EFFECT OF INTRA-RAW SPACING AND NITROGEN FERTILIZER RATE ON YIELD AND YIELD COMPONENTS OF CABBAGE (*Brassica oleracea var.capitata*. L) AT HOLETA, CENTRAL HIGHLANDS OF ETHIOPIA

M.Sc. THESIS

BY

ANBESU JIMA

March, 2012

JIMMA UNIVERSITY

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In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Horticulture (Vegetable Science)

By

Anbesu Jima

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Jimma University

APPROVAL SHEET

SCHOOL OF GRADUATE STUDIES JIMMA UNIVERSITY

As Thesis research advisor, I herby certify that I have read and evaluated this Thesis prepared, under my guidance, by Anbesu Jima, entitled "Effect of Intra-row Spacing and Nitrogen Fertilizer rate on Yield and Yield components of Cabbage (*Brassica oleracea var*. *capitata*L) at Holeta, Central Highlands of Ethiopia. I recommend it be submitted as fulfilling the Thesis requirement.

Derbew Belew (Ph.D)	__________________	___________
Name of Major-Advisor	Signature	Date
Tesfaye Bekele (Ph.D)	__________________	___________
Name of Co-Advisor	Signature	Date

As members of the Examining Board of the Final M.Sc Thesis Open Defense Examination, we certify that we have read, evaluated the Thesis prepared by Anbesu Jima Gurji and examined the candidate. We recommend that it be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Horticulture (Vegetable Science).

________________________	_____________	______________
Name of Chairperson,	Signature	Date
________________________	_____________	_____________
Name of Internal Examiner	Signature	Date
________________________	_______________	___________
Name of External Examiner	Signature	Date

DEDICATION

This thesis work is dedicated to my grandmother Banchiyiwosen Melke and my father Jima Gurji.

STATEMENT OF AUTHOR

I declare that this is my bonafide work and all sources of materials used for this thesis work have been duly acknowledged. The thesis has been submitted in partial fulfillment of the requirements for the degree of Master of Science at Jimma University and is reserved at the University Library to be made available to users. I solemnly declare that this thesis work is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Name: Anbesu Jima

Place: Jimma University, Jimma, Ethiopia

Date of Submission.............................. Signature...........................

BIOGRAPHICAL SKETCH

Anbesu Jima Gurji, the author, was born on April 12, 1973 at Lume wereda, East Showa Zone of Oromia region. He attended his elementary School at Ejere, Junior secondary school at Modjo and Secondary school at Zeway towns. Following the completion of his secondary education, he joined the then Alemaya now Haramaya University, and graduated with B.Sc. Degree in Plant Science in June 1994. He was employed by Oromia Agricultural Bureau and served the Bureau until he joined the graduate studies program of Jimma University College of Agriculture and Veterinary Medicine to pursue a graduate study leading to a Master of Science degree in Horticulture (Vegetable Science). He is married and has two children.

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ABREVATIONS AND ACRONYMS

BSHS	Brazilian Society of Horticultural Science
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
CSIRO	The Commonwealth Scientific and Industrial Research Organization
EARO	Ethiopian Agricultural Research Organization
CSSE	Crop Science Society of Ethiopia
FAO	Food and Agricultural Organization
NAARR	New Alcheny Agriculture Research Report
SDFAO	Statistical Division Food and Agricultural Organization
UN	United Nations
UNESCO	United Nations Educational Science and Culture Organization
USDA	United States Department of Agriculture

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EFFECT OF INTRA-RAW SPACING AND NITROGEN FERTILIZER RATE ON YIELD AND YIELD COMPONENTS OF CABBAGE (*Brassica oleracea var.capitata.* L) AT HOLETA, CENTRAL HIGHLANDS OF ETHIOPIA

