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Response of Head Cabbage (*Brassica olearacea L.*) Yield to Application of Different Rates of Inorganic Nitrogen and Phosphorus Fertilizers at Bore, Southern Ethiopia

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Abstract: The field trial was conducted during 2017 and 2018 main cropping season at the Bore Agricultural Research Centre which is located in Gudji Zones, of Southern Ethiopia to determine the effect of different application rates of nitrogen and phosphorus fertilizers on growth, yield and yield components of head cabbage and to identify their economically appropriate rates that maximize yield of head cabbage. The experiment was carried out to study cabbage variety Olsen to added N and P nutrients in respect to growth, yield and yield related parameters of the crop. The longest head initiation (90 days) and longest (140) days to maturity was attained in 294 kg ha^{-1} Nitrogen and 138 kg ha^{-1} phosphorus treatment, while shortest head initiation (64.33 days) was obtained in control treatment. The maximum plant height (26.4 cm) was recorded for the treatment T3P4 (235 +138 kag ha^{-1}), while the lowest (16.9 cm) plant height was recorded from the T1P1 (control) treatment. Nutrient levels markedly influenced the diameter, height, head mass and yield of head cabbage. The maximum average head diameter (25.44 cm) and average height (27.33 cm) was recorded in treatment receiving 235 kg N and 82 kg P ha^{-1}. Combined application of 235 kg N ha^{-1} with the 82 kg P ha^{-1} produced the highest (2356.67 g) untrimmed head weight of cabbage followed by second maximum (2133.33 g) untrimmed head weight with the rate of 235 kg N ha^{-1} with the 110 kg P ha^{-1} while the least (1120.67 g) untrimmed head weight was recorded for the control treatment. Combined application of 235 kg nitrogen and 82 kg phosphorus ha^{-1} (N3P2) recorded maximum (69.00 t) head yield without wrapper ha^{-1} and the lowest (27.66 t ha^{-1}) was recorded by control treatment. The marginal rate of returns, which determines the acceptability of any treatments shows that treatments that received 235 kg N ha^{-1} in combination with 82 kg ha^{-1} of P yielded 43498% marginal revenue. Therefore, this combined nutrient application rates can be recommended in the research area and similar agro-ecologies since it is the most feasible rates for the producers because of its low cost of production and higher benefits.

Keywords: Combined, Nitrogen, Nutrient, Olsen, Phosphorus, Treatment

1. Introduction

Head cabbage is scientifically known as *Brassica oleracea* var. *capitata*. It belongs to the *Cruciferae* family which includes also kale (*Brassica oleracea* var *acephala*), Chinese cabbage (*Brassica pekinensis* (Lour Rapr.) and Brussels sprouts (*Brassica oleracea* var. *gemmifera* DC). It was introduced initially to China before 2000 years ago, where the heading *(Brassica oleoracea* L*)* types were developed [38].

Cabbage thrives best during cool, moist seasons [11, 29, 35, 36]. Even though it requires 500 mm of water for its growing period [2], good drainage is important; as too much water tends to split heads when they are mature [31, 36]. Water should not be deficient from head formation until harvest time, as this will drastically limit yields [2]. According to Lecuona it can be grown throughout the year and its optimum soil pH ranges from 6.0 to 7.0 [17]. Its growth season is between 80 to 100 days [10].

It has long been accepted that applications of nitrogen fertilizer to cabbage increased yields, plant uniformity, and quality [34]. To produce optimum yields of good quality cabbages, often high amounts of nitrogen fertilizer are applied. The recommended total amounts of nitrogen fertilizer for cabbage are 160 to 260 kg ha^{-1}. In reality, the amount of nitrogen fertilizer used is probably higher as farmers may apply more fertilizer than recommended to secure yields. Nitrogen produces reliable and optimal yield and quality of vegetables [16]. It is however, the most difficult element to manage in a fertilization system in order to ensure an adequate, yet not excessive, amount of available nitrogen within the rhizosphere from planting to harvest [1].

Nitrogen and phosphorus are one of the nutrients of major importance in the growth of head cabbage. Lack of these major nutrients causes the plant to be stunted and becomes yellow in appearance thereby decrease yield. An adequate supply of nitrogen is essential for vigorous vegetative growth, head formation and optimum yield of cabbage [37]. However, the response of the crop to nitrogen and phosphorus varies under different soil and agro climatic conditions and thus affecting the optimum level of nitrogen and phosphorus. Achieving and maintaining appropriate levels of soil fertility, especially plant nutrient availability, is of paramount importance in agricultural land to remain capable of sustaining crop production at an acceptable level.

In the past, agricultural production was focused on maximizing the quantity of vegetables produced for commercial market while in the last few decades the organic management of crops has gained great popularity because of increased consumers' awareness of the health problems that come from food grown under conventional and intensive farming. Differences between organic and conventional farming systems, especially in soil fertility management, may affect the nutritive composition of plants. Soils vary in their capacity to provide nutrients to crops and crops differ in their requirements, therefore, most soils cannot supply all essential nutrients to crops [26]. Fertilizers recommendations are therefore, developed to quantify the amount of nutrients for various crops which are to be applied through fertilizers. Therefore the activity was proposed to determine the effect of different application rates of nitrogen and phosphorus fertilizers on growth, yield and yield components of head cabbage and to identify their economically appropriate rates that maximize yield of head cabbage.

2. Literature Review

2.1. Origin, Importance and Ecology

Cabbage originated from a wild non-heading type, 'Cole wart' (*Brassica oleracea var. sylvestris*). The genus *Brassica* includes about 100 species, majorities of which are native to the Mediterranean region. The crop is attributed to Mediterranean center of origin. It is also considered that the real headed cabbage was evolved in Germany. The Savoy (yellowish green) cabbage originated in Italy and spread to France and Germany in the sixteenth and seventh centuries [18]. The cabbage seems to have originated in Europe around 1000BC, after which it was introduced into the Middle East and other areas. Today, cabbages can be found all around the world, making is possible for everyone to experience its benefits [4].

