	3590.30[b]
F1	3399.20[a]	3600.20[b]
F2	3063.90[b]	3994.90[a]
F3	2986.60[b]	3559.40[b]
LSD $_{(0.05)}$	295.210	299.66
CV (%)	9.78	8.32

Key: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}. Means with the same letter within columns are not significantly different (P =.05)

Table 11. Effect of interaction between mulch type and fertilizer rate on cabbage head weight at commercial maturity (means ± Std. error)

Treatment	Head weight (g)	
	Season I	Season II
M0F0	2416.00 ± 153.07	3004.17 ± 86.10
M0F1	2958.33 ± 336.99	2404.17 ±173.26
M0F2	2675.00 ± 229.47	2591.67 ± 283.70
M0F3	2845.00 ± 209.52	2557.50 ± 157.47
M1F0	2816.67 ± 233.33	3987.50 ± 283.49
M1F1	3579.17 ± 152.13	4154.67 ± 76.61
M1F2	2839.50 ± 136.68	4850.44 ± 70.53
M1F3	3064.67 ± 61.84	3870.83 ± 241.77
M2F0	3462.50 ± 330.72	3779.17 ± 234.34
M2F1	3660.17 ± 212.33	4241.67 ± 160.13
M2F2	3677.17 ± 108.98	4542.67 ± 151.17
M2F3	3050.00 ± 225.00	4250.00 ± 253.72
LSD $_{(0.05)}$	508.876	516.555
CV (%)	9.78	8.32

Key: M0 = No mulch, M1 = Black plastic mulch, M2 = Wheat straw mulch, F0 = 0 kgha^{-1}, F1 = 60 kgha^{-1}, F2 = 120 kgha^{-1}, F3 = 180 kgha^{-1}

4. CONCLUSION

Black plastic and wheat straw mulches, increased cabbage LAI, height, stem and head diameter and head weight, compared to bare soil. Wheat straw mulch is recommended as it is cheaper compared to plastic mulch and increases organic matter content of soil. Whereas NPK application rates of 120 and 60 kgha^{-1} increased growth and yield of cabbage, the rate of 120 kgha^{-1} is recommended to meet the high nutrient demand of cabbage. 180 kg ha^{-1} rate has to be eliminated as it is toxic and results in cabbages of low weight.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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