ABSTRACT

*A field experiment was conducted to investigate the effect of intra-row spacing and nitrogen fertilizer rate on yield and yield components of cabbage. The study was conducted from December 2010 to May 2011 at Holeta Agricultural Research Center. Three intra-row spacing (20, 30 and 40 cm) and four nitrogen fertilizer levels (0, 50,100 and 150 kg/ha) were used. The experiment was laid out in Randomized Complete Block Design (RCBD) in 3x4 factorial arrangements with three replications. Copenhagen market variety of cabbage was used for this experiment. Results indicated that head weight and unmarketable yield were very highly significantly (P<0.001) affected by the interaction effect of intra-row spacing and nitrogen fertilizer rates. The highest head weight (1.52 kg/plant) and lowest unmarketable yield (0.83 t/ha) were obtained at the interaction of 40 cm intra-row spacing with 150 kg/ha nitrogen fertilizer rates. Days to maturity, leaf number, leaf area, plant spread, head height, head diameter, whole plant fresh weigh , dry matter, harvest index and nitrogen left after harvest were very highly significantly (P<0.001) affected by nitrogen fertilizer rate and intra-row spacing. Wider plant spread (51.8 cm), larger leaf number (13.7), wider leaf area (463 cm^2), longer head height (16.7 cm), wider head diameter (16.6 cm) were recorded at higher (150 kg/ha) nitrogen fertilizer rate. Higher marketable yield (78.2 t/ha), higher total yield (80 t/ha), higher harvest index (0.8) and higher nitrogen left after harvest (0.22%) were also recorded at higher nitrogen fertilizer rate (150 kg/ha), but lower dry matter percentage (7.78%) was recorded at this rate. Intra-row spacing of 40 cm was found to be superior for plant spread, head diameter, head height, leaf number, leaf area, whole plant fresh weight and nitrogen left after harvest. For higher gross yield 20 cm intra-row spacing was superior. Higher profitable yield (78 t/ha) or birr 230,530.00 per hectare was obtained at the combination of 150 kg/ha nitrogen fertilizer rate with 20cm intra row spacing. Correlation analysis indicated that marketable yield was significantly correlated with outer leaf number (r=0.71***), head height (r=0.73 ***), head diameter (r=0.87***), whole plant fresh weight (r=0.8***), head weight(r=0.67) and harvest index (r=0.7***). Results of current investigation revealed that 20 cm intra-row spacing and 150 kg/ha nitrogen fertilizer rates can be used for higher marketable yield and profitability. Farmers at Holeta could therefore be advised to use this combination for high profitable cabbage yield. However, further investigations may be suggested to be carried out on different soil type, at different seasons, year and location so as comes up with precise and comprehensive recommendation.*

1. INTRODUCTION

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 originated from wild non-headed type 'cole wart' (*Crambe cordifolias*) from Western Europe and Northern Shore of Mediterranean (Semuli, 2005). It has been domesticated and used for human consumption since the earliest antiquity. It is cool season crop that is very popular with gardeners and commercial producers.

Cabbage is known for its nutritional importance and it is rich in mineral and vitamins like A, B_1, B_2 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 (Ruzawlah *et al*., 2002). Cabbage can grow easily under wide range of environmental condition in both temperate and tropical, but cool moist climate is most suitable (Rai and Asati, 2005). Optimum growth 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 to 90 percent (FAO, 2012).

Cabbage is grown for its head in more than ninety countries throughout the world (Meena *et al*., 2010). The major cabbage growing countries of the world are China, India, South Korea, Germany, Japan and South Africa (Sarker, 2002). Cabbage ranks fifth among the vegetable crops of the world. The area planted with headed cabbage worldwide in 2009 was estimated at about 3.2 million hectare in 124 countries producing some 71 million tones. In the same year, area planted by cabbage was about 2.5 million hectare in Asia, 0.5 million hectare in Europe, 80,000 hectare in America and 120,000 hectare in Africa (Nina, 2011). In Africa a total of 2 million tons were produced in 2008 and it has shown an increase by 20% over the 10-year period between 1998 and 2008. The five cabbage producer 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 (SDFAO, 2010). Area, production and yield of head cabbage in Ethiopia in 2007/2008 were 1989 hectares, 11,765 tons and 5.9 t/ha respectively. In 2008/2009 it grew to 3399 hectares, 24,133.4 tons and 7 t/ha respectively. Within these two years the area has increased by 70% where as the production has increased by 105%. In Oromia Regional State the area covered by head cabbage in year 2008/2009 was 2188.9 hectares while the production was 15,601.9 ton and the yield is 7 t/ha (CSA, 2008). The world average yield is 10-40 t/ha (Ogbodo, 2009).