Today, China is the largest producer of cabbage, followed by India and Russia, which is the biggest consumer of cabbage. Around the world, cabbage is prepared in different ways. While it can be eaten raw, as a salad, cabbage can be steamed, pickled, stewed, sautéed or braised. Sauerkraut and kimchi are the most popular pickled variants while the coleslaw is one of the most popular salads. Cabbage is a leafy vegetable from the wide family of "brassicas". It is grown annually, and we eat its dense green or purple leaves in many different dishes. Head of cabbage, which can grow from 0.5 to 4 kilograms, is rich in vitamins and minerals, has almost no fat and is very rich in fiber which makes it very healthy to eat. Cabbage health benefits includes reducing risk of cancer, improving brain and nervous system health, promoting bone health, maintaining blood pressure, detoxifying the body, promoting bowel regularity, regulating sugar level and promoting weight loss. Other benefits includes improving health of hair, skin and nails, helping prevent or heal acne, healing stomach ulcers, helping care for the heart, promoting healthy pregnancy and boosting immunity [4].

It thrives in well-drained, moisture-retentive, loamy soils well supplied with organic matter. It does not grow well in highly acidic soil. The ideal soil pH ranges from 5.5 to 6.5 and it should not be allowed to drop below 4.5. Cabbage can be grown easily under a wide range of environmental conditions but cool moist climate is most suitable. The optimum soil temperature for seed germination is 22-26.2°C. The optimum temperature for growth is between 25.2 to 34.2°C. Whereas, temperature above 43.2°C, growth is arrested in most of the cultivars. Cabbage plants that are exposed to temperatures of 10-13°C for prolonged periods will produce premature seed stalks instead of heads [30].

2.2. Response of Vegetables to Nutrient Application

Vegetable producers use manures, organic residues and other wastes as an alternative source of fertilizer to produce vegetable crops. However, these organic materials are not processed and applied as a raw. Experiments done in India showed that treatment combinations with organic and inorganic fertilizers recorded significantly higher cabbage head yield (42.42 t ha^{-1}) over the control with an addition of 150 kg N ha^{-1} fertilizer in combination with 10 t ha-1 FYM over the control head yield (38.10 t ha^{-1}). In another field experiments the application of 240 kg N, 45 kg P, 180 kg K and 45 kg S ha^{-1} performed best in recording plant height, root length, number of loose leaves and heading leaves, leaf length and breadth, thickness and diameter of head and yield. The maximum marketable yield (87.09 t ha^{-1}) was recorded in an application of 240 kg N, 45 kg P ha^{-1} [3]. Lesic *et al.,* reported that cabbage has high requirements for all nutrients, especially nitrogen and for achieving high yields it ranged from 130 to 310 kg N ha^{-1} [18].

Cabbage has good responsiveness on animal manure application in quantity of 40 t ha^{-1}. Organic fertilization enhances soil biological activity, improves nutrient mobilization and soil structure and increases soil water retention. Systems relying on organic fertilizers as plant nutrient sources have different dynamics of nutrient availability than those using mineral fertilizers. Sustainable crop production with integrated use of mineral and organic fertilizer has proved to be highly beneficial. Several studies have shown the positive effect of combined use of mineral and organic fertilizers in fields that continuously for a few years received only N, P and K, without any micronutrient or organic fertilizer [5, 15].

To produce optimum yields of good quality vegetables, often high amounts of nutrients are applied. However, it is usually not feasible to supply sufficient concentrations of essential plant nutrient elements to sustain plant growth for an extended period. The role of nitrogen in vegetable growth has been investigated in a number of vegetable crops. Generally, vigorous growth was attributed to higher nitrogen regimes [33]. Melton and Dufault studied the effect of various rates of nitrogen, phosphorous and potassium on 'Sunny' tomato transplant growth and transplant quality. It was observed that nitrogen was a major factor affecting tomato transplant growth in both years of research [20].

2.2.1. Response of Head Cabbage to Nutrient Application

Cabbage has high requirements for all nutrients, especially nitrogen, and cabbage demands for achieving high yields ranged from 130 to 310 kg N ha^{-1} [18, 26]. Nitrogen over use in modern agriculture is of major importance with respect to both environmental concerns and the quality of plant products. Cabbage, as other cruciferous vegetables, has high nutritional value and contains specific sulphur compounds glucosinolates that increase its antioxidant activity. Nitrogen and phosphorus are one of the nutrients of major importance in the growth of head cabbage. Lack of these major nutrients causes the plant to be stunted and becomes yellow in appearance thereby decrease yield. An adequate supply of nitrogen is essential for vigorous vegetative growth, head formation and optimum yield of cabbage. However, the response of the crop to nitrogen and phosphorus varies under different soil and agro climatic conditions and thus affecting the optimum level of nitrogen and phosphorus. Achieving and maintaining appropriate levels of soil fertility, especially plant nutrient availability, is of paramount importance in agricultural land to remain capable of sustaining crop production at an acceptable level.

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2.2.2. Response of Head Cabbage to Nitrogen Fertilizers

To produce optimum yields of good quality cabbages, often high amounts of nitrogen fertilizer are applied. The recommended total amounts of nitrogen fertilizer for cabbage are 160 to 260 kg·ha-1 [9]. In reality, the amount of nitrogen fertilizer used is probably lower as farmers may apply minimum fertilizer than recommended to secure yields. Nitrogen produces reliable and optimal yield and quality of vegetables. It is however, the most difficult element to manage in a fertilization system in order to ensure an adequate, yet not excessive, amount of available nitrogen within the rhizosphere from planting to harvest [25].
Higher levels of nitrogen have often been found to induce optimum yields in *Brassica* vegetables. Zebarth, *et al.* (1991) observed a positive yield response up to 500 kg ha^{-1} N, but that percentage nitrogen recovery was lower at the higher rates [39].

