



**Effect of Nitrogen and Intra Row Spacing on Growth and Head Yield of
Cabbage (*Brassica oleracea* L. *Var. capitata*) at Bako Agricultural Polytechnic
College, West Shewa, Ethiopia**

MSc. Thesis

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**HAWASSA UNIVERSITY
COLLEGE OF AGRICULTURE**

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**Effect of Nitrogen and Intra Row Spacing on Growth and Head Yield of
Cabbage (*Brassica oleracea* L. *Var. capitata*) at Bako Agricultural Polytechnic
College, West Shewa, Ethiopia**

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**A THESIS SUBMITTED TO SCHOOL OF PLANT AND HORTICULTURAL
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DEGREE OF THE MASTER OF SCIENCE IN PLANT SCIENCE
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December, 2022

APPROVAL SHEET - 1

This is to certify that the thesis entitled “**Effect of Nitrogen and Intra Row Spacing on Growth, Head Yields of Cabbage (*Brassica oleracea* L. var. *capita*) at Bako Agricultural Polytechnic College, West Shewa, Ethiopia**”, Submitted in partial fulfillment for the degree of Master of Science in Agriculture (specialization: **Horticulture**), the Graduate Program of the Department of Plant and Horticultural Sciences, and has been carried out by **Chimdessa Wakuma Geldassa** under my/our supervision. Therefore I recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

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DEDICATION

This thesis is dedicated to my beloved wife Motu Gari and children Kena, Lami, Meti and Gadise for their endless love.

STATEMENT OF THE AUTHOR

First, I declare that this Thesis is my own work and that all sources of materials used for this Thesis have been duly acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for MSc degree at the Hawassa University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that the thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LIST OF ACRONMYS AND ABBREVIATIONS

ANOVA	Analysis of Variance
Cm	Centimeter
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAO	District Agricultural Office
DF	Degree of freedom
DM	Days to maturity
DMC	Dry matter content
FAO	Food and Agriculture organization
HD	Head diameter
MHW	Marketable head weight
Kg/ha	Kilogram per hectare
LA	Leaf Area
NLBH	Number of leaf before heading
NUFLAH	Number of unfolded leaf after heading
LSD	List significant difference
m	Meter
m.a.s.l	Meter above sea level
PH	Plant height
RCBD	Randomized Completely Block Design
SAS	Statistical Analysis Software
USA	United States of America

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Effect of Nitrogen and Intra Row Spacing on Growth and Head Yields of Cabbage (*Brassica oleracea* L. Var. *capitata*) at Bako Agricultural Polytechnic College, West Shewa, Ethiopia

Chimdessa Wakuma (BSc)

ABSTRACT

Low soil fertility and spacing are considered as serious problems among several production limiting factors in cabbage crop production. Nitrogen is one of the critical plant nutrients in cabbage yield and its information in relation to plant spacing in the study area is very limited. The current study aimed to evaluate the effect of nitrogen fertilizer rate and intra row spacing on growth and head yield of cabbage under field conditions. Thus, field experiment was conducted at Bako Agricultural Polytechnic College, West Shewa zone of Oromia National and Regional state during the wet season of 2021/2022. The treatments consisted of four levels nitrogen rate (0, 50, 100 and 150 kg/ha) and three intra row spacing (15, 25 and 35 cm) which were laid down in a Randomized Complete Block Design (RCBD) with three replications. Data on phenology, growth and yield components of cabbage were collected and analysis of variance was done using SAS version 9.3. The results revealed that some of the growth and yield related parameters of cabbage were significantly influenced by rate of nitrogen and intra row spacing. Days to maturity, number of leaf before heading, plant height, head diameter, leaf area, above ground plant fresh weight, marketable weight, unmarketable weight, total yield, dry matter and head firmness were very highly significantly ($p < 0.001$) affected by the treatment combination. The highest marketable head weight (80.40 t/ha) were obtained at the combination of 150 kg/ha nitrogen rate with 35 cm intra row spacing where as the lowest (33.00 t/ha) were recorded in plots that received no nitrogen rate with 15 cm intra row spacing. The highest (82.00 t/ha) and lowest (37.99 t/ha) total head yield was recorded by treatment combination of 150 kg/ha nitrogen fertilizer with 35 cm intra row spacing and no nitrogen fertilizer rate with 25 cm intra row spacing, respectively. Larger leaf number before heading (15.67), longer plant height (35.97 cm), wider head diameter (17.84 cm) and wider leaf area (441.12 cm²) were recorded at higher (150 kg/ha) nitrogen fertilizer rate. Plant height, head diameter, above ground plant fresh weight and marketable head weight were found superior at 35 cm intra row spacing. Result of current study shown that 150 kg/ha nitrogen fertilizer rate and 35 cm intra row spacing can be used for higher marketable head yield of cabbage. But future study need to be designed to be carried out at different locations and seasons so as to come up with valid recommendation.

Key words: cabbage, intra row spacing, marketable head, nitrogen fertilizer, head

1. INTRODUCTION

1.1. Background and justification

Cabbage (*Brassica oleracea var. capitata* L.) belongs to the family cruciferae and it is biennial crop with a very short stem supporting a mass of overlapping leaves to form a compact head. It is originated in Western Europe and northern shore of Mediterranean (Abera, 2019). It is a widely grown vegetable through out the world. It has been domesticated and used for human consumption since the earliest antiquity. It also remains a very vital crops for farmers and gardeners enabling the small scale farmers to be financially viable mainly in Africa and Asia. Cabbage is a cool season crop that is very popular with gardeners and commercial producers and also the most popular food crops (Embaby and Lotfy, 2015).

Cabbage is known for its nutritional importance and it is rich in mineral and vitamins like A, B₁, B and C. It is also known for its cooling effect being an appetizer, it aides digestion thereby help preventing constipation. It also protects against cancers (Kibar *et al.*, 2014).

Cabbage can grow easily under wide range of environmental condition in both temperate and tropical, but cool moist climate is most suitable. Optimum growth of cabbage occurs at a mean daily temperature of about 17 °c with daily mean maximum of 24 °c and minimum of 10 °c. Mean relative humidity should be in the range of 60 and 90 % (Damtew, 2020). Cabbage is grown on all types of soils from sands to heavy soils with a pH of 5.5 - 6.5. Sandy or sandy-loam soils are considered best for very early crop. Clay loams and silty soils are preferred for late crops(Damtew, 2020). Cabbage is well grown at an altitude of 1500 - 3000 m.a.s.l. in Ethiopia (Asfaw and Eshetu, 2015).

Cabbage is grown for its head in more than ninety countries throughout the world. The top ten cabbage growing countries of the world in 2017 are China, India, Russian Federation, Republic of Korea, Ukraine, Indonesia, Japan, USA, Poland and Romania (Abera, 2019). The world cabbage production is estimated to be 71, 451,138 tons, while area coverage was 2, 513,707 ha in the same year with productivity of 28.423 t/ha (FAOSTAT, 2021). The five cabbage producers in African countries are Kenya, Egypt, Ethiopia, Niger and South Africa and these five countries have

maintained the dominance of the sector throughout this period. Ethiopia accounted for 12% of the total production in Africa (Damtew, 2020).

Area, production and yield of head cabbage in Ethiopia in 2018/19 were 5,170.52 hectares, 31,483.75 tons and 6.1 t/ha, respectively. The area and production in 2019/20 were decreased to 3,629 hectares and 24,565.05 tons, respectively but the productivity grew to 6.8 t/ha (CSA, 2020). Within these two years the area has decreased by 29.80 % whereas the production has decreased by 21 %. In Oromia, regional state the area covered by head cabbage in year 2019/20 was 2,331.62 ha while the production was 15,871.79 tons and the yield is 6.8 t/ha (CSA, 2020). In West Shewa Zone the area, production and yield of head cabbage in 2019/20 were 280.60 hectares, 1,338.71 tons and 4.8 t/ha. In general the productivity of cabbage in Ethiopia is below the world average yield is 10 - 40 t/ha (Damtew, 2020). But the average cabbage yield of national as well as in Oromia region is very low when compared to the world average. Among the major factors for the low productivity of head cabbage in Ethiopia in general and in Oromia region, especially that of around Bako in particular are poor fertility status of the soil, inappropriate use of fertilizer rate, plant population per unit area, disease, pests and inappropriate agronomic practices (Melkamu *et al.*, 2015).

The current farmer's practice of cabbage production around Bako is similar to other parts of the country. They cultivated this crop both by rain fed and irrigation using commercial fertilizer of NPS and Urea. Moreover, the fertilizer rates and plant spacing used for production of cabbage is not uniform among farmers which has resulted in low yield with different defects which are too small, cracked, burst, rotten and loose heads having low acceptances in the market (Asfaw and Eshetu, 2015).

In general crop production can be increased either by improving inherent genetic potential of the crop or through application of better agronomic management such as optimum fertilizer rate and plant spacing which contribute to substantial amount of crop. The possibility of securing high yield depends much upon a proper consideration of optimum number of plants per unit area and the pattern in which the given quantity of seeds or plant population is arranged in the field of planting (Abera, 2019). This is due to the fact that the quantity of solar radiation, which penetrates a crop canopy greatly, depends on planting pattern or spacing and individual plant morphology.

Cabbage has high requirements for all nutrients, especially nitrogen. Nitrogen is one of the critical plant nutrients in cabbage yield and it is significant to note that nitrogen response is directly associated to the soil type, emphasizing that soil varying in fertility status react differentially to the applied fertilizer. Cabbage demands 130 to 310 kg/ha nitrogen fertilizer for achieving high yields (Richard *et al.*, 2016). Thus, it requires applying of appropriate rate of fertilizer for the enhance of cabbage productivity and sustainable yield. Many experiments show that nitrogen application increases the total yield of cabbage (Patrick *et al.*, 2014). But this is possible as long as it is managed properly in terms of rate and time of application.

Therefore, nitrogen rate and plant spacing have to be regulated to obtain high yield from cabbage. Thus, knowledge on the interaction among these factors is helpful to optimize cabbage yield through efficient use of land and rate of fertilizer. In western parts of Ethiopia, particularly around Bako area, there is a need by farmers to increase productivity of high value crops like cabbage to maximize their profit from small plot of farm they have.