The average cabbage yield of national as well as farmers around Holeta is very low when compare to the world average. The major factors for the low productivity of this crop in Ethiopia in general and around Holeta in particular are low fertility status of the soil, inappropriate use of fertilizer rate, inappropriate plant population per unit area, disease, pests and inappropriate agronomic practices.

The current farmers and commercial producers practice of cabbage production around Holeta is similar to other part of the country. They cultivated this crop by rain fed and irrigation using commercial fertilizer of DAP and Urea. The fertilizer rates they used is not uniform and it range from 50-150 kg/ha of DAP and 50-100 kg/ha of Urea. Moreover, the plant spacing they used is also not uniform. Due to this the yield they obtained is low (10-20 t/ha) (Wolmera Agricultural Office, 2010). Its quality is also poor. Some cabbage heads are very small where are others are very big, cracked, burst rotten and loose heads which are fewer acceptances in the market.

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 plant density and fertilizer rate which contribute to substantial amount of crop (Frezer, 2007). 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 (Endale and Gebremedhin, 2001). 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 (Jerry *et al*., 1980).

Likewise the plant density, low soil fertility also considered as serious problems among several production limiting factors in the study area. 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 (Frezer, 2007). Thus, it requires applying of appropriate rate of fertilizer for the enhanced cabbage productivity and sustainable yield. Many experiments show that nitrogen application increases the total yield of cabbage (Westveld *et al*., 2003). But this is possible as long as it is managed properly in terms of rate and time of application.

Therefore, plant density and nitrogen level 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 central highlands of Ethiopia, particularly around Holeta, there is a need by farmers to increase productivity of cash 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 optimum plant population and nitrogen fertilizer rate. Moreover, information on cabbage plant density and nitrogen application rate for optimum yield and other agronomic practices are limited. Since most of the farmers in this area has smaller plots of land and the yield obtained from this is very low. Due to this their income is less and they unable to improve their livelihood. So it is important to increase the yield of cabbage from this small plot of land to improve the income of farmers around this area. Therefore the present work was initiated with the following objectives:

- To determine the effect of intra-row spacing and nitrogen fertilizer rate on yield and yield components of cabbage
- To assess the interaction effect of intra-row spacing and nitrogen fertilizer rate on yield and yield components of cabbage
- To determine the treatment combinations that gain good return to farmers.

2. LITERATURE REVIEW

2.1. Description and Origin of Cabbage

Cabbage (*Brassica oleraceae*. *var capitata*), is also known as cole crops. It belongs to family Brassicaceae (or Cruciferae) and generally referred as Brassicas. It is important groups of crop worldwide. It is originated from Western Europe and Northern Shore of Mediterranean region where it has been grown for more than 3000 years. It has chromosome number 2n=2x=18 (Ijoyah *et al*., 2001). It is dicotyledonous biennial crop, but it grows as an annual. In the first season growth it produces the head and in the second season it produces seeds. Cabbage form several different head shapes: pointed conical, or oblong, round or bell shaped or drummed shaped. Cabbage generally classified as headed which is round, oval or flat. Chinese 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 (Semuli, 2005). The genus Brassica includes about 100 species majority of which are native to Mediterranean region. The crop is attributed to the Mediterranean centre of origin (Rai and Asati, 2005). It is widely grown as cool-season crop and is very popular with gardeners.

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 ß-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 (Rai and Asati, 2005). 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. Flavor in cabbage is due to the glucoside sinigrin (Rai and Asati, 2005). A 100 g edible portion of cabbage contains 1.8 mg protein, 0.1 mg fat, 4.6 mg carbohydrate, 0.6 g mineral, 29 mg calcium, 0.8 mg iron and 14.1 mg sodium (Singh and Naik, 1996).