Parmar *et al.* (1999) recorded higher yields in cabbage with increased nitrogen rates. The application of 200 kg·ha-1 N produced significantly higher yield over 150 kg·ha-1 N but at par with 250 kg·ha-1 N. This was attributed to the fact that higher nitrogen levels favored the growth of plants with larger leaf area and it was more usefully utilized in head formation [23]. Everaarts and De Moel (1998) also reported increasing uniformity with increasing amounts of nitrogen applied. In cabbage production uniformity of heads is important. Increase in relative core length was observed when nitrogen application rate increased, whereas dry matter content of the heads decreased. This was associated with softer head tissue at higher nitrogen availability, thereby having less physical resistance to stalk elongation [8].

2.2.3. Response of Head Cabbage to Phosphorus Application

Among the various factors involved, nutrient supply is an important input for realizing higher cabbage yield and its nutrient content. Results from the previous experiment showed that the response of cabbage is high to nitrogen and moderate to phosphorus application. The importance of nitrogen, phosphorus, potassium and sulphur on the growth and yield of vegetable crops is well established [13]. Phosphorus is also essential nutrient element which helps in the good growth of the roots of vegetable crops. The production increases progressively with the increased amount of N-fertilizer along with phosphorus fertilizer. Application of NPK at the rate of 70, 100 and 70 kg ha-1per hectare respectively increased the number of leaves per plant, size and weight of cabbage head significantly as compared with control treatment. Increased levels of nitrogen with constant doses of phosphorus and potassium increases cabbage yield [14].

3. Materials and Methods

3.1. Description of the Study Sites

The field trial was conducted during 2017 and 2018 main cropping season at the Bore Agricultural Research Centre which is located in Guji Zones, of Southern Ethiopia. The climatic condition of the area is most humid and sub humid moisture condition, which relatively longer growing season. Bore is found at Latitude of 6°26'52" N and Longitude 38°56'21" E at an altitude of 2736masl. The annual rainfall ranges from1400-1800 mm with a bimodal pattern that extended from April to November. The mean annual minimum and maximum temperature is 10.1°C and 20°C, respectively (Anonymous, 2014). The soil is clay in texture and very strongly acidic with pH around 4.01-5.33 [12].

3.2. Description of Experimental Materials

Head cabbage variety Olsen was used as experimental material. The seeds of this variety were obtained from the open commercial market. The choice of this variety was due to its good adaptability and short vegetative cycle. The seed of variety is normally found in the market at large and it is widely cultivated and consumed in different highland parts of the Zone and best variety for midlands of the area.

3.3. Description of Experimental Design and Treatments

The experiment was laid out in a Factorial arrangement of Randomized complete Block Design having two factors i.e., nitrogen and phosphorus with three replications. The treatments include four levels of nitrogen and four levels of phosphorus. There were 16 treatment combinations such as N_1P_1, N_1P_2, N_1P_3, N_1P_4, N_2P_1, N_2P_2, N_2P_3, N_2P_4, N_3P_1, N_3P_2, N_3P_3, N_3P_4, N_4P_1, N_4P_2, N_4P_3 and N_4P_4. The treatment details were as (i) Levels of nitrogen (N)-N1: control; N2: 176 kg; N3: 235 kg; N4: 294 kg ha^{-1}; (ii) Levels of phosphorus (P_2O_5) P1: control; P2: 82 kg; P3: 110 kg; P4: 138 kg ha^{-1}. Forty five days of old seedlings of head cabbage was transplanted using spacing of 50cm*40cm on plots size of 3.0 m x 2.4 m. The distance between the plot and the block is 0.8 m* 1.0 m, respectively. The plot consists of six rows and six plant populations per single row, totally 36 plants per plot were employed. The treatments were applied on permanent plots (3 m * 2.4 m) in a randomized complete block design with three replications. Half dose of nitrogen and full dose of phosphorus was applied to the respected treatment as basal dose and the remaining 50% nitrogen will be given to the treatment at time of head initiation. Urea and NPS fertilizers were used as sources of N, P_2O_5 respectively. Urea (46% N) and DAP (46% P2O5 + 18% N) TSP (46% P_2O_5) were used as sources of N and P, respectively.

3.4. Soil Sampling and Analysis

Initially a soil sample was collected before land preparation from the depth of 30 cm from different spots of the experimental field using auger. Then a composite soil sample was made and air dried, crushed and it was passed through 2 mm sieve in the laboratory for analysis of physico-chemical properties of the soil. After harvested the crop, soil samples were also taken from 0-30cm soils depth for each replications and composited treatment wise. Then a composite soil was analyzed for determining the soil textural class, pH, CEC, organic carbon, EC, organic matter, total nitrogen, available P, available K, and Sulphur. The values for each physico-chemical characteristics of the experimental soil were presented in Table 1.

3.5. Management of the Experiment

The nursery was prepared by removing plant residues and breaking big soil aggregates. Seedlings of the cabbage were raised in a seed bed. The soil of the seed bed was well ploughed with a spade and prepared in to loose friable dried masses and obtained good tilth that can provide a favorable condition for the vigorous growth of young seedlings. The seeds of the cabbage were sown on raised bed and watered once in a day until the seedlings were emerged and ready for transplanting. In the nursery fertilizer was not applied. Five days before transplanting the seedlings were hardened by reducing irrigation frequency. Then healthy and uniform seedlings were transplanted to a treatment plots after 45 days of sowing. All doses of phosphorus were applied once at time of transplanting and the doses of nitrogen were applied 50% at time of transplanting and 50% before head initiation as per treatment dose. Other agronomic practices including weeding, irrigation and cultivation were done uniformly in all plots.