However, farmers of this area who grow cabbage frequently give less attention to fertilizer rate and optimum plant population. According to agricultural development agent workers of Bako, Tibe district, 2019 says that farmers of this area apply fertilizer which is not recommended and most of them do not apply fertilizer to cabbage crops, other farmers apply different farmyard manures and different crop residues which is collected from their houses (BTDAO, 2019). Moreover, information on nitrogen application rate and cabbage plant spacing for optimum yield and other agronomic practices are limited. So, it is important to increase the yield of cabbage to improve the income of farmers around this area.

Therefore, considering the above facts, this study was designed to investigate the effect of different nitrogen fertilizer rate and intra row spacing for growth and head yield of cabbage production.

1.2. Objectives

1.2.1. General objective

- To investigate the effects of nitrogen fertilizer rate and intra row spacing on growth and head yield of cabbage.

1.2.2. Specific objective

- To investigate the effects of different rates of nitrogen fertilizer and intra row spacings on growth and head yield of cabbages in Bako area, West Shewa Zone of Ethiopia.

2. LITERATURE REVIEW

2.1. Description of cabbage

Cabbage (*Brassica oleraceae. var capitata* L.), is also known as cole crops. It belongs to family Brassicaceae (or Cruciferae) and generally referred as Brassicas (Richardson, 2016). The genus Brassica includes about 100 species majority of which are native to Mediterranean region. The crop is attributed to the Mediterranean center of origin. It is important groups of crop worldwide.

Cabbage generally classified as headed which is round, oval or flat. Head cabbage is oval and flat, moreover it is loosely formed and light in weight. Head formation in cabbage is quantitative trait controlled additively with low dominance effect. It is only head cabbage that changes in leaf shape becoming wider because of the shorter petiole length with increasing leaf position and thus cabbage acquired the developmental change in leaves. Cabbage has been domesticated and used for human consumption since the earliest antiquity (Singh *et al.*, 2015).

2.2. Importance of cabbage

Cabbage is grown for its leaves and commonly used as vegetable. Cabbage is an excellent source of mineral such as calcium, iron, sodium, potassium, phosphorus. It has substantial amount of β -caroten, ascorbic acid and others. It has calories (27%), fat (0.1%) and carbohydrate (4.6%). It is good source of protein (1.3%) which contains all essential amino acids; particularly sulfur containing amino acids (Damtew, 2020). The only part of the cabbage plant that is normally eaten by human being is the leafy head; more precisely, the spherical cluster of immature leaves, excluding the partially unfolded outer leaves. Cabbage is used us row in salad such as coleslaw, as a cooked vegetable, or preserved in pickle or sauerkraut. Flavour in cabbage is due to the glucoside sinigrin (USDA, 2014).

2.3. Cabbage production in Ethiopia

Ethiopia has favorable climate and edaphic conditions for the production of tropical, sub-tropical and temperate vegetables in the lowlands (<1500 meters above sea level), midlands (1500-2200) and highlands (>2200), respectively (Hunde, 2017). The country has a variety of vegetable crops grown in different agro-ecological zones by small farmers, mainly as a source of income and food.

Commercial producers are also involved in the production, processing and marketing of vegetables. These crops are produced under rain fed and irrigation conditions. It is produced both in cereals based cropping system and in monoculture.

At present different crops are produced in many home gardens and also commercially in different parts of the country. But most of the production is by smallholder. Cabbage production in Ethiopia is scattered in the highlands but the larger production is found at the central high lands of the country. The most important cabbage varieties cultivated in Ethiopia are Copenhagen and Early drum head. Other warm season vegetables such as tomato, onion, and capsicum are grown in lowland areas under irrigation, whereas the high land areas offer favourable condition to grow cool season vegetable like cabbage, garlic, shallot, carrot etc. In Ethiopia, land holders living near urban center largely practice vegetable farming (Damtew, 2020).

Most of the vegetables produced in Ethiopia including cabbage are grown from imported seeds from various countries except limited once such as shallot, garlic, hot pepper and kale, which has been traditionally produced. The production of vegetable varies from cultivating a few plants in a backyard, for home consumption, to large scale production for the domestic and export markets. The crop can generally be very important source of vitamin, mineral, and protein to a country like Ethiopia where the people experience malnutrition due to heavy dependence on cereals. Its primary contribution in solving the health problem is through providing vitamins and minerals.

2.4. Environmental requirements and agronomic management of cabbage

Cabbage grows well on a wide range of environments. But for optimum production, it requires well drained sandy loam soil with pH of 5.5 - 6.5, rain fall of 700 - 900 mm and temperature of 17-24^{0C}. Cabbage poorly tolerate water logging, thus is water logged location are unsuitable for cabbage production. On the other hand, cabbage is very sensitive to soil moisture deficit.

Maximum growth and yield can only be obtained when a particular supply of water is available to the plant throughout the growth. Good drainage is important, as too much water tends to split heads when they are matured (Solomon and Arega, 2020). Water should not be deficient from head formation until harvest time, as this will drastically limit yields. It is propagated by seed and

system of planting is by transplanting seedlings that are pre-raised on seed beds. Asfaw and Eshetu (2015) cabbage requires the seed rate of 0.6 kg/ha and sowing depth is 1-1.5 cm and spacing of 60 cm by 40 cm between rows and plants, respectively. Fertilizer requirement is 150 kg/ha DAP and 100 kg/ha Urea. Its days to maturity are 80 - 100 days.

2.4.1. Nutritional requirement of cabbage

Cabbage has high requirements for all nutrients, especially nitrogen. According to Richard *et al*, (2016) cabbage demands 375 kg/ha nitrogen fertilizer for achieving high yield. Adequate application of nitrogen fertilizer promotes vigorous vegetative growth and dark green color of cabbage (Solomon and Arega, 2020). Nitrogen is important in the formation of chlorophyll and is also a component of proteins. Lack of nitrogen causes slow, spindly growth and pale foliage, resulting in limited production. In Ethiopia application of nitrogen fertilizer averagely 130 kg/ha, in Oromia regain 110 kg/ha (CSA, 2020).

Increased in head mass and yield up to 150 kg/ha N, beyond which there was a reduction in yield. The reason suggested for such a response was that nitrogen significantly increased growth parameters, which in return synthesized more plant metabolites thereby increasing yield. High temperature causes nutrients, especially nitrogen, to be available to the growing plants much quicker and will result in high quality yields (Semuli, 2005).

2.4.2. Maturity, harvesting and yield of cabbage

Determining the optimum time of harvest is often difficult and differs between heading and non-heading types (Semuli, 2005). According to the author the principal harvest maturity index is based on size. Heading type cabbage may be harvested as small as 10 cm in diameter and continued until 15 cm. The maturity indicator for non-heading type are that the color of the leaves will change from deep green to light green and the leaves will spread outwards. Harvest maturity for heading type is also based on head compactness and firmness to the touch. A firm or compact head is mature. A very loose head is immature and should not be harvested. Harvest maturity may also be based on arrangement of the wrapped leaves; when they are spread and the head is exposed it is usually matured. A mature cabbage has a longer post-harvest life than immature cabbage. Delayed

harvest even a few days beyond maturity can result in split heads and increased incidence of field disease.

Delayed harvesting may cause the head to split. Cabbage is ready for harvest when the head has attained its expected full size and its firmness. The early cultivar takes 60-80 days, the medium 80-100 days and late 100 - 130 days for harvest after transplanting (Semuli, 2005). Cabbage should be sorted according to size, shape, and compactness of the head. There are three established size categories (small, medium, large) for domestic marketing of cabbage, based on the weight of the head. Small size heads weight 0.8 kg or less, medium sized heads weight between 0.9 kg and 1.4 kg, and large sized cabbage heads weigh 1.5 kg or more. Only the cabbage with crisp and turgid leaves should be packed for market. The heads should be a color typical of the cultivar (i.e. green, red or pale yellow green), firm, and heavy for the size and free of insect, decay, leafy head and other defect.

The marketable sizes are those with; compact head, minimum head weight of 0.45 kg, non-damage to edible portion of the plant. Whereas non-marketable sizes are; those that did not headed, heads too small in size and weight, head burst or split, damage by insect or disease, miscellaneous categories in which some essential quality for marketable was lacking. Westerveld *et al.* (2003) also noted that a cabbage heads that are burst (split), rotten, and non-headed are considered as unmarketable. When cabbage doesn't form head, this condition is called blindness and can arise due to excess nitrogen to form more leaves than are loosely held and do not make a head.

The yield of early maturing cabbage ranges between 30-40 t/ha, whereas medium and late maturing cabbage yield 40-60 t/ha (Rai and Asati, 2005). The crop is hand harvested by cutting the stem below the head but including a few of the loose outer leaves. In large scale production, mechanical harvesting may be used where the production is intended for processing. To preserve quality, cabbage may be stored for several months at high relative humidity (95 %) and low temperature (0°C) (Semuli, 2005).

2.5. The role of nitrogen fertilizer in cabbage production

The doubling of agricultural food production worldwide over the past four decades has been associated with a seven fold increase in use of nitrogen fertilizer (Herel *et al.*, 2007). As the consequence, both the recent and future identification of the use of nitrogen fertilizer in agriculture already has and will continue to have major determinate impacts on agriculture (Herel *et al.*, 2007). Plants take up nitrogen in the form of nitrate (NO_3^-) or ammonium (NH_4) from organic matter, inorganic matter and fixation of free nitrogen by microorganisms. Nitrogen plays a major role in protein formation and as a component of chlorophyll. Chlorophyll is required for light energy absorption by the process of photosynthesis. Therefore, adequate nitrogen supply enhances the amount of chlorophyll as the result of increase photosynthesis. A deficiency of nitrogen reduces the formation of chlorophyll, as result plants lose their green color leading to reduction the rate of photosynthesis (More, 2006).

Therefore, nitrogen is the motor of plant growth and being the essential constituent of protein, it is involved in all the major processes of plant development and yield formation. It stimulates vegetative growth and encourages the development of large stems and leaves. Nitrogen tends to produce succulence, a quality of great importance in many vegetables. A good nitrogen supply of the plant is also important for the uptake of the other nutrients of the three elements commonly supplied by fertilizers; nitrogen has the quickest and most pronounced effect. Adequate nitrogen nutrition is essential for producing higher crop yield of good quality. As natural soil nitrogen supply is rarely sufficient, growers usually apply nitrogen fertilizer in economically wasteful and can be lost to environment. An adequate supply of nitrogen is associated with vigorous vegetative growth and a deep green color.