2.3. Cabbage Production in Ethiopia

Ethiopia 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. Largely cabbage is produced by irrigation rather than rain fed. 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. Most of the production is by smallholder. Other vegetables such as onion, garlic, shallot capsicum, tomato, head cabbage etc are produced by individual growers and others by private investors as well as state enterprises. The most important cabbage verities 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, where as the high land areas offer favorable condition to grow cool season vegetable like cabbage, garlic, shallot, carrot etc. In Ethiopia, land holders living near urban centre largely practice vegetable farming. Most vegetables are not commonly practiced by the rural peasant holders (Fekadu and Dendena, 2006).

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. As population increases, the needs for intensive agriculture becomes a paramount importance to maximize output to which vegetable are favorable.

The marketing aspect of vegetable seed in the country including cabbage is heavily dependent on imported source of seed. The seed market in the country is predominantly imported from abroad and only few importers are involved in the importation. In 2010 about six private companies (Segel Generation Business PLC., Markos PLC., AJMU import and export and others) and two public companies (Ethiopia Fruit and Vegetable Marketing Enterprise and Agricultural Input and Supply Enterprise) are involved in the importation of seed and this has influenced the national market (Dawit *et al*., 2004).

2.4. Agronomic Management of Cabbage

Cabbage grows well on a wide range of soil. But it requires well drained sandy loam soil, with pH of 6-6.5, rain fall of 700-900 mm and 17-24 ^{0}C. Water logging is unsuitable for cabbage production. It is propagated by seed and system of planting is transplanting. It requires 0.6 kg/ha and sowing depth is 1-1.5 cm and spacing of 60 cm by 40 cm between rows and plants. Fertilizer requirement is 150 kg/ha DAP and 100 kg/ha Urea. Irrigation interval should be 5-7 days. Its days to maturity are 80-100 days. In Ethiopia its productivity is 25-30 t/ha when improved practices are followed and 7 t/ha when grows conventionally at farmers' level (Simret *et al.,* 1994).

Currently farmers and commercial producers practice of cabbage production around Holeta is similar to other part of the country. They cultivated cabbage by rain fed and irrigation using commercial fertilizer of DAP and Urea. The rate of fertilizers they used range from 100-150 kg/ha DAP and 50-100 kg/ha Urea. Moreover, the plant spacing they used is not uniform and it ranges from 15 to 40 cm between inter row spacing and 15 to 25 cm between intra row spacing. They irrigate in five days interval. The main problem of pest in this area is Aphids. They used chemical Malathion to control it. Due to these poor agronomic practices and Aphids the yield they obtained is low and it ranges from 10-20 t/ha (Wolmera Agricultural Office, 2010). The quality of cabbage produced in the area is also poor. Some cabbage heads are very small where are others are very big. There are also cabbages which are cracked, burst rotten and loose heads which are fewer acceptances in the market.

2.4.1. Nutritional requirement and their management

The quantity of fertilizer requirements in cabbage depends on fertility status of the soil which is determined by soil testing. Cabbage requires large amounts of fertilizer. As it benefit from higher levels of organic matter, it is suggested that animal manure (if available) be the basis of the fertilizer program. The most important nutrient that important for cabbage is nitrogen, phosphorus, potassium and sodium molybdate. In cabbage fertilizers (especially nitrogen) promote rapid growth, high yield, and high produce quality. High value crops such as cabbage, proper nutrition is important in order to produce a high yield and also good quality. There is a correlation between the amount of nitrogen applied and quality of cabbage. Cabbage head will not form if there is shortage of nitrogen. On the other hand, excess nitrogen may cause the formation of loose heads with internal decay. The demand for phosphorus is greater during head formation and shortage will result in purple leaves. Potassium deficiency can also result in necrosis and reduce head quality but an excess of potassium can cause cracked heads. Cabbage also requires sulfur, magnesium and boron. High temperature causes nutrients, especially nitrogen, to be available to the growing plants much quicker and will result in high quality yields Semuli, (2005). A side dressing of nitrogen is desirable after the head has formed to about half the size to maturity.