3.6. Crop Data Collection

3.6.1. Phenological Data's

Days to 50% head initiation: Days to 50% head initiation was recorded when half of the plants in a net plot formed heads.

Days to 90% head maturity: It was recorded from the date of transplanting to when 90% of the heads from the net plot reached maturity. This was determined by the leaf color change, compactness or firmness of the head.

3.6.2. Growth Parameters Data's

Number of expanded leaves per plant: The number of leaves per plant was counted and mean of five plants was recorded before the start of head initiation excluding unfolded and dead leaves.

Plant height: The height of the plant was measured by placing a meter scale from ground level to the tip of the outer longest leaf of an individual plant at the time of 90% days to head maturity. Thus, mean of five selected plants of a single plot was recorded and expressed in centimeter (cm).

3.6.3. Yield and Yield Components Data's

Average fresh weight of untrimmed head per plant: The fresh weight of heads with unfolded leaves per plant was found from the average weight of selected five plants and expressed in gram (g) when yield data was taken.

Average fresh weight of trimmed head per plant: The fresh weight of marketable head per plant was found from the average weight of five plants and was expressed in gram (g) when yield data was taken.

Diameter of head: Five heads were taken randomly. Then sectioning of head was done horizontally with a sharp knife at the middle portion. The diameter of head was measured as the horizontal distance from one side to another side of the selected head and was expressed in centimeter (cm).

Height of head: Head height (cm) was obtained from five representative plants per net plot area and measured by cutting vertically using a ruler at the time of harvesting.

Gross head yield with wrapper: Heads with unfolded leaves of all the plants within a net plot area (harvested area 2 m×2.8 m) were weighed and converted to tons per hectare.

Marketable yield without wrapper per plot: Heads without unfolded leaves of all the plants within a net plot area (harvested area 2 m×2.8 m) were weighed and converted to tons per hectare.

3.7. Partial Budget Analysis

Variable cost of N and P fertilizer was largely used for partial budget analysis**.** Price fluctuations during the production season were considered. Marginal Rate of Return, which refers to net income obtained by incurring a unit cost of fertilizer, was calculated by dividing the net increase in yield of cabbage due to the application of each rate to the total cost of N and P fertilizer applied at each rate. This enables to identify the most economic rate and source of N and P fertilizer for cabbage production [6]. This was achieved by dividing the total variable cost by the net benefit multiplied by 100.

$$\text{MRR (\%)} = \frac{\text{Marginal benefit}}{\text{Marginal cost}} \times 100$$

3.8. Statistical Data Analysis

Analysis of variance procedures was used on every measured parameter to determine the significance of differences between means of treatments using the SAS 9.1.3 systems software for each parameters, and separated by the least significant difference (LSD) using the statistical package. Yield and yield related data was statistically analyzed using the Proc Glm function of SAS and means were compared using LSD at a probability level of 5% [27].

4. Results and Discussions

4.1. Soil Physicochemical Properties

4.1.1. Soil Physicochemical Properties of Site Before Planting

The analytical results of soil prior to planting indicated that the textural class of the soil was clay which is comfortable for production (Table 1). Accumulation of different organic materials during previous growing seasons might have resulted in high pre-plant organic carbon content (3.02%), which might have contributed to the high level of total N (0.30%), low level of available phosphorus (4.52 ppm), high level of exchangeable potassium (262.25 mg/kg (ppm)), and medium level of CEC (22.11 Meq/100g) in the soil. Tekalign *et al.* (1991) and Berhanu (1980) rated 0.12-0.25% total N as high, >3% OC as high and Olsen *et al.* (1954) rated available phosphorus range 5-10 ppm as medium. While Jones, J. Benton (2003) rated available K range 141-300 as high and CEC of. Hazelton and Murphy (2007) rated CEC 12-25 cmol (+) kg^{-1} as medium. The soil pH was also very strongly acidic with a value of 4.3 (pH-H2O). Generally, the soil physical and chemical analysis prior to planting indicated that the soils of the experimental fields are potentially productive from the perspectives of chemical properties of soils for cabbage growth except soil acidity of the soil since the ideal soil pH ranges from 5.5 to 6.5 and it should not be allowed to drop below 4.5. Therefore for better fertilizer response the physical nature of the soil should be improved through composted manure and lime to improve moisture retention and raise soil pH.

Table 1. *Soil Physiochemical properties of experimental site before planting.*

Soil characters	Values	Examination standards
pH (by 1: 2.5 soil water ratio)	4.30	ES ISO 10390: 2014 (1:2.5)
Total nitrogen (%)	0.30	ES ISO 11261: 2015 (Kjeldahl Method)
Organic carbon (%)	3.02	Walkley and Black Method
Available phosphorous (mg/kg (ppm))	4.52	ES ISO 11261: 2015 (Olsens Method)
Cation exchange capacity (Meq/100g)	22.11	Ammonium Acetate Method
Available potassium (mg/kg (ppm))	262.25	Ammonium Acetate Method
Available sulfur (mg/kg (ppm))	31.19	Turbidometreic
Soil texture:		Bouyoucos Hydrometer Method
Sand	28	
Silt	43	
Clay	31	
Class	Clay	

Source: Tekalign et al. (1991), Berhanu (1980), Olsen et al. (1954), Jones, J. Benton (2003) and Hazelton and Murphy (2007).

4.1.2. Soil Physicochemical Properties After Crop Harvest

The analysis of the experimental soil after harvest for pH, available phosphorus, total nitrogen, sulfur, available potassium, organic carbon, cation exchange capacity and texture is indicated in Table 2. The result revealed that available phosphorus organic carbon, total nitrogen and CEC were increased while available sulfur and available potassium decreased after the application of nitrogen and phosphorus to the experimental plot. However, the range of pH change was only from 4.11 to 5.35 with treatment employed (Table 2) which could be due to the inactivation of nitrogenous fertilizer we used which correspondingly increased the level of soil pH.