Since nitrogen favors vegetative growth, it may delay maturity of fruits and seeds. Excessive quantities of nitrogen can under some conditions prolong the growing period and delay crop maturity (Damtew, 2020). This is most likely to occur when adequate supplies of other plant nutrients are not present. The supply of nitrogen is related to carbohydrate utilization. When nitrogen supplies are insufficient, carbohydrates will be deposited in vegetative cells which will cause them to thicken. When nitrogen supplies are adequate, and conditions are favourable for growth, proteins are formed from the manufactured carbohydrates. Less carbohydrate is thus

deposited in the vegetative portion, more protoplasm is formed, and, because protoplasm is highly hydrated, a more succulent plant results. Excessive succulence in some crops may have a harmful effect. In excessive nitrogen fertilization lodging may occur and in some cases excessive succulence may make a plant more susceptible to disease or insect attack.

2.6. Cabbage response to nitrogen fertilization

For high value crops such as cabbage, proper nutrition is important in order to produce a high yield and good quality (Yebirzaf, 2017). The most important nutrient for cabbage are nitrogen, phosphorus and sodium molybdate. Application of fertilizers (especially nitrogen) promote rapid growth, high yield and high quality of cabbage. For instance, Haque *et al.* (2006) observed that higher fertility level favored the head initiation and maturity of head cabbage. Similarly Solomon *et al.* (2018), observed shortest head initiation duration (63.33) when 294 kg N ha⁻¹ and 10 ton manure ha⁻¹ was applied , where the longest (81.66) in plot that recieved no N fetlizers. This effect of nitrogen was also true in other vegetable. For example, Sisay *et al.* (2008) reported that the shortest duration of carrot plants to reach maturity was recorded for the highest level of N (309 kg/ha) and the excessive N fertilizer hastened maturity of crop plants while low levels of N delayed the maturity. Another experiment conducted by Abera (2019) showed that increased nitrogen fertilizer from 0 to 150 kg/ha decreased in days to maturity from 84 to 61 days. The earliest days to maturity (61 days) was observed at higher nitrogen fertilizer rate (150 kg/ha), whereas the longest days to maturity (84 days) recorded at nil application.

According to Prasad *et al.* (2009) who reported that the application of 120 kg/ha of nitrogen, gave the maximum head weight (1.63 kg) of cabbages. Similar results are observed by Yebirzaf (2017) who reported that increasing nitrogen level from 0 to 150 kg/ha resulted in progressive increase in head weight of cabbage through increasing the vegetative growth and production of good quality foliage and promotes carbohydrate synthesis and ultimately increased yield of Plants.

Increasing nitrogen level from zero 0 to 120 kg/ha increased head diameter from 98 to 218 mm (Keteseeman, 2006). This was possibly due to higher synthesis of carbohydrate and their translocation to the sink, that is; cabbage head which subsequently helped in the formation of larger and comparatively broader head of the cabbage. It is also because of the reason that the

nitrogen favors more leaf number and leaf area which form the diameter. In another experiments with the application of 120 kg/ha N and 100 kg/ha P, maximum number of outer leaves, head length, head width, total and net head weight and total yield were obtained (Prasad *et al.* 2009). Whereas the maximum plant height, plant spread, leaf area and head diameter were recorded with the application of 140 kg N/ha and 120 kg P/ha. Application of 120 kg N and 100 kg P/ha also gave the best head yield cabbage in the Gangetic plains of West Bengal (Prasad *et al.*, 2009). In an other study, cabbages that received the highest nitrogen rates were larger and had a darker green color compared to those received the lowest nitrogen rates (Westerveld *et al.*, 2003).

Head width and height, yield of cabbage increase with increasing rate of nitrogen fertilizer application (Parmar *et al.*, 2009). Haque *et al.* (2006) compared three levels of nitrogen fertilizer rate (60 kg/ha, 120 kg/ha and 180 kg/ha) in Bangladesh on clay loam soil showed that maximum yield of cabbage (65.11 t/ha) were obtained from the plot receiving fertilizer rate of 180 kg nitrogen and 60 kg P₂O₅ per hectare. According to these authors, the application of 200 kg/ha nitrogen on loam soil produced significantly higher yield than 150 kg/ha nitrogen, but at par with 250 kg/ha nitrogen. This was attributed due to the fact that higher nitrogen levels favor the growth of plants with larger leaf area and it was more useful utilized in head formation.

2.7. Cabbage response to spacing

The possibility of securing high yield depends much on a proper consideration of optimum number of plant per unit area and the pattern in which the given quantity of seed or plant population is arranged in the field of planting. The most suitable crop density is that insures higher yields, good quality and low production cost. In cabbage, number of days from transplanting to head initiation varied among different plant densities. In general wider spaced cabbage plants required more numbers of days for head initiation than closer spaced plants (Manasa *et al.*, 2017). According to him the highest leaf number (13.8) was recorded at wider spacing (40 cm) while the lowest leaf number (11.4) was recorded at narrowest spacing (20 cm).

Hossain *et al.* (2011) reported the maximum head yield (18.8 t/ha) recorded in the case of closer spacing (60 x 40 cm) whereas the lowest yield (16 t/ha) was recorded at wider spacing (60 x 60 cm) in cabbage. Similar results was reported by Manasa *et al.* (2017) where the maximum

marketable yield (18.4 t/ha) was obtained from the spacing of 45 x 45 cm while, minimum yield (12.5 t/ha) at lower plant density. This is due to the reality that as plant spacing decreases, total plant population increases and this in turn contributes to increase in total head yield.

Generally, increasing plant density decreased plant growth parameters, i.e., plant fresh weight, dry matter content (Asadul *et al.*, 2015).

Dragan (2007) reported highest cabbage head diameter (16.6 cm) recorded in the case of lowest crop density (8 m²) whereas the lowest diameter (9.6 cm) was recorded at higher plant density (16.6 m²). It was observed that head diameter decreased in parallel with increased crop density. In the contrary, higher cabbage yield (73 t/ha) were recorded in the case of higher plant density (16.6 m²) but the lowest yield (71 t/ha) was recorded at lower plant density (8 m²). The higher crop densities were as the result recommended for cabbage production. It is however, important to compare the issue of probability of such a production with the higher cost of transplant and manual labor.

The increasing plant population increased competition among plant resulting in reduced marketable yield (Semuli, 2005). Increasing plant population with cabbage has the potential for increasing yield and profit whereas plant spacing related to head weight and percent marketable yield. Although in cabbage, high plant density reduce head size and head weight, a greater number of head per unit area that increase total yield is obtained (Draga, 2007). Generally cultivation aspect such as plant population and nitrogen nutrition are vital in maximizing of cabbage head yield. Nitrogen fertilizer and plant spacing has great influence on growth and yield of cabbage.

3. MATERIAL AND METHODS

3.1. Description of the study area

The study was conducted at Bako Agricultural Polytechnic College. The college is located at about 233 kms, from the capital city, Addis Ababa and 125 kms from the Zonal capital of the West Shewa, Ambo in Oromia National Regional State. The latitude of the area is 9° 7' 20" N and the longitude is 37° 3' 45" E. The annual average rainfall is 1000 - 1200 mm. The district has unimodal rain fall. The main rainy season start from the mid of may and ends the month of September covers most parts of the district. This season is the main cropping season for different crops in the district. The altitude ranging from 1600 to 2800 meters above sea level.

Table 1. Soil physicochemical properties of the experimental site before planting

Parameters	Values
pH	5.6
Organic matter (%)	0.14
Organic carbon (%)	1.73
Total nitrogen (%)	0.27
CEC (meq/100g soil)	68.10
EC μ hos/cm	0.165
Available P (ppm)	26.10
Ex. Mg mol(+)/kg soil	4.20
Ex. Ca mol(+)/kg soil	16.00
Ex. Na mol(+)/kg soil	0.01
Ex. K mol(+)/kg soil	0.24
Soil Texture	
Sand (%)	49
Silt (%)	16
Clay (%)	35
Class	Sandy caly loam

pH = Soil reaction, OM = Organic matter, CEC = cation exchange capacity, EC = electrical conductivity, μ hos = micromhos, ppm = part per million, Ex. = exchange.

3.2. Experimental material

Copenhagen variety, one of the most popular and reliable early round-headed cabbage, was used for this experiment. This variety is widely adopted and requires 80-90 days to maturity after transplanting. Copenhagen market was selected for this experiment, because it is produced widely in Ethiopian and it has high demand in Addis Ababa market. In Ethiopia, it is well grown in an altitude of 1500-3000 m.a.s.l (Asfaw and Eshetu, 2015).

3.3. Experimental treatments and design

The experiment comprises of two factors namely, four level of nitrogen fertilizer rates: 0, 50, 100 and 150 kg/ha and three levels of intra row spacing: 15, 25 and 35 cm. The two factor experiment

was laid out in 4 x 3 factorial arrangements using Randomized Complete Block Design (RCBD) with three replications. A total of 12 treatment combinations were used in this experiment. For the application of each of the 12 treatments, a plot with dimension of 3 m length x 2.4 m width was used. A distance of 0.5 m between plots and 1 m between blocks were maintained. The number of cabbage plants per plot were 80, 48 and 32 for the intra row spacing of 15, 25, and 35 cm, respectively. There were four rows per plot.

Table 2. Details of treatment combinations used in the study

Nitrogen(N) fertilizer rate(kg/ha)	Intra row spacing(S)(cm)	Treatment interaction		Interaction code
0	15	0 kg x 15 cm	T1	N0S1
	25	0 kg x 25 cm	T2	N0S2
	35	0 kg x 35 cm	T3	N0S3
50	15	50 kg x 15 cm	T4	N1S1
	25	50 kg x 25 cm	T5	N1S2
	35	50 kg x 35 cm	T6	N1S3
100	15	100 kg x 15 cm	T7	N2S1
	25	100 kg x 25 cm	T8	N2S2
	35	100 kg x 35 cm	T9	N2S3
150	15	150 kg x 15 cm	T10	N3S1
	25	150 kg x 25 cm	T11	N3S2
	35	150 kg x 35 cm	T12	N3S3

3.4. Experimental layout

An area of 41.5 m × 9.2 m was divided into three equal blocks. Each block was divided into 12 plots where 12 treatment combinations were allocated at random. There were 36 unit plots and the size of each unit plot was 3 m × 2.4 m. The distance maintained between two blocks and two plots were 1 m and 0.5 m, respectively. The seedlings were planted with maintaining distance row to row 60 cm and plant to plant with 15 cm, 25 cm and 35 cm.