2.4.2. Intercultural operation

Regular intercultural operations are necessary for proper aeration of root system and control of weed to promote healthy plant growth. Cabbage is very sensitive to soil moisture. Maximum growth and yield can only be obtained when a particular supply of water is available to the plant throughout the growth. It requires 500 mm of water for its growing period. Good drainage is important, as too much water tends to split heads when they are matured (Simret *et al.*, 1994). Water should not be deficient from head formation until harvest time, as this will drastically limit yields. According to Simret *et al.* (1994), first irrigation is given just after transplanting of seedlings and therefore, irrigation may be done at 5-7 days interval according to season and soil conditions.

Weed is also the main problem in cabbage production. Weeding earlier before it harms the plant can increase yield. Most of weed management can be carried out by hand and also at time of hoeing. Hoeing is the most important intercultural practice which helps the crop well aerated and also weeds control. Crop protection also has to be considered in cabbage production. Cabbage can be affected by disease such as Black rot, Club root, Turnip mosaic virus, Sclerotinia rot and pests such as Cut warm, Aphids, Cabbage white butterfly, Budarm and other pests (More . 2006).

2.4.3. Maturity, harvesting, marketable yield and quality of cabbage

Determining the optimum time of harvest is often difficult and differs between heading and non heading types (George, 2002). 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 (Semuli, 2005). 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 (George, 2002). In Ethiopia, especially around Holeta it takes three to four months to mature.

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 (NAARR, 1986). 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 harvest of cabbage should be marketable and non marketable. 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 (NAARR, 1986). 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 ($0^{o}C$) (George, 2002).

Quality is also one of the important factors in cabbage production. Cabbage growers aim to harvest their crop with the least possible number of cuts. To achieve this, good cultural methods are necessary at all stages of production. Careful attention to size of transplants, fertilizing, irrigation and pest and disease control helps to ensure even maturity. Cell-produced transplants are more uniform in their maturity than are seedbed- produced plants. This in one of the major reasons grows are using this method of producing seedlings (Murison and Nipier, 2006).

After trimming outer wrapper leaves, cabbage heads should be a color typical of the cultivar (green, red, or pale yellow-green), firm, heavy for the size and free of insect, decay, seed stalk development and other defects. Leaves should be crisp and turgid.

2.5. Status of Soil Fertility in Highlands of Ethiopia

Ethiopia faces a wide set of soil fertility issues that require approaches that go beyond the application of chemical fertilizers that only practice at scale to date. Core constraints include topsoil erosion some sources list Ethiopia among the most severely erosion-affected countries in the world erosion rates are estimated at 10-13 mm p.a. on average. The report prioritizes four areas in which significant improvements in on-farm practice will yield substantial production gains; acidity-affected soils covering over 40 percent of the country, significantly depleted organic matter due to widespread use of biomass as fuel, depleted macro and micro-nutrients, depletion of soil physical properties, and soil salinity (Gete *et al.,* 2010). Low soil fertility is currently a major constraint to achieve high yield of crops in Ethiopia. Reports showed that nitrogen and phosphorus were the two major plant nutrients limiting crop production in most of the high lands of Ethiopia (Asnakew *et al*., 1991).

Recycling of nutrient in the Ethiopian highlands is generally low with 50-80% of dung and 70-90% of crop residues being removed for use as fuel in household energy consumption, for construction or for use as animal feed (Tadele, 2008). The average nitrogen and phosphorus depletion in East Africa, particularly in Ethiopia is estimated to be around 47-88 kg/ha/year in general and 100 kg/ha/year in particular in the high land (Asnakew *et al*., 1991). Major factors contributing to nutrient depletion are soil erosion, fixation of phosphorus, and leaching in respect of nitrogen and potassium, further accelerating by deleterious land use practices resulting from high population pressure (Henao and Baanants, 1999).