The result obtained from composited soil analysis showed that the treatments with 235 kg N ha^{-1} and 138 kg ha^{-1} of Phosphorus rate gave an increase of 5.35% pH, 3.11% OC and 0.31% of total nitrogen. However 294 kg N ha^{-1} and 138 kg ha^{-1} of Phosphorus rate gave an increased available S of 22.05 mg/kg of soil and application of 138 kg ha^{-1} of phosphorus gave 30.62 Meq/100 g CEC. Similarly, the combined application of the highest rate of 235 kg ha^{-1} and 138 kg ha^{-1} phosphorus increased the P_2O_5 level from 4.52 to 16.26 mg kg^{-1} after harvest. As the rate of nitrogen and phosphorus application increases, the soil characteristic parameters were increased with increase in nitrogen and phosphorus concentration. Maximum pH (5.35) was recovered, when 235 kg ha^{-1} and 138 kg ha^{-1} phosphorus applied with relatively higher rate of phosphorous. This increase in pH of the soil increased the availability of cations under acid soils in the study area.

Table 2. *Soil Physiochemical properties of experimental site after crop harvest.*

Treatments		PH	P (mg/kg)	S (mg/kg)	K (mg/kg)	CEC (Meq/100g)	OC (%)	OM (%)	TN (%)	C: N	Texture			Class
N rate (kg ha^{-1})	P rate (kg ha^{-1})										Sand	Clay	Silt	
0	0	4.3	13.38	10.34	105	24.32	2.87	4.94	0.3	9.52	30	44	26	Clay
0	82	4.58	14.99	8.06	106	23.88	3.07	5.29	0.31	9.91	28	44	28	Clay
0	110	4.48	9.81	20.16	136.5	21.33	3.11	5.37	0.3	10.24	26	42	32	Clay
0	138	4.33	6.93	14.68	74.2	30.62	3.03	5.22	0.3	10.17	26	46	28	Clay
176	0	4.13	12.75	13.13	105	20.44	2.89	4.99	0.3	9.61	26	46	28	Clay
176	82	4.11	12.02	15.16	106	28.66	3.06	5.27	0.31	9.77	26	46	28	Clay
176	110	4.01	9.18	6.09	152.25	19.66	2.8	4.82	0.3	9.76	26	46	28	Clay
176	138	5.29	12.66	16.11	127.2	21.43	2.87	4.94	0.3	9.58	30	42	28	Clay
235	0	5.15	16.53	20.16	99.75	20.18	2.92	5.03	0.31	9.51	30	44	26	Clay
235	82	5.26	14.29	14.87	104	21.13	2.89	4.98	0.3	9.61	30	44	26	Clay
235	110	4.86	8.76	12.65	126	18.77	2.8	4.82	0.3	9.8	28	42	30	Clay
235	138	5.35	16.26	14.68	100.7	17.79	3.11	4.87	0.31	9.45	30	42	28	Clay
294	0	5.07	9.48	15.16	111.3	24.04	2.82	5.36	0.30	10.2	30	44	26	Clay
294	82	4.98	12.87	12.77	100.7	19.29	2.78	4.8	0.31	8.86	30	44	26	Clay
294	110	5.33	11.07	11.7	131.25	20.03	2.84	4.89	0.3	9.59	30	44	26	Clay
294	138	5.06	10.44	22.05	105	19.8	2.84	4.89	0.3	10.74	30	42	28	Clay

4.2. Phenological Parameters of Head Cabbage

4.2.1. Days to 50% Head Initiation

The analysis of variance indicated that interaction effects of Nitrogen and Phosphorus had significant ($p<0.05$) effect on days to 50% heading (Table 3).

Table 3. *Interaction effect of N and P on days to 50% head initiation of head cabbage.*

Phosphorus (kg ha^{-1})	Nitrogen (kg ha^{-1})			
	0	176	235	294
0	64.33^{i}	70.66^{f}	72.00^{ef}	71.33^{f}
82	65.33^{hi}	80.66^{b}	79.66^{bc}	78.33^{c}
110	67.00^{gh}	72.33^{ef}	79.66^{bc}	78.66^{bc}
138	68.00^{g}	73.66^{e}	76.00^{d}	90.00^{a}
LSD (0.05) N*P=2.14; CV (%) =1.74				

Means in columns and rows followed by the same letter(s) are not significantly different at 5% level of significance. LSD (0.01) = Least Significant Difference at 1% level; and CV (%) = coefficient of variation in percent.

The shortest head initiation (64.33 days) was obtained in control treatment where the longest (90 days) duration was attained in 294 kg ha^{-1} Nitrogen and 138 kg ha^{-1} phosphorus treatment (Table 3). The control treatment resulted in early finish of heading before attaining of fully required physiological maturity and matured early as compared to those higher doses. This might be due to lower N and P rates not enough to enhance the development of the crop and hastening head formation and maturity.

4.2.2. Days to 90% Maturity

The analysis of variance indicated that interaction effects of Nitrogen and Phosphorus had significant ($p<0.05$) effect on days to maturity (Table 4). Plots treated with lowest (control) combination rates took shorter period to mature which might be because lower rate of Nitrogen and Phosphorus not enough to enhance the development of the crop and hastening head formation and maturity. While plots treated with maximum 294 kg ha^{-1} Nitrogen and 138 kg ha^{-1} phosphorus combination rates took longer (140) days to mature. The increase in days to maturity due to nutrient application might be related to its role in stimulation of plant growth by the assimilation of major elements and changes in protein synthesis and finally related to growth and production of the crop.