3.5. Preparation of the main field

The selected experimental plot was opened in the early of July, 2021 with a farm tractor and was exposed to the sun for a week. After three days the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed and finally obtained a desirable tilth of soil for planting of cabbage seedlings. The experimental plot was partitioned into the unit plots in accordance with the experimental design. The experimental plots were prepared and the layout was arranged appropriately.

3.6. Transplanting of seedlings in the main field

Seedlings were transplanted in the field in August, 2021. Healthy and uniform sized seedlings were transplanted to the experimental field at thirty days after sowing. The seedlings were uprooted carefully from the seedbed to avoid any damage to the root system. Transplanting was done in the afternoon carefully. Urea (46% N) as the main source of nitrogen was applied into two equal split where the first half was applied at transplanting while the remaining half was applied 30 days after transplanting. As a source of phosphorous 100 kg/ha P₂O₅ in the form of Triple Super Phosphate (46% P₂O₅) was applied for all plots at the time of transplanting.

3.7. Intercultural operation

When the seedlings established in the plots it was always kept under careful observation. Other cultural practices like weeding, hoeing and pest control were done uniformly for all treatments where Aphids and cutworms were controlled by chemicals like Agro - Thioate 40% EC and DATRATE 5% EC, respectively were accomplished for better growth and development of the crops.

3.8. Harvesting

Harvesting was done when the plants formed compact or firm heads. Harvesting of head was done after two months when it reached at physiological maturity as per the treatments and after necessary data was recorded. Different yield contributing data was recorded from the five harvested plants which were selected at random of each unit plot and mean value was used for the analysis.

3.9. Data collection

Data was recorded on the following parameters from the sample plants during the course of experiment. Five plants were randomly selected from each unit plot for the collection of data. The plants in the outer rows and the extreme end of the middle rows were excluded from the random selection to avoid the border effect.

3.9.1. Phenological parameters

Days to 50% head initiation (DHI): The plants were observed daily to evaluate the initiation of heads. The number of days elapsed was counted from transplanting until 50 % of the plants in each plots initiated heads and the average number of days was used for further analysis.

Days to 50% head maturity (DHM): It was recorded from the date of transplanting to when 50 % of the heads from the net plot reaches maturity. This was determined by the compactness or firmness of the head.

Days to maturity (DM): When the cabbage head was compacted and firm to the touch it is matured. The other indicator of maturity of head cabbage is the arrangement of wrapped leaves. At the time of maturity, the wrapped leaves are spread so that the heads are exposed. A very loose head is immature and should not be harvested (Semuli, 2005). Cabbage heads were harvested based on these indicators by counting the number of days starting from transplanting until 90 % of the cabbage head in each plot attained physiological maturity.

3.9.2. Growth parameters

Number of leaf before heading (NLBH): The numbers of leaves of five randomly selected plants in the plot before heading were counted at 40 days after transplanting (Demoz, 2016). The number

of leaves randomly selected five plants were counted and the mean of these five plants were taken as number of leaves per plant before heading and used for analysis.

Number of unfolded leaf after heading (NUFLAH): Number of fully developed unfolded outer leaves after heading from each randomly selected five plants were counted at the time of harvesting.

Plant height (PH) (cm): The cabbage plant height was measured from five randomly selected plant samples from the central rows of the plot. The measurement was done by using ruler starting from ground level to the tip of the outer longest leaf of individual plant and is expressed in centimeter. The mean of five selected plants from each plot was recorded and computed for analysis.

Head diameter (HD) (cm): At harvest, five randomly taken samples of cabbage heads from the central row were taken and the head diameter was measured at widest part using caliper (model LEG ilox-250 mm, US patent) and was expressed in centimeter.

Leaf area (LA) (cm²): Leaf area was measured on graph paper that has one centimeter square grid lines, and the number of grid squares that are inside of the leaf on the paper was the area of the leaf. Based on this from randomly taken sample plants, three leaves from the bottom to the top part of each plant was measured using grid square and the data are recorded as the average leaf area per plant.

3.9.3. Yield parameters

Above ground plant fresh weight (APFW) (kg/ plant): randomly selected sample plants were taken from the central rows of each plot and the above ground plant parts were measured using the beam balance.

Marketable head yield (MHY) (t/ha): at time of harvesting, clean, disease-free, and undamaged heads were harvested, weighed fresh and converted to t/ha. Each head free from disease and physical damage with a fresh weight higher than 1 kg was considered a marketable yield and it was converted to t/ha (Kolota and Piotr, 2015).

Unmarketable head yield (UMY) (t/ha): cabbage such as non-headed, split (burst), disease affected and under sized head were recorded as unmarketable and calculated on the basis of t/ha.

Total head yield (TY) (t/ha): total number of heads and their weight were recorded as sum of marketable and unmarketable head yield and calculated on the basis of t/ha.

Dry matter content (DM) (%): biomass of two randomly selected healthy plants were taken from each plots and the whole part was chopped and mixed together. Two hundred grams sample was taken from the chopped cabbage and dried in an oven at 78 °C for 48 hours until constant weight was attained (Sumeli, 2005). Percentage dry matter content was calculated as the ratio between dried and fresh weight of cabbage and multiplied by hundred.

Harvest index (HI): harvest index is the ratio of economic yield to biological yield. It characterizes the movement of dry matter to the economic part of the plant. It was measured by taking the above ground plant weight and only marketable head weight separately and harvest index was taken as the ratio of marketable head weight to total weight of the plant.

Head firmness (HF): head firmness or compactness was calculated using the formula:

$$\text{Compactness rate} = \frac{\text{Head volume (4/3 * pi * radius}^3\text{)}}{\text{Head weight (g)}}$$

To determine the cabbage head volume, the circumference of the cabbage head was measured. The volume (V) was estimated as $V = 4/3 * \text{Pi} * r^3$, where V = volume, r = radius). Head volume (cm) was computed according to Radovich and Kleinhenz (2004) by assuming a spherical shape. Where theoretically compactness rating of 1 means the head is very compact and it contains no air. Generally the lower the rate of compactness, the more compact the head was and vice versa.

Total soluble solids (TSS) (°Brix): ten gram sample was blended and the juice was used to measure the total soluble solids using hand held Refractometer (ATAGO, model: HR-5).

3.10. Data Analysis

Data was analysed statistically using proc GLM (General linear model) procedure of SAS version 9.3 software (SAS Institute Inc. 2009). Whenever the treatment differences show significant difference, means were tested using LSD (Least Significant Difference) value at 5 % significance level.

The correlation analysis was performed to determine extent of association between yield and yield components as influenced by different nitrogen application rate and intra row spacing.

4. RESULT AND DISCUSSION

4.1. Phenological parameter

4.1.1. Days to 50 % head initiation (D50HI)

The analysis of variance revealed that the days to 50 % head initiation was highly significantly ($P < 0.01$) influenced by the main effects of intra row spacing and the interaction effect but the main effect of fertilizer rates was non significant (Appendix Table 1).

The highest days to 50 % head initiation (51.50) was recorded with the wider intra row spacing (35 cm) whereas the lowest days to 50 % head initiation (46.25) was recorded with the narrower intra row spacing (15 cm) which was not statistically different from the narrower intra row spacing (25 cm). It seems that cabbage plant that placed at wider spacing and received high rate of nitrogen and might got high photosynthesis rate and dry matter accumulations due to higher number of leaves coupled with higher availability of nutrients leading to vegetative growth for longer period and as such the productive phase was delayed. Similar results was observed by Manasa *et al.* (2017) who reported that wider spaced plants require maximum days for head initiation (50.44) whereas minimum number of days (47.73) for closer spaced plants in cabbage.

The highest days to 50 % head initiation (54.00) was obtained from interaction receiving no nitrogen fertilizer rate with the widest intra row spacing (35 cm). On the other hand, significantly the smallest days to 50 % head initiation (44.00) was obtained when cabbage plants were grown at 50 kg/ha nitrogen fertilizer rate application with narrowest intra row spacing (15 cm) (Table 3).

4.1.2. Days to 50 % head maturity (D50HM)

The analysis of variance shown that the days to 50 % head maturity was very highly significantly ($P < 0.001$) affected by the nitrogen fertilizer rate, the intra row spacing and the interaction of both nitrogen fertilizer rate with intra row spacing (Appendix Table 1).

4.1.3. Days to maturity (DM)

The analysis of variance revealed that days to maturity was very highly significantly ($P < 0.001$) influenced by the effects of nitrogen fertilizer rate (Table 3 and Appendix Table 1) as well as the combination effects of nitrogen fertilizer rate with intra row spacing (Table 3 and Appendix

Table 1). But days to maturity was not significantly ($P > 0.05$) affected by the intra row spacing treatment.

The highest days of maturity (81.00 days) was recorded at the treatment combination of no nitrogen fertilizer rate with 25 cm intra row spacing and 35 cm intra row spacing but which were not statistically different from plot that received no nitrogen fertilizer rate combined with the narrowest intra row spacing (15 cm). On the other hand, the lowest days of maturity (60.00 days) was obtained from head cabbage grown at 150 kg/ha nitrogen fertilizer rate combined with the widest intra row spacing (35 cm) followed with combination of 150 kg/ha nitrogen fertilizer rate with the narrowest intra row spacing (15 cm) (Table 3).