Nitrogen is the most deficient and the major plant nutrients limiting crop production in most of the highlands. Nitrogen deficiency can occur on almost any type of soil, but is most likely in cool, wet area or on soils, that are frequently water logged. Substantial quantities of nitrogen may be immobilized in organic form that is not readily available to crops. Compared with other nutrients, nitrogen fertilizer are highly soluble and may be lost by leaching, de-nitrification, volatilization, erosion and substantial quantities may also be immobilized in organic form that are not ready available to crops (Tadele, 2008). It is not surprising that considerably more nitrogen relative to other nutrients is supplied to crops as fertilizer and is removed in harvest. This highest rate is require because of both the high nitrogen need in plants and its general mobility in the soil causing high degree of loss before it is absorbed by plants.

2.6. The Role of Nitrogen in Cabbage

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. 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 (More, 2006). 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 favorable 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.

All plants require sufficient supplies of macronutrients for healthy growth, and nitrogen is a nutrient that is commonly in limited supply. Nitrogen deficiency in plants can occur when organic matter with high carbon content, such as sawdust, is added to soil. Soil organisms use any nitrogen to break down carbon sources, making nitrogen unavailable to plants. This is known as "robbing" the soil of nitrogen. All vegetables apart from nitrogen fixing legumes are prone to this disorder.

Nitrogen deficiency can be prevented in the short term by using grass mowing mulch, or foliar feeding with manure, and in the longer term by building up levels of organic matter in the soil. Sowing green manure crops such as grazing rye to cover soil over the winter will help to prevent nitrogen leaching, while leguminous green manures such as winter tares will fix additional nitrogen from the atmosphere (Sanderson *et al.,* 1999).

2.7. Cabbage Response to Nitrogen Fertilization

Higher levels of nitrogen have often been found to induce optimum yield in Brassica vegetables. Parmar *et al*. (1999) reported that increased yield of cabbage head to about 4 kg m^2 fresh mass more than plants grow without nitrogen fertilizer. He also recorded higher yield in cabbage with increased nitrogen rate. 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. Similar observations on cabbage were made by Ghanti *et* *al*. (1982) where yield contributing characters such as head diameter and gross mass of heads and marketable heads increase with increase in the levels of nitrogen up to 200 kg/ha. Gupta (1987) observed significantly higher cabbage yield at 150 kg/ha than yield at 0, 50, and 100 kg/ha nitrogen yet par with yield at 200 kg/ha nitrogen on clay soil. Increased yield was attributed to increase in head mass.

Everaarts and Mole (1998) reported increasing uniformity with increasing amounts of nitrogen applied. In cabbage production uniformity of head is important. Increase in relative core length was observed when nitrogen application rate increases, whereas dry matter content of the head decreased. This was associated with softer head tissue at higher nitrogen availability, there by having less physical resistance to stalk elongation. He also observed decreases in percent dry mass of the heads, increased number of burst heads and increased tip burn in the head with increasing fertilizer nitrogen rate from 150 kg/ha to 250 kg/ha. It was therefore concluded that higher nitrogen fertilizer of 250 kg/ha decreased the quality of cabbage heads on loam soil.

Head width and height increase with nitrogen fertilizer application. It has been accepted that application of nitrogen fertilizer to cabbage increase yield, plant uniformity, and quality. An experiment conducted by Haque *et al*. (2006) in Bangladesh to compare three levels of nitrogen fertilizer rate that applied in split (60 kg/ha, 120 kg/ha and 180 kg/ha) on clay loam soil showed that maximum yield of cabbage (65.11 t/ha) were found from the plot receiving fertilizer rate of 180 kg nitrogen and 60 kg P_2O_5 per hectare.

2.8. 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.

Dragan (2007) reported highest cabbage head diameter (16.6 cm) recorded in the case of lowest crop density (8 m^2) where as the lowest diameter (9.6 cm) was recorded at higher plant density (16.6 cm^2). 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 cm^2) but the lowest yield (71 t/ha) was recorded at lower plant density (8 m^2). 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.