Table 4. *Interaction effect of N and P on days to maturity of head cabbage.*

Phosphorus (kg ha^{-1})	Nitrogen (kg ha^{-1})			
	0	176	235	294
0	109.66^{j}	117.00^{h}	118.00^{h}	125.00^{f}
82	108.00^{j}	120.00^{g}	132.00^{d}	132.66^{cd}
110	108.00^{j}	127.00^{e}	135.33^{b}	139.00^{a}
138	112.00^{i}	134.33^{bc}	139.66^{a}	140.33^{a}
LSD (0.05) N*P=1.71; CV (%) =0.82				

Means in columns and rows followed by the same letter(s) are not significantly different at 5% level of significance. LSD (0.01) = Least Significant Difference at 1% level; and CV (%) = coefficient of variation in percent.

4.3. Growth Parameters of Head Cabbage

4.3.1. Number of Expanded Leaves

The combined effect of nitrogen and phosphorus was found significant ($P<0.05$) for the characters of number of expanded leaves and Plant height of head cabbage.

Combined application of 294 kg nitrogen and 138 kg phosphorus ha^{-1} (N4P4) recorded maximum number of outer leaves (8.33) per plant, while the lowest (5.00) number was recorded from the control (Table 5). The higher nutrient rates, relative to lower rates, increased leaf count regardless of the sampling date. Leaf count increased from plots received of maximum plant nutrient for transplanted treatments, respectively as nitrogen was increased from 176 to 294 kg ha^{-1}. The tendency for the leaf count to increase in response to increasing nitrogen application is in agreement with the results of [20]. They observed increases in tomato leaf count as nitrogen was increased during both years of their study.

4.3.2. Plant Height

The mean data revealed that plant height was significantly ($P<0.05$) influenced by the combination of Nitrogen and Phosphorus nutrients and it tended to increase with the application of higher amount of nutrients. Plant height is one of the important growth contributing characters for cabbage plant. It depends on several factors like genetic makeup, nutrient availability, climate, soil, etc. Among those nutrient availability is one of the important factors for desirable plant height.

The maximum plant height (26.4 cm) was recorded for the treatment T3P4 (235 +138 kag ha^{-1}), while the lowest (16.9 cm) plant height was recorded from the T1P1 (control) treatment (Table 4). [24] Noted significant difference in plant height of head cabbage due to different source of nutrients. The increments of plant height in broccoli by the application of 240 kg N, 100 kg P and 80 kg ha^{-1} also reported by [21]. Nitrogen and Phosphorus were the mineral nutrient that boosts plant growth and development [22].

Table 5. *Mean Interaction effects of N and P_2O_5 fertilizers on plant height and expanded true leaves of head cabbage at Bore during 2018 and 2019 cropping season.*

Treatments	ETLV (no)	PH (cm)
N1P1	5.00^{d}	16.9^{de}
N1P2	6.66^{abcd}	19.10^{cde}
N1P3	7.00^{abcd}	17.9^{cde}
N1P4	7.33^{abc}	21.06^{abcde}
N2P1	8.00^{ab}	17.8^{cde}
N2P2	5.66^{cd}	19.5^{cde}
N2P3	6.66^{abcd}	20.9^{abcde}
N2P4	6.00^{bcd}	19.6^{cde}
N3P1	7.33^{abc}	17.3^{cde}
N3P2	7.66^{abc}	20.7^{abcde}
N3P3	7.00^{abcd}	18.9^{cde}
N3P4	6.66^{abcd}	26.4^{a}
N4P1	6.33^{abcd}	22.9^{abc}
N4P2	7.00^{abcd}	25.7^{ab}
N4P3	7.66^{abc}	20.5^{bcde}
N4P4	8.33^{a}	22.5^{abcd}
Mean	6.95	20.42
LSD (5%)	2.25	5.78
CV (%)	19.45	17.01

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance; PH = Plant height (cm), ETLV=No of expanded true leaves, LSD = Least Significant difference; NS = Not significant; CV = Coefficient of Variation.

4.4. Yield Components and Yield of Head Cabbage

4.4.1. Yield Related Components

(i). Head Diameter and Head Height

As shown in Table 6. Effect of N and P levels on growth and yield parameters of cabbage (*Brassica oleracea* L.) under Bore soil conditions was significantly different ($P<0.05$). Diameter of head is an important yield contributing character of cabbage. Nutrient levels markedly influenced the diameter, height, head mass and yield of head cabbage (Table 6). The maximum average diameter (25.44 cm) and average height (27.33 cm) was recorded in treatment receiving 235 kg N and 82 kg P ha^{-1}. The minimum diameter (10.31cm) and minimum (12.33 cm) height was noted by control treatment. It was observed that fertilizer application at different levels result a remarkable change in height and diameter of the head. This result was corroborated with the findings of [28]. Din *et al.* reported significantly higher diameter of head cabbage by the application of 120-90-80 NPK ha^{-1}, respectively [7]. That means application of higher nutrient to some level induced maximum diameter and height of cabbage. There was a strong positive correlation between diameter, height and yield without wrapper.