Table 3. Effect of treatments interaction on phenological parameters

	Phenological parameters								
	D50HI			D50HM			DM		
Treatment	S1	S2	S3	S1	S2	S3	S1	S2	S3
N0	46.00 ^{ef}	47.00 ^{d^{ef}}	54.00 ^a	63.00 ^b	64.00 ^b	68.00 ^a	80.00 ^a	81.00 ^a	81.00 ^a
N1	44.00 ^f	51.00 ^{bcd}	48.00 ^{cde}	59.33 ^c	62.67 ^b	63.67 ^b	74.33 ^c	75.00 ^{bc}	78.33 ^{ab}
N2	48.00 ^{cde}	48.00 ^{cde}	53.00 ^{ab}	58.33 ^{cd}	57.00 ^{de}	60.33 ^c	68.67 ^d	65.00 ^{ef}	67.00 ^{de}
N3	47.00 ^{def}	46.00 ^{ef}	51.00 ^{abc}	55.00 ^e	55.33 ^e	55.67 ^e	62.33 ^{fg}	64.33 ^{ef}	60.00 ^g
LSD (5%)	3.51			ns			ns		
CV (%)	4.29			2.11			2.85		

Treatment means followed by the same letter(s) within the same column are not significantly different at 5% probability level. D50HI = days to 50% head initiation, D50HM = days to 50% head maturity, DM = days to maturity

4.2. Growth parameter

4.2.1. Number of leaf before heading (NLBH)

The analysis of variance shown that the number of leaf before heading was very significantly ($P < 0.001$) influenced by the effects of nitrogen fertilizer rate (Appendix Table 2) and the combination of nitrogen fertilizer rate with intra row spacing (Table 4 and Appendix Table 2).

The highest number of leaf before heading (15.67) was recorded at the treatment combination of the highest nitrogen fertilizer rate (150 kg/ha) and widest intra row spacing (35 cm). But the smallest number of leaf before heading (9.67) was recorded at the treatment combination of no nitrogen fertilizer rate with narrowest intra row spacing (15 cm) (Table 4). This was due to higher amount of nitrogen fertilizer received by the plants in wider spacing. This results agree with that of Asadul *et al.* (2015) who noticed that maximum number of leaves per plant was

recorded at 150 kg/ha with intra row spacing 50 cm while the minimum was from the no nitrogen rate with 30 cm intra row spacing.

4.2.2. Number of unfolded leaf after heading

Number of unfolded leaf after heading was significantly ($P < 0.05$) affected by nitrogen fertilizer rate (Appendix Table 2) and highly significantly ($P < 0.01$) influenced by the combined effect of nitrogen fertilizer rate with intra row spacing (Table 4 and Appendix Table 2).

The highest number of unfolded leaf after heading (15.33) was recorded at treatment combination of 150 kg/ha nitrogen fertilizer rate combined with 15 cm intra row spacing (Table 6). But the lowest number of unfolded leaf after heading (10.00) was obtained from treatment combination at plot that received no nitrogen fertilizer rate combined with 15 cm intra row spacing.

Table 4. Effect of treatments interaction on growth parameters

treat ment	Phenological parameters														
	NLBH			NULAH			PH (cm)			HD (cm)			LA (cm ²)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
N0	9.6 7 ^c	10. 00 ^c	10. 67 ^c	10.0 0 ^f	13.0 0 ^{bcde}	11.6 7 ^{ef}	27.0 1 ^f	28.0 7 ^{ef}	29.0 0 ^{def}	12.6 7 ^g	12.7 7 ^g	14.6 7 ^{cdef}	201. 95 ^g	198. 87 ^g	215. 84 ^g
N1	12. 33 ^{bc}	13. 67 ^{ab}	14. 00 ^{ab}	13.0 0 ^{bcde}	12.0 0 ^{def}	14.3 3 ^{abc}	30.1 7 ^{cdef}	32.3 3 ^{bcde}	33.3 3 ^{bcd}	13.1 0 ^{fg}	13.7 7 ^{efg}	15.6 7 ^{bcd}	282. 69 ^{ef}	294. 00 ^e	276. 00 ^f
N2	14.3 3 ^{ab}	14.6 7 ^{ab}	15.3 3 ^a	14.67 ab	12.33 cde	14 ^{abc} d	32.0 7 ^{bcde}	34.13 abc	35.4 7 ^{ab}	14.1 3 ^{defg}	15.0 7 ^{cde}	19.2 7 ^a	400. 00 ^c	365. 96 ^d	370. 09 ^d
N3	15. 67 ^a	15. 33 ^a	15. 67 ^a	15.3 3 ^a	15.0 0 ^{ab}	13.0 0 ^{bcde}	34.1 4 ^{abc}	35.2 0 ^{abc}	38.5 7 ^a	15.9 3 ^{bc}	16.9 7 ^b	20.6 3 ^a	467. 00 ^a	411. 36 ^c	445. 00 ^b
LSD(5%)	ns			2.21			5.06			1.77			ns		
CV (%)	12.02			9.95			9.25			6.83			3.16		

Treatment means followed by the same letter(s) within the same column are not significantly different at 5% probability level. NLBH = number of leaf before heading, NULAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter, LA = leaf area.

4.2.3. Plant height (PH) (cm)

Plant height was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate and highly significantly ($P < 0.01$) affected by the combination of both treatments (Table 4). However, the effect of intra row spacing was not significantly ($P > 0.05$) different.

The highest plant height (38.57 cm) was recorded at the treatment combination of 150 kg/ha nitrogen fertilizer rate combined with 35 cm intra row spacing. But the smallest plant height (27.01 cm) was recorded at the treatment combination of no nitrogen fertilizer rate with 15 cm intra row spacing (Table 6). Plants that were grown in a narrower spacing and no fertilizer applied resulted in shorter plants. This could be attributed to insufficient amount of nutrients to facilitate increase in plant height. This is because when plants are crowded they tend to strive to access available light.

4.2.4. Head diameter (HD) (cm)

Head diameter was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate, intra row spacing and the combination of both treatments.

The highest head diameter (20.63 cm) was recorded in plot that received 150 kg/ha nitrogen fertilizer rate and planted at 35 cm intra row spacing which was not statistically significantly different with the treatment combination of 100 kg/ha of nitrogen fertilizer combined with 35 cm intra row spacing. On the other hand, the smallest head diameter (20.67 cm) was recorded at the treatment combination of no nitrogen fertilizer rate and 15 cm intra row spacing which was not statistically significantly differed from the treatment combination 50 kg/ha nitrogen fertilizer rate with 25 cm intra row spacing (Table 4).

4.2.5. Leaf area (LA) (cm²)

Leaf area was significantly ($P < 0.05$) affected by the main effects of nitrogen fertilizer rate and intra row spacing and both treatment combination (Appendix table 2).

Regarding to the combination effect, the largest leaf area (467.00 cm²) was recorded at 150 kg/ha nitrogen fertilizer rate combined with the intra row spacing of 15 cm whereas the

smallest leaf area (198.87 cm²) was recorded at the treatment combination of no nitrogen fertilizer rate combined with the intra row spacing of 15 cm which was not statistically significantly different from no nitrogen fertilizer rate combined with the intra row spacings of 15 cm and 35 cm (Table 6).

4.3. Yield parameter

4.3.1. Above ground plant fresh weight (APFW) (kg/ plant)

Above ground plant fresh weight was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate, intra row spacing (Appendix Table 3) and the combination of both treatments (Table 5). The maximum above ground plant fresh weight (2.47 kg/plant) was recorded at the higher nitrogen fertilizer rate (150 kg/ha) tested. The lowest above ground plant fresh weight (1.27 kg/plant) was recorded in plot that received no nitrogen fertilizer rate (Table 7 and Appendix Table 3). This shows increasing fertilizer rate from 0 to 150 kg/ha increased biomass of cabbage in this study. The current finding compatibles with that of Semuli (2005) who reported that untrimmed head weight was recorded at higher nitrogen rate than lower nitrogen fertilizer rate.

The highest above ground plant fresh weight (2.06 kg/plant) was recorded at the widest intra row spacing (35 cm) whereas the lowest (1.93 kg/plant) above ground plant fresh weight was recorded at the narrowest intra row spacing (15 cm) tested in this study. This could be due tot the fact that the wider plant spacing between plants promote vegetative growth and gave more fresh weight. Similar results was obtained by Asadul *et al.* (2015) who reported that higher plant fresh weight was observed at wider spacing than the narrower.

The highest above ground plant fresh weight (2.61 kg/plant) was recorded at the treatment combination of 150 kg/ha nitrogen fertilizer rate combined with the intra row spacing of 35 cm. The lowest above ground plant fresh weight (1.26 kg/plant) was recorded from plots that recieved no nitrogen fertilizer rate reacted with the narrowest intra row spacing of 15 cm which was not statisticaly significantly different from treatment combination of no nitrogen fertilizer rate combined with intra row spacing of 25 cm and 35 cm (Table 5).

4.3.2. Marketable head weight (MHW) (t/ha)

Cabbage marketable head weight was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate and by both treatment combinations. However, intra row spacing was not statistically significantly ($P > 0.05$) different from each other (Appendix Table 3).

The highest marketable head weight (79.49 t/ha) was obtained at the highest nitrogen fertilizer rate of 150 kg/ha (Appendix Table 3) which was not statistically significantly different from 100 kg/ha nitrogen application. The lowest marketable head weight (32.98 t/ha) was recorded from plot that received no nitrogen fertilizer rate. This is due to nitrogen that increases the vegetative growth and produces good quality of foliage and promotes carbohydrate synthesis through photosynthesis and ultimately increased yield of plants. This finding is in line with that of Yebirzaf (2017) who reported that increasing nitrogen level from 0 to 150 kg/ha resulted in progressive increase in marketable head weight of cabbage.

The highest marketable head weight (80.40 t/ha) was obtained at the treatment combination of the highest nitrogen fertilizer rate of 150 kg/ha combined with the intra row spacing of 35 cm (Table 5), but statistically it was not different from the treatment combination of 150 kg/ha combined with 15 cm and 25 cm intra row spacings. The lowest marketable head weight (32.11 t/ha) was found at the treatment combination of no nitrogen fertilizer rate combined with 15 cm intra row spacing which was statistically similar with plots that received no nitrogen fertilizer rate combined with 25 cm and 35 cm of intra row spacings. This is due to the fact that increased application of nitrogen significantly increases the growth parameters which might have synthesized more plant metabolites, due to better availability of metabolites for the increment of cabbage plant in terms of marketable head weight. Moreover, the increased marketable head weight with increasing intra row spacing recorded in the present study is probably associated with low competition for plants for growth factors that limit the growth and development of plants including nutrients, moisture, light and etc. Moniruzzaman (2011) noticed that highest marketable head weight (1090 g) in cabbage at the widest spacing of 60 x 45 cm and lowest head weight (1071 g) from the 60 x 40 cm spacing.