Dufault and Waters (1985) reported that broccoli head mass decrease linearly when plant population were increased from 24,000 to 72,000 plants/ha with nitrogen kept constant at 112, 169 or 224 kg/ha. It was however observed that despite reduction of head mass, marketable yield increases at highest plant population of 72,000 plants/ ha. It was observed that whenever plant population were increased from 24,000 to 72,000 plants/ha, marketable yield of cauliflower decreased. The explanation given was that increasing plant population increased competition among plant resulting in reduced marketable yield (Semuli, 2005).

Ghanti *et al.* (1982) studied the response of 'Pusa Drumhead' cabbage to nitrogen phosphorus and spacing in order to find suitable combination of nitrogen, phosphorus and spacing to obtain higher yield. They observed significant effect of different spacing on the yield contributing characters such as head diameter, head gross and head net mass were obtain at 50x70 cm spacing and decreasing as intra-row spacing decrease from 40x70 cm to 30x70 cm. Closer spacing increase competition for water and nutrients and subsequently reduces vegetative growth which led to a decrease in the diameter as well as mass of heads. Nonetheless, close spacing of 30x70 cm produced maximum number of marketable heads which was 55% more than that of 50x70 cm spacing. The maximum number of marketable head from 30x70 cm spacing contributes to higher yield of about 35% and 18% more than that recorded when intra row spacing increase from 30 cm to 50 cm.

Singh and Naik (1988) recorded significantly higher yields with closer spacing (45 cm inter row x30 cm intra row) spacing than wider spacing (45 inter row spacing x 45 cm intra row spacing and 45 inter row spacing x 60 cm intra row spacing) of cabbage. Yields from closer spacing was approximately 49% and 45% more than yield recorded under 45x60 cm spacing in the first and second year, respectively. Furthermore, 63% and 92% more marketable heads were obtained from the close spacing than the widest spacing. More number of marketable heads per unit area in the case of closer spacing was attributed to increase yield. As spacing was increased there was no significance increases in head mass even though the widest spacing recorded maximum head mass. This was attributing to the fact that spacing competition for the growth factors increased.

Plant population studies are common features of many horticultural crops, including cabbage. There are several citations in the literature that provide information related to optimum plant population evaluations for cabbage that has been conducted over the past 30 years. A very common range in optimum plant population recommendation for cabbage is for stand of 20,000 to 70,000 plants per hectare. Increasing plant population with cabbage has the potential for increasing yield and profit where as 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 (Draga, 2007).

Purushottam (2001) compared five different spacing (45x60 cm, 45x50 cm, 45x40 cm, 45x30 cm and 45x20 cm) for two varieties. The result showed that among the tested spacing, head yield was statistically higher at 45x30 cm and 45x 20 cm plant spacing that is 408 g and 565 g head respectively. The yield recorded were 39.9 t/ha in 45x20 cm spacing and 35.8 t/ha yield in 45x30 cm spacing, respectively. The result showed that increasing plant population per unit area decreased the head weight simultaneously. There was also a positive linear correlation between closer plant spacing and cabbage yield.

Semuli (2005) also reported the that the trimmed cabbage head of 1.42 kg/plant and highest yield of 71.75 t/ha were produced at 100 kg/ha nitrogen and the highest yield of trimmed and untrimmed cabbage (74.14 and 129 t/ha) were obtained from 30x50 cm spacing even though the total yield (per unit area) from 40x50 cm spacing were not significantly different from 30x50 cm and 50x50 cm spacing.

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. Higher nitrogen fertilizer and wider spacing generally increased marketable head of cabbage.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted at Holeta Agricultural Research Center (HARC) from December 2010 to May 2011. HARC is located in Oromia Regional State and the site is located at latitude of 9^{o}3’0’’N, longitude of 38^{o}3’0’’E and altitude of 2400 m.a.s.l at 30 km west of Addis Ababa on the way to Welega road. The rainy season of the area span from June to October and the mean annual rainfall is about 900 mm. The field has history of being used for different experiments on horticultural crops (Tadele, 2008). As the result of soil analyses conducted by Zeway Soil Laboratory indicated and showed in Table 1 the experimental site had loam soil. Generally this soil is less fertile for cabbage production.