Table 6. *Combined Mean Interaction effect of N and P_2O_5 fertilizers on head height, diameter of head, untrimmed head mass, trimmed head mass, of Head cabbage at Bore during 2018 and 2019 cropping season.*

Treatments	Yield related parameters			
	HH (cm)	DH (cm)	UTHM (gm)	THM (gm)
N1P1	12.33^{j}	10.31^{k}	1120.67^{j}	952.57^{j}
N1P2	16^{i}	14.80^{j}	1403.67^{i}	1193.12^{i}
N1P3	18^{h}	16.10^{i}	1435.0^{i}	1219.75^{i}
N1P4	18^{h}	16.86^{i}	1487.67^{i}	1264.52i
N2P1	19.33^{g}	18.23^{h}	1655.00^{h}	1406.75^{h}
N2P2	22de	19.98^{ef}	1947.33^{efg}	1655.23^{efg}
N2P3	23.33^{c}	22.16^{b}	2005.00^{def}	1704.25^{def}
N2P4	24.66^{b}	21.72^{bcd}	2113.33^{bc}	1796.33^{bc}
N3P1	19.33^{g}	18.56^{gh}	1844.33^{g}	1567.68^{g}
N3P2	27.33^{a}	25.44^{a}	2356.67^{a}	2003.17^{a}
N3P3	24.33^{b}	20.99^{cde}	2133.33^{b}	1813.33^{b}
N3P4	24.33^{b}	22.04^{bc}	2066.67^{bcd}	1756.67^{bcd}
N4P1	20.33^{f}	19.13^{fgh}	1906.67^{fg}	1620.67^{fg}
N4P2	2.33^{de}	20.82^{de}	2002.00^{def}	1701.7^{def}
N4P3	22.66^{cd}	20.14^{ef}	2017.00^{cde}	1714.45^{cde}
N4P4	21.66^{e}	19.66^{fg}	1929.33^{efg}	1639.93^{efg}
Mean	21.00	19.18	1838.98	1563
LSD (5%)	0.92	1.12	103.46	87.94
CV (%)	2.66	3.52	3.38	3.38

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance; HH=head height, DH=diameter of head, UTHM=untrimmed head mass, THM=trimmed head mass, LSD = Least Significant difference; NS = Not significant; CV = Coefficient of Variation.

(ii). Untrimmed and Trimmed Weight of Head Cabbage

The untrimmed and trimmed weight of head cabbage was highly significantly ($P<0.05$) influenced by the main effect of the application of different levels of nitrogen and phosphorus and their interaction (Table 6). Combined application of 235 kg N ha^{-1} with the 82 kg P ha^{-1} produced the highest (2356.67 g) untrimmed head weight of cabbage followed by second maximum (2133.33 g) untrimmed head weight with the rate of 235 kg N ha^{-1} with the 110 kg P ha^{-1} while the least (1120.67 g) untrimmed head weight was recorded for the control treatment (Table 6). The increase in head weight might be attributed to the beneficial effect of nutrient on stimulating the meristimic activity for producing more tissues and organs, in addition to its vital contribution in several biochemical processes in the plant, related to growth and yield development [19].

4.4.2. Yield Components

(i). Yield with Wrapper

From the present research it was observed yield with and without wrapper varied significantly (P<0.05) among the treatments tested due to application of nutrients (Table 7).

The highest head yield with wrapper (73.83 t ha^{-1}) was found from the treatment combination of N3P2 (dose of 235 kg N ha^{-1} + 82 kg P ha^{-1}) followed by 1813.33 t ha^{-1} with dose of 235 kg N ha^{-1} + 110 kg P ha^{-1} at 5% level of significance, while the lowest yield with wrapper (29.59 t ha^{-1}) was recorded in the treatment T1P1 (zero application). From the above result it was observed that combination of fertilizers with recommended rate of NP_2O_5 fertilizers is the best for production of highest head yield with wrapper.

(ii). Yield Without Wrapper

Similar to wrapper yield, the yields of cabbage without wrapper was significantly (P<0.05) affected both by the main and interaction effect of nitrogen and phosphorus (Table 6). The combined effect of nitrogen and phosphorus was found significant for most of the characters of head cabbage. Combined application of 235 kg nitrogen and 82 kg phosphorus ha^{-1} (N3P2) recorded maximum (69.00 t) head yield without wrapper ha^{-1} and the lowest (27.66 t ha^{-1}) was recorded by control treatment. Yield without wrapper or marketable head yield was reduced due to the application of nutrients above 235 kg N and 82 kg P ha^{-1}. It might be due to increase in all the above mention parameters that attribute to increase the final yield ha^{-1} which is due to more vegetative growth, development, photosynthesis, dry matter synthesis and translocation to storage organ. It might be also due to the optimum accumulation of N and translocation of micronutrient such as boron and thus yield from the crops get increases. Similar results were found by [32, 28]. Din *et al*. also reported that maximum head yield was recorded in treatment receiving 120 kg N, 90 kg P and 80 kg K/ha [7].

For the current experiment higher yields at higher nitrogen doses could be attributed to great head height, diameter and mass obtained at higher nitrogen and phosphorus doses. Westerveld *et al*. reported increases in head width (diameter) and height as nitrogen application was increased up to 255 kg·ha^{-1}. Generally excessive application cannot increase economic yield rather plants used for luxury consumption [37]. Solomon *et al*. reported that Application of optimum N and FYM not only increased crop productivity, but also improved quality of the product as expressed in terms of its highest marketable to unmarketable yield ratio, mainly due to reduced cracking and improved size, particularly for the reduced or balanced application of fertilizer [30].

Table 7. *Mean Interaction effects of N and P_2O_5 fertilizers on head height, diameter of head, untrimmed head mass, trimmed head mass, yield with wrapper and without wrapper of Head cabbage at Bore during 2018 and 2019 cropping season.*

Treatments	YWR (t ha^{-1})	YWOR (t ha^{-1})
N1P1	29.59^{n}	27.66^{n}
N1P2	32.88^{m}	30.73^{m}
N1P3	36.13^{l}	33.76^{l}
N1P4	38.52^{k}	36.00^{k}
N2P1	42.72^{j}	39.92^{j}
N2P2	51.58^{h}	48.21^{h}
N2P3	59.49^{f}	55.60^{f}
N2P4	66.37^{c}	62.03^{c}
N3P1	43.34^{j}	40.51^{j}
N3P2	73.83^{a}	69.00^{a}
N3P3	71.69^{b}	67.00^{b}
N3P4	63.20^{d}	59.06^{d}
N4P1	48.00^{i}	44.86^{i}
N4P2	60.81^{e}	56.83^{e}
N4P3	53.78^{g}	50.27^{g}
N4P4	51.36^{h}	48.00^{h}
Mean	51.45	48.09
LSD (5%)	1.16	1.09
CV (%)	1.36	1.36

Means within the same column followed by the same letter (s) are not significantly different at 5% level of significance; YWR=yield with wrapper and YWOR=without wrapper, LSD = Least Significant difference; NS = Not significant; CV = Coefficient of Variation.