4.3.3. Unmarketable head yield (UMY) (t/ha)

The analysis of variance revealed that unmarketable yield was very highly significantly ($P < 0.001$) affected by the nitrogen fertilizer rate and the interaction between nitrogen fertilizer rate and intra row spacing (Table 5 and Appendix Table 3). But unmarketable head yield was not

statistically significantly ($P > 0.05$) affected by intra row spacing as indicated in Table 7 and Appendix Table 3.

The lowest unmarketable head yield (1.72 t/ha) was recorded when plants were grown with the highest dose of nitrogen fertilizer rate (150 kg/ha), on the contrary, the highest unmarketable head yield (6.02) was produced from plots that received no nitrogen fertilizer rate.

The lowest unmarketable yield (1.23 t/ha) was recorded with the interaction of the highest nitrogen fertilizer rate (150 kg/ha) combined with the widest intra row spacing (35 cm) whereas the highest unmarketable yield (6.20 t/ha) was recorded with interaction of no nitrogen fertilizer rate combined with the widest intra row spacing (35 cm) which is not statistically significantly different from the narrowest intra row spacing (15 cm) (Table 5 and Appendix Table 3). This could be due to the synergic effect of intra row spacing and nitrogen fertilizer rate that at narrower intra row spacing and lower fertilizer rate the plant population is higher and the competition for nutrients will be higher which lead under size and non-headed cabbage, whereas at wider intra row spacing and higher fertilizer rate since the population was small and the competition becomes lesser and most plant can grow well and reach marketable size which this reduce unmarketable head yield. Moreover, cabbage is a heavy feeder for nitrogen fertilizer where inadequate amount of nitrogen fertilizer results in loss of head formation. The other reasons for unmarketable head yield were pests (Aphids), burst and rotten. The highest unmarketable head yield of cabbage in response to no fertilizer application at narrowest intra row spacing may be associated with less availability of growth resources and thus high competition that resulted in reduction in leaf number and head diameter. The present result was agreed with the finding of (Kolota and Piotr, 2015) who confirms that higher number of unmarketable plant is higher at no nitrogen application with lowest intra row spacing.

Table 5. Effect of treatments interaction on yield component parameters

Treatment	Yield parameters											
	APFW (kg/plant)			MHW (t/ha)			UMY (t/ha)			THY (t/ha)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
N0	1.26 ^e	1.30 ^e	1.25 ^e	33.00 ^d	32.11 ^d	33.80 ^d	6.00 ^a	5.88 ^{ab}	6.20 ^a	39.00 ^e	37.99 ^e	40.00 ^e
N1	1.87 ^{cd}	1.76 ^d	1.94 ^c	63.00 ^{bc}	59.48 ^c	54.98 ^c	5.00 ^{bc}	4.52 ^{dc}	5.35 ^{abc}	68.00 ^{bc}	64.00 ^{cd}	60.33 ^d
N2	2.37 ^b	2.34 ^b	2.42 ^b	72.09 ^b	69.98 ^b	72.89 ^b	4.00 ^{cd}	3.02 ^e	3.11 ^e	76.09 ^{ab}	73.00 ^{abc}	76.00 ^a
N3	2.48 ^{ab}	2.33 ^b	2.61 ^a	80.01 ^a	78.06 ^a	80.40 ^a	1.99 ^f	1.94 ^f	1.23 ^f	82.00 ^a	80.00 ^a	81.63 ^a
LSD(5%)	ns			Ns			ns			9.36		
CV (%)	5.09			8.07			14.65			8.57		

Treatment means followed by the same letter(s) within the same column are not significantly different at 5% probability level. APFW = above ground plant fresh weight, MHW = head weight, UMY = unmarketable head yield, THY = total head yield.

4.3.4. Total head yield (THY) (t/ha)

Total head yield was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate and the interaction (Table 5 and Appendix Table 3), however, the intra row spacing was not statistically significant (Table 7 and Appendix Table 3).

The highest total head cabbage yield (81.21 t/ha) was recorded at the highest nitrogen fertilizer rate (150 kg/ha) tested which was not statistically significantly different from the rate of 100 kg/ha nitrogen fertilizer rate whereas the lowest yield of cabbage head (39.00 t/ha) was recorded from the plot that received no nitrogen fertilizer rate. Increasing nitrogen fertilizer from 0 to 150 kg/ha increased cabbage head yield. This result is compatible with the finding of Abera (2019) who reported that higher total cabbage yield was recorded at 150 kg/ha nitrogen application and the lowest was from no nitrogen application.

In terms of interaction effect, significantly the highest total yield (82.00 t/ha) was obtained from treatment combination of 150 kg/ha nitrogen fertilizer rate combined with 15 cm intra row spacing. On the contrary, the lowest total head yields were recorded from plots that received no nitrogen fertilizer rate interacted with 25 cm of intra row spacing as indicated in Table 5 but which was not differ statistically from no nitrogen fertilizer rate combined with 15 cm and 35 cm intra row spacing. These could be associated with the fact that higher nitrogen rates favored the growth of plants with larger leaf areas and thus higher head formation, head diameter and weight of heads. Moreover, total head yield was increased with the decreasing in intra row spacing where the number of plants per unit area increased that leads to highest head yield of cabbage. The trend of the present result was agreed to the findings of Aquino *et al.* (2005). Under intermediate levels of nitrogen and closer intra row spacing, more number of plants per unit area leads highest head yield of cabbages with good head compactness.

Table 6. Effect of treatments interaction on yield component parameters

Treatment	Yield parameters												NAH (%)		
	DMC (%)			HI			HF			TSS (^o Brix)					
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
N0	5.07 ^c	5.22 ^c	5.66 ^c	0.43 ^{cd}	0.38 ^d	0.45 ^{bcd}	1.96 ^{cd}	2.23 ^{bc}	2.97 ^{ab}	8.4 ³ _f	9.08 _{abc}	9.02 ^{bc} _d	0.2 _{0^f}	0.22 _e	0.23 _{de}
N1	6.61 ^b	5.64 ^d	7.08 ^b	0.53 ^{abc}	0.49 ^{abc} _d	0.49 ^{abc} _d	1.20 ^d	1.58 _{cd}	2.13 ^{bc} _d	9.1 _{0^{abc}}	8.76 _{de}	8.89 ^{cd}	0.2 _{3^{de}}	0.24 _d	0.25 _d
N2	6.53 ^b	6.78 ^b	9.07 ^a	0.41 ^d	0.42 ^{cd}	0.40 ^d	1.52 ^{cd}	1.85 _{cd}	3.91 ^a	8.7 _{8^{de}}	9.23 _{ab}	8.90 ^{cd}	0.2 _{6^c}	0.28 _{bc}	0.31 _b
N3	6.68 ^b	7.11 ^b	9.43 ^a	0.54 ^{ab}	0.58 ^a	0.48 ^{abc} _d	1.66 ^{cd}	1.95 _{cd}	3.78 ^a	9.3 _{1^{ab}}	8.50 _{ef}	9.35 ^a	0.3 _{1^b}	0.32 _a	0.34 _a
LSD(5%)	ns			0.11			0.95			0.29			0.21		
CV (%)	6.41			14.32			25.34			1.91			8.52		

Treatment means followed by the same letter(s) within the same column are not significantly different at 5% probability level. DMC = dry matter content, HI = harvest index, HF = head firmness, TSS = total soluble solids, NAH = nitrogen left after harvesting

4.3.5. Dry matter content (DMC) (%)

Dry matter content of head cabbage was very highly significantly ($P < 0.001$) affected by nitrogen fertilizer rate, intra row spacing and by both the interaction (Table 6 and Appendix Table 4).

The highest dry matter content percentage (7.74%) of cabbage plant was recorded at 150 kg/ha nitrogen fertilizer rate even though it is not statistically significantly different from 100 kg/ha nitrogen fertilizer rate. But the lowest (5.31 %) was recorded at the lowest nitrogen fertilizer rate (Table 7 and Appendix Table 4). With the increase of nitrogen application, the dry matter content per plant increases due to more availability of nutrients among the plants during vegetative growth and later caused accumulation of metabolites. Hasan *et al.* (2017) observed similar results with this study.

Maximum dry matter content (7.81%) was obtained when cabbage plants were grown at the widest intra row spacing (35 cm) while the lowest dry matter content (6.19 %) was recorded at the narrower intra row spacing (25 cm). It was revealed that with the increase of intra row spacing, the dry matter content of the plant showed increasing trend because of less competition for nutrients.

Regarding to the interaction effect, significantly maximum dry matter content (9.43 %) was recorded at the nitrogen fertilizer rate (150 kg/ha) combined with the widest intra row spacing (35 cm) which was not significantly different from higher dose of nitrogen fertilizer rate (100 kg/ha) combined with the highest intra row spacing(35 cm). The lowest dry matter content (5.07%) was recorded in plots that received no nitrogen fertilizer rate combined with all possible intra row spacing where the dry matter contents were statistically not different from each other as indicated in Table 6. With increased rate of nitrogen and intra row spacing , it ensured maximum vegetative growth that ensured highest dry matter content. This shows that with increasing nitrogen fertilizer rate and wider intra row spacing, the crops can get more sun light than the narrower intra row spacing this facilitates photosynthetic rate of the plant in relation to fertilizer.

4.3.6. Harvest index (HI)

The analysis of variance revealed that harvest index was highly significantly ($P < 0.01$) influenced by the effect of nitrogen fertilizer rate as well as significantly ($P < 0.05$) affected by the interaction of nitrogen fertilizer rate with intra row spacing (Table 6), while this parameter was not significantly ($P > 0.05$) influenced by the effect of intra row spacing (Appendix Table 4).

The highest harvest index (0.53) was recorded at the highest nitrogen fertilizer rate (150 kg/ha) tested which was not statistically different from 50 kg/ha nitrogen fertilizer rate. The lowest harvest index (0.41) was recorded from plots that received no nitrogen fertilizer rate. This shows that harvest index increased with increasing level of nitrogen fertilizer rate indicating the importance of nitrogen for the allocation of assimilates to harvestable parts of cabbage crops. The finding of Semuli (2005) showed that the ratio of trimmed head to untrimmed head was higher at higher nitrogen level than lower nitrogen level.