Figure 1. *Effects of N and P_2O_5 fertilizers on head yield.*

4.5. Economic Analysis

The idea of an economic optimum is based on the wisely appealing notion of doing something only as long as it pays to do it. This marginal principle basically suggests that the producer should apply fertilizer only as long as the cost is no more than the additional benefit from increased crop yield. In birr terms, the end result is that the producer will maximize net returns (revenue minus cost). To illustrate this point, we have performed a simple cost-benefit analysis with the results given in Table 8. Partial budget analysis was done based on the view of CIMMYT Economics Program recommendations, which stated that the application of nutrients with the marginal rate of return above the minimum level (100%) is economical. The result indicated that the application of nitrogen and phosphorus on Olsen cabbage variety had gave promoting benefit over the control treatment [6].

In this study, the costs of Nitrogen, Phosphorus fertilizer and labor cost for fertilizer application and weeding varied, while other costs were constant for each treatment. In order to recommend the present result for end users, it is necessary to estimate the minimum rate of return acceptable to farmers in the recommendation domain. Based on partial budget analysis, the net benefit accrued from the experiment ranged from nitrogen application alone is 139127 to 153833 birr per hectare compared with non-application of nutrients which is 98376 birr per hectare. For the phosphorus treatments alone net benefit ranged from 107834 to 125654 birr per hectare benefit. This is an indication of the level of profitability of the fertilizer application treatments.

The marginal rate of returns, which determines the acceptability of any treatments shows that treatments that received 235 kg N ha^{-1} in combination with 82 kg P ha^{-1} yielded best result 434.98 marginal revenue. However, the marginal rate of returns for the Nitrogen fertilizer alone was higher than those for the phosphorus fertilizer. All in all the highest net benefit 241456 birr was obtained from treatment combination of 235 kg N ha^{-1} with 82 kg ha^{-1} of P with a marginal rate of return 434.98 but the lowest net benefit 98376 birr was obtained from the treatment non-application of nutrients only in two growing season. This means that for every 1.00 birr invested for 235 kg N ha^{-1} with 82 kg ha^{-1} of P input and its application in the field, farmers can expect to recover the 1.00 birr and obtain an additional 434.98 birr. In general, the negative value of MRR percentage indicated that the loss on investment, whereas, the positive number indicated that a profit or gain on combined use of nitrogen and phosphorus fertilizer to produce the output. Therefore, the economic rates for producers with low cost of production and higher benefits were the treatment combination of 235 kg N ha^{-1} with 82 kg ha^{-1} of P.

The marketable head yield was adjusted by 10% adjustment coefficient and the marginal rate of return (MRR) and net benefits are calculated by current Urea price was 15 kg^{-1}, NPS 17 kg^{-1} and field price of cabbage was 4.00 birr kg^{-1}.

Table 8. *Cost Benefit Analysis of Cabbage Production.*

Treatments	Adjusted yield (t ha^{-1})	Gross Benefit (Birr ha^{-1})	Total variable cost (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	MRR
N1P1	24.894	99576	1200	98376	0
N1P2	27.657	110628	2794	107834	5.9335
N1P3	30.384	121536	3470	118066	15.1361
N1P4	32.4	129600	3946	125654	15.9412
N2P1	35.928	143712	4122	139590	79.1818
N2P2	43.389	173556	4262	169294	212.171
N2P3	50.04	200160	6117	194043	13.3418
N2P4	55.827	223308	6493	216815	60.5638
N3P1	36.459	145836	6708.75	139127	D
N3P2	62.1	248400	6944	241456	434.979
N3P3	60.3	241200	7220	233980	D
N3P4	53.154	212616	7496	205120	D
N4P1	40.374	161496	7663	153833	D
N4P2	51.147	204588	7857	196731	D
N4P3	45.243	180972	8133	172839	D
N4P4	43.2	172800	8609	164191	D

Where, t=tone, ha=hectare and MRR= marginal rate of return, D=dominance.

5. Conclusions and Recommendation

The present study was initiated to assess the effects of different levels of nitrogen and phosphorus on yield and yield components of head cabbage. Accordingly, four levels of N and four levels of phosphorus fertilizer were evaluated at Bore, southern Ethiopia in 4 X 4 factorial arrangements using randomized complete block design with three replications on a plot size of 3.0 m x 2.4 m per treatment unit. Cultivation aspects such as nutrient requirements are vital in maximization of cabbage head yields. It is therefore, important for the end user to determine the best combination of optimum nitrogen and phosphorus levels.

The results of the experiment indicated a significant response of nitrogen and phosphorus with respect to growth and yield characters of head cabbage. Balanced use of nitrogen and phosphorus significantly increased the head mass, diameter and head yield and reduced the percentage of deformed head as well as percentage of unmarketable head compared to lower dose of nitrogen and phosphorus. Hence, the application of 235 kg nitrogen with 82 kg phosphorus ha^{-1} (N3P2) was found beneficial for growth and yield of head cabbage under highland areas of Bore.

Based on cost benefit analysis the highest net benefit 241456 birr was obtained from treatment combinations of 235 kg nitrogen with 82 kg phosphorus ha^{-1} with a marginal rate of return of 434.98. Therefore the most attractive rates for the producers with low cost of production and higher benefits in this case were treatment combination of 235 kg nitrogen with 82 kg phosphorus ha^{-1}.

Conflict of Interest

We declare that we have no competing interests.

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