Regarding to the interaction effect, the highest harvest index (0.58) was recorded at the highest nitrogen fertilizer rate (150 kg/ha) combined with the narrower intra row spacing (25 cm). But the lowest harvest index (0.38) was recorded from control nitrogen fertilizer rate combined with the narrower intra row spacing (25 cm).

4.3.7. Head firmness (HF)

The analysis of variance revealed that the head firmness (head compactness) was very highly significantly ($P < 0.001$) influenced by intra row spacing (Appendix Table 4) and by the interaction effect (Table 6 and Appendix Table 4). But it was not significantly ($P > 0.05$) affected by the effect of nitrogen fertilizer rate.

The highest head firmness (3.20) was obtained when plants grown at the widest intra row spacing (35 cm) whereas the lowest head firmness (1.58) was recorded at the narrowest intra row spacing (15 cm) even though it was not statistically different from the narrower intra row spacing (25 cm).

Focusing the interaction effect, 100 kg/ha nitrogen fertilizer rate combined with 35 cm intra row spacing recorded the highest cabbage head firmness with the values of 3.91 and which was not statistically different from the combined effect of 150 kg/ha nitrogen fertilizer rate

combined with the widest intra row spacing (35 cm). Plants grown with 50 kg/ha nitrogen fertilizer rate under the narrowest intra row spacing (15 cm), on the other hand, recorded the minimum (1.20) cabbage head firmness as indicated in Table 6. The highest head firmness produced at the highest rate of nitrogen fertilizer could be due to the involvement of nitrogen in physiological processes of plants as well as the availability of more space for plants which leads to vigorous growth of cabbage plants. Similarly, at wider intra row spacing there is less competition for nutrients, moisture and light among the plants to produce the required food for their growth.

4.3.8. Total soluble solids (TSS) (°Brix)

The analysis of variance revealed that total soluble solids was very highly significantly ($P < 0.001$) influenced by the interaction effect of nitrogen fertilizer rate with intra row spacing (Table 6 and Appendix Table 4) but it was not statistically significantly ($P > 0.05$) affected by the effects of nitrogen fertilizer rate and the effect of intra row spacing.

In terms of nitrogen fertilizer rates, the highest total soluble solids (9.05) of cabbage was found when cabbage plants were grown with the application of 150 kg/ha nitrogen fertilizer rate but the lowest total soluble solids (8.84) was obtained when the cabbage plant were grown with no nitrogen fertilizer rate (Table 7).

The highest total soluble solids (9.04) were obtained when cabbage plants were grown at the widest intra row spacing (35 cm) compared to the narrowest intra row spacing but it was not significantly different from both the two intra row spacing of 15 cm and 25 cm while the lowest total soluble solids (8.89) was recorded with the narrower intra row spacing (25 cm).

In the interaction effect, significantly the highest total soluble solids (9.35) was obtained with treatment combinations of 150 kg/ha nitrogen fertilizer rate combined with 35 cm of intra row spacing. On the other hand, the smallest total soluble solids (8.43) was obtained when cabbage plants were grown under no nitrogen fertilizer rate interacted with narrowest intra row spacing (15 cm) (Table 6). The increased total soluble solid in head might be due to the fact that nitrogen is the major constituents of plant protein, amino acid and carbohydrate; as a result of increased up take nitrogen might have increased total soluble solid.

4.4. Nitrogen left after harvesting

The amount of nitrogen left in the soil after harvest was highly significantly ($P < 0.01$) affected by the nitrogen fertilizer rate, intra row spacing (Appendix Table 5) and the interaction (Table 6 and Appendix Table 5).

The highest amount of nitrogen (0.32%) left in the soil was recorded from the treatment that applied highest nitrogen fertilizer rate (150 kg/ha) whereas the lowest (0.22%) was recorded from plots that received no nitrogen fertilizer rate. The nitrogen left in the soil with no nitrogen fertilizer rate and 50 kg/ha nitrogen fertilizer rate were decreased when compared with the availability of nitrogen before planting (0.27 %) but increases in the case of 100 and 150 kg/ha of nitrogen fertilizer rate. The current finding agrees with the report of Frezer (2007) that increasing nitrogen fertilizer rate increased post-harvest soil total nitrogen.

The highest amount of nitrogen left after harvest (0.28 %) was recorded at the widest spacing (35 cm). The lowest nitrogen (0.25) left was recorded at the narrowest intra row spacing (15 cm) (Table 7). The nitrogen left in the soil decreased in all intra rows spacing when compared with the presence of nitrogen before planting (0.27 %) in the soil. The decrease of soil total nitrogen at highest plant density was probably due to the increased plant population that resulted in higher removable of nitrogen from the soil by the plants. This results were in agreement with the finding of Manasa *et al.* (2017) who reported that the available soil nitrogen after harvest was higher at 60 x 60 cm (157.47 kg/ha) than 60 x 45 cm (150.81 kg/ha) in cabbage.

The highest amount of nitrogen left after harvest (0.34%) was recorded at the highest nitrogen fertilizer rate (150 kg/ha) combined with the widest intra row spacing (35 cm). The lowest nitrogen (0.20 %) left was recorded in plots that received no nitrogen fertilizer rate combined with the narrowest intra row spacing (15 cm) (Table 6).

4.5. Correlation analysis among growth and yield parameters

The correlation analysis showed that total head yield of cabbage was very highly significantly and positively correlated with number of unfolded leaf after heading ($r = 0.558^{**}$), number of leaf before heading ($r = 0.733^{**}$), plant height ($r = 0.703^{**}$), head diameter ($r = 0.601^{**}$), leaf area ($r = 0.909^{**}$), above ground plant fresh weight ($r = 0.927^{**}$) and marketable head weight ($r = 0.892^{**}$). Total head yield was also very highly significantly and negatively correlated with days to 50% head maturity ($r = -0.823^{**}$), dry matter content ($r = -0.872^{**}$) and unmarketable

head yield ($r = - 0.825^{**}$) as indicated in Table 9. The results of correlation analysis generally indicate that improving growth and yield parameters like number of leaf before heading , plant height, head diameter, marketable head weight and leaf area of cabbage by agronomic practices including nitrogen application rate and proper intra row spacing also improves yield of head cabbage. In other words, positively correlated parameter showed that the yield was increased as the yield related parameter increased while negatively correlated parameters showed that yield was increased as parameters decreased. Therefore, optimization of nitrogen fertilizer and intra row spacing is critically important to improve head yield of cabbage.

Table 7. Correlations of growth parameters to yield components of head cabbage

	D50HI	D50HM	DM	NLBH	NUFLAH	PH	HD	LA	APFW	MHW	UMY	THY	DMC	HI	HF
D50HM	0.377	1													
DM	-0.034	0.912	1												
NLBH	0.077	-0.689	-0.778	1											
NUFLAH	-0.084	-0.456	-0.468	0.475	1										
PH	0.220	-0.523	-0.666	0.566	0.384	1									
HD	0.439	-0.441	-0.670	0.543	0.310	0.675	1								
LA	0.022	-0.857	-0.937	0.780	0.539	0.672	0.640	1							
APFW	0.022	-0.817	-0.896	0.762	0.553	0.674	0.652	0.946	1						
MHW	-0.087	-0.797	-0.825	0.762	0.559	0.622	0.544	0.847	0.814	1					
UMY	-0.068	0.825	0.919	-0.740	-0.418	-0.639	-0.714	-0.912	-0.869	-0.823	1				
THY	-0.049	-0.823	-0.872	0.733	0.558	0.703	0.601	0.909	0.927	0.832	-0.825	1			
DMC	0.269	-0.529	-0.697	0.612	0.341	0.659	0.854	0.653	0.746	0.577	-0.654	0.684	1		
HI	-0.158	-0.332	-0.288	0.362	0.268	0.258	0.125	0.266	0.162	0.696	-0.301	0.296	0.072	1	
HF	0.561	0.071	-0.170	0.062	-0.049	0.294	0.767	0.117	0.133	-0.098	-0.223	0.066	0.565	-0.338	1
TSS	0.144	-0.215	-0.310	0.172	0.156	0.267	0.272	0.297	0.303	0.239	-0.297	0.218	0.262	0.025	0.164

D50HI = days to 50% head initiation, D50HM = days to 50% head maturity, DM = days to maturity, NLBH = number of leaf before heading, NULAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter, LA = leaf area, APFW = above ground plant fresh weight, MHW = marketable head weight, UMY = unmarketable head yield, THY = total head yield, DMC = dry matter content, HI = harvest index, HF = head firmness, TSS = total soluble solids, NAH = nitrogen left after harvesting.

5. CONCLUSION

The results of the present study showed that the nitrogen fertilizer rate and intra row spacing influenced most of the growth and yield components of head cabbage. Fertilizer rate had significantly affected parameters like marketable head weight, total head yield, dry matter content and head firmness. Intra row spacing had significantly affected parameters dry matter content and head firmness but not affected marketable head weight and total head yield. Significantly the highest marketable head weight (80.40 t/ha), total head yield (81.63 t/ha), dry matter content (9.43 %) and head firmness (3.78) were obtained at the highest rate of nitrogen fertilizer rate of 150 kg/ha combined with the widest intra row spacing of 35 cm. Significantly the highest above ground plant fresh weight (2.61 kg/plant) was also recorded at the combination effect of the highest rate of nitrogen fertilizer 150 kg/ha with the highest intra row spacing 35 cm.

Significantly the highest unmarketable head yield (6.20 t/ha) was recorded from the treatment combination of no nitrogen fertilizer rate combined with 35 cm intra row spacing used in the present study. Moreover, significantly the highest dry matter content (9.43%) and total soluble solids (9.35) were obtained with the application of 150 kg/ha nitrogen fertilizer on plants spaced with 35 cm intra row spacing. The production of head cabbage with the application of 150 kg/ha nitrogen fertilizer rate with plants spaced at 35 cm intra row spacing recorded the highest total head yields. Moreover, application of 150 kg/ha nitrogen fertilizer rate reduced maturity days of head cabbage as compared to the control of nitrogen fertilizer rate. Furthermore, significantly lowest total head yield of cabbage was obtained with the treatment combination of no application of nitrogen fertilizer rate combined with 25 cm intra row spacing.

The correlation analysis showed that total head yield of cabbage was very highly significantly and positively correlated with number of unfolded leaf after heading ($r = 0.558^{**}$), number of leaf before heading ($r = 0.733^{**}$), plant height ($r = 0.703^{**}$), head diameter ($r = 0.601^{**}$), leaf area ($r = 0.909^{**}$), above ground plant fresh weight ($r = 0.927^{**}$) and marketable head weight ($r = 0.892^{**}$). Total head yield was also very highly significantly and negatively correlated with days to 50% head maturity ($r = -0.823^{**}$), dry matter content ($r = -0.872^{**}$) and unmarketable head yield ($r = -0.825^{**}$). In terms of yield the current study identified that the combination application of the highest nitrogen fertilizer rate (150 kg/ha) with the narrowest (15 cm) intra row spacing was found best for total head yield cabbage production in the study area.

Application of the highest rates of nitrogen and implementation of closest intra row spacing is important to improve the production and productivity of head cabbage.

Therefore, as the obtained results of the effect of nitrogen fertilizer rate and intra row spacing on growth and head yield of cabbage were limited to one season and area, future studies should be designed to study the effects across different agroecological zones and seasons until optimum nitrogen fertilizer rate and intra row spacing will be recommended.

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7. APPENDICES

Appendix Table 1. Analysis of variance for phenological parameters

Source of variation	Df	Mean square and significance level		
		D50HI	D50HM	DM
Replication	2	23.012**	42.351***	205.113***
Nitrogen rate	3	3.222ns	53.556***	221.000***
Intra row spacing	2	21.938**	7.194***	0.063ns
Combination of treatments	11	26.454***	50.997***	179.402***
Error	24	4.333	1.611	4.139
Total	42	78.959	155.709	609.717
	CV (%)	4.292	2.109	2.849

* = significant at probability level of 0.05 level, ** = highly significant at probability level of 0.01 level, *** = very highly significant at probability level of 0.001 level, ns = not significant ($P > 0.05$), Df = degree of freedom, D50HI = days to 50 % head initiation, D50HM = days to 50 % head maturity and DM = days to head maturity.

Appendix Table 2. Analysis of variance for growth parameters

Source of variation	Df	Mean square and significance level				
		NLBH	NUFLAH	PH	HD	LA
Replication	2	12.232***	5.123**	30.465**	13.891***	255.647*
Nitrogen rate	3	16.111***	3.861*	34.292***	12.165***	32273.236***
Intra row spacing	2	0.632ns	0.028ns	7.907ns	10.981***	311.989*
Combination of treatments	11	14.929***	7.301**	34.542**	19.026***	27111.080***
Error	24	2.611	1.722	9.015	1.103	106.757
Total	42	46.515	18.035	116.221	57.166	60.058.709
CV (%)		12.019	9.946	9.251	6.826	3.156

* = significant at probability level of 0.05 level, ** = highly significant at probability level of 0.01 level, *** = very highly significant at probability level of 0.001 level, ns = not significant ($P > 0.05$), Df = degree of freedom, NLBH = number of leaf before heading, NUFLAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter and leaf area

Appendix Table 3. Analysis of variance for yield component parameters

Source of variation	Df	Mean square and significance level			
		APFW	MHW	UMY	THY
Replication	2	0.652***	0.354***	8.017***	705.785***
Nitrogen rate	3	0.919***	0.306***	10.609***	1040.119***
Intra row spacing	2	0.011***	0.001ns	0.134ns	5.044ns
Combination of treatments	11	0.768***	0.254***	9.046***	861.831***
Error	24	0.010	0.017	0.347	30.869
Total	42	2.360	0.932	28.153	2643.648
CV (%)		5.097	13.688	14.652	8.569

* = significant at probability level of 0.05 level, ** = highly significant at probability level of 0.01 level, *** = very highly significant at probability level of 0.001 level, ns = not significant (P > 0.05), Df = degree of freedom, APFW = Above plant fresh weight, MHW = marketable head weight, UMY = unmarketable yield, THY = total head yield.

Appendix Table 4. Analysis of variance for yield component parameters

Source of variation	Df	Mean square and significance level			
		DMC	HI	HF	TSS
Replication	2	2.121***	0.013**	2.016***	0.151**
Nitrogen rate	3	3.642***	0.012**	0.471ns	0.023ns
Intra row spacing	2	2.579***	0.0005ns	2.205***	0.019ns
Combination of treatments	11	5.586***	0.012*	2.289***	0.260***
Error	24	0.186	0.004	0.319	0.029
Total	42	13.928	0.0415	7.300	0.482
CV (%)		6.406	14.322	25.343	1.912

* = significant at probability level of 0.05 level, ** = highly significant at probability level of 0.01 level, *** = very highly significant at probability level of 0.001 level, ns = not significant ($P > 0.05$), Df = degree of freedom, DMC = dry matter content, HI = harvest index, HF = head firmness and TSS = total soluble solid

Appendix Table 5. Significance level for nitrogen fertilizer on growth and yield parameters

Parameters	Pr > F	Significance levels			
		P > 0.05	P < 0.05	P < 0.01	P < 0.001
D50HI	0.2028	Ns			
D50HM	<.0001				***
DM	<.0001				***
NLBH	<.0001				***
NUFLAH	0.0368		*		
PH	0.0002				***
HD	0.0001				***
LA	<.0001				***
APFW	<.0001				***
MHW	<.0001				***
UMY	<.0001				***
THY	<.0001				***
DMC	<.0001				***
HI	0.0033			**	
HF	0.0557	ns			
TSS	0.1597	ns			

ns = not significant, * = significant at $P < 0.05$, ** = highly significant at $P < 0.01$, *** = very highly significant at $P < 0.001$, D50HI = days to 50 % head initiation, D50HM = days to 50 % head maturity and DM = days to head maturity. NLBH = number of leaf before heading, NUFLAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter and leaf area, WPFW = above ground plant fresh weight, MHW = Marketable head weight, UMY = unmarketable yield, THY = total head yield, DMC = dry matter content, HI = harvest index, HF = head firmness and TSS = total soluble solid

Appendix Table 6. Significance level for intra row spacing on growth and yield parameters

Parameters	Pr > F	Significance levels			
		P > 0.05	P < 0.05	P < 0.01	P < 0.001
D50HI	0.0024			**	
D50HM	0.0005				***
DM	0.893	ns			
NLBH	0.1899	ns			
NUFLAH	0.9372	ns			
PH	0.1425	ns			
HD	<.0001				***
LA	0.0145		*		
APFW	0.0009				***
MHW	0.6262	ns			
UMY	0.4815	ns			
THY	0.5773	ns			
DMC	<.0001				***
HI	0.4532	ns			
HF	0.0001				***
TSS	0.1807	ns			

ns = not significant, * = significant at $P < 0.05$, ** = highly significant at $P < 0.01$, *** = very highly significant at $P < 0.001$, D50HI = days to 50% head initiation, D50HM = days to 50% head maturity and DM = days to head maturity. NLBH = number of leaf before heading, NUFLAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter and leaf area, APFW = above ground plant fresh weight, MHW = marketable head weight, UMY = unmarketable yield, THY = total head yield, DMC = dry matter content, HI = harvest index, HF = head firmness and TSS = total soluble solid.

Appendix Table 7. Significance level for combined effects on growth and yield parameters

Parameters	Pr > F	Significant levels			
		P > 0.05	P < 0.05	P < 0.01	P < 0.001
D50HI	0.0001				***
D50HM	<0.0001				***
DM	<.0001				***
NLBH	0.0002				***
NUFLAH	0.0015			**	
PH	0.0029			**	
HD	<.0001				***
LA	<.0001				***
WPFW	<.0001				***
HW	<.0001				***
UMY	<.0001				***
THY	<.0001				***
DMC	<.0001				***
HI	0.0237		*		
HF	<.0001				***
TSS	<.0001				***

ns = not significant, * = significant at $P < 0.05$, ** = highly significant at $P < 0.01$, *** = very highly significant at $P < 0.001$, D50HI = days to 50% head initiation, D50HM = days to 50% head maturity and DM = days to head maturity. NLBH = number of leaf before heading, NUFLAH = number of unfolded leaf after heading, PH = plant height, HD = head diameter and leaf area, APFW = above ground plant fresh weight, MHW = marketable head weight, UMY = unmarketable yield, THY = total head yield, DMC = dry matter content, HI = harvest index, HF = head firmness and TSS = total soluble solid

Appendix Table 8. Laboratory result of soil nitrogen analysis after harvest

Treatment combination (Nitrogen rate X Intra row spacing)	Percentage of nitrogen left in the soil after harvest
0 kg X 15 cm	0.20
0 kg X 25 cm	0.22
0 kg X 35 cm	0.23
50 kg X 15 cm	0.23
50 kg X 25 cm	0.24
50 kg X 35 cm	0.25
100 kg X 15 cm	0.26
100 kg X 25 cm	0.28
100 kg X 35 cm	0.31
150 kg X 15 cm	0.31
150 kg X 25 cm	0.32
150 kg X 35 cm	0.34

Appendix figure 1. Sample of data recording activities



Measuring of plant height



Measuring of head diameter



Weighing of head cabbage weight



Head cabbage weighted



Weighing of above ground plant fresh weight



Counting number of leaf before heading



Data taking



Study site

BIOGRAPHICAL SKETCH

The author was born on the 5th of July 1979 at a small village called Chitu Wereberi Kebele in Bako Tibe Wereda, West Shewa Zone of Oromia National and Regional State, Ethiopia from his father Wakuma Geldassa and his mother Sufe Gurmu. He attended his elementary education at Sheboka Primary School from 1987- 1994 and secondary education at Ambo comprehensive Secondary School from 1995-1998. After successful passing the Ethiopian School Leaving Certificate Examination (E.S.L.C.E), he joined Awassa College of Agriculture (now it is called Hawassa University) in 1999 and graduated with the Degree of Bachelor of Science in Plant Science (Plant Production and Dryland Farming) in July 2002. He worked in Governmental Organization in Gambella National and Regional State at Gambella ATVET college as junior instructor for one and half years. Then he was transferred from Gambella ATVET college to Bako ATVET College. In 2017 he joined the school of graduate study at Hawassa University to pursue his M.Sc. degree in Horticulture. He is married and a father of two boys and two girls.