Table 1. Soil physical and chemical properties of the experimental site

Parameters	Soil properties
% OM	0.16%
% Total Nitrogen	0.19%
pH	7.6
Available P in ppm	28.17
EC µmhos/cm	0.191
CEC (meq/100g soil)	70.99
Ex. Ca (mol(+)/kg soil	18.38
Ex.Mg mol(+)/kg soil	6.97
Ex Na mol(+)/kg soil	0.02
Ex K mol(+) /kg soil	0.22
Texture	
% sand	48
% silt	36
% clay	16
class	Loam

CEC cation exchange capacity, EC= electrical conductivity Ex = exchange,

OM= Organic matter, µmhos= micromhos, ppm=part per million

3.2. Experimental Material

Copenhagen market variety, one of the most popular and reliable early round- headed cabbages, was used for this experiment. This vigorous variety is widely adopted and requires 80-90 days of maturity after transplanting. Copenhagen market was selected for this experiment, because it is produced widely in high altitude of 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 (Girma, 2002). It is the most important cash crop in the central highlands of Ethiopia, including surrounding of Addis Ababa. Seed of the variety had 99% purity and 85% germination percentage, with validity till 2013. It was purchased from Markos, PLC Addis Ababa, Ethiopia.

3.3. Experimental Design

The experiment comprises three levels of intra-row spacing: 20, 30 and 40 cm with 50 cm inter row and four nitrogen fertilizer rates: 0, 50,100 and 150 kg/ha. The two factor experiment was laid out in 3 x 4 factorial arrangements using Randomized Complete Block Design (RCBD) with three replications. A total of 12 treatment combinations were used in this experiment (Table 2). For the application of each of the 12 treatments, a plot with dimension of 2.4 m length x 2 m width and 4.8 m^2 gross plot size was used. A distance of 0.5 m between plots and 1m between blocks was maintained. The number of cabbage plants per plot was 48, 32 and 24 for the intra row spacing of 20, 30, and 40 cm respectively. There were four rows per plot. Population of cabbage were 50,000 plants/ha for 50 cm inter row spacing with 40 cm intra row spacing, 66,666 plants/ha for 50 cm inter row spacing with 30 cm intra row spacing and 100,000 plants/ha for 50 cm inter row with 20 cm intra row spacing.

Table 2. Treatment combinations of intra-row spacing with fertilizer rate

Intra-row spacing (cm)	Nitrogen fertilizer level (kg/ha)	Treatment combination	Plant population (plants/ha)
20	0	20 cm x 0 kg	100,000
	50	20 cm x 50 kg	100,000
	100	20 cm x 100 kg	100,000
	150	20 cm x 150 kg	100,000
30	0	30 cm x 0 kg	66,666
	50	30 cm x 50 kg	66,666
	100	30 cm x 100 kg	66,666
	150	30 cm x 150 kg	66,666
40	0	40 cm x 0 kg	50,000
	50	40 cm x 50 kg	50,000
	100	40 cm x 100 kg	50,000
	150	40 cm x 150 kg	50,000

3.4. Experimental Procedures

Seedlings were raised on a seed bed and transplanting to main field after one month. The field was well prepared and irrigated three days before transplanting. Then it was transplanted to the main field according to the experimental design and layout (Appendix plate 4). Phosphorus fertilizer (triple super phosphate) was applied once during planting at the rate of 50 kg/ha and the four rates of nitrogen (0, 50, 100 and 150 kg/ha) in the form of urea was applied in split, half at transplanting and half at forty five days after transplanting. It was plowed, weeded and hoed three times. It was irrigated in five days interval until the plant matures.

3.5. Data Collected

To evaluate the effect of intra row spacing and nitrogen fertilizer levels on cabbage yield and yield components, six samples were taken from the two middle rows per plot. On the basis of six sampled plant head from each experimental unit, gross yield, marketable and unmarketable yield were weighed and converted in to t/ha. Plant whole fresh weight, days to maturity, head diameter and height, leaf number and area, and harvest index were also taken from six samples per plot. Dry matter percentage was determined by taking slices from two heads per plot and dried at 78 ^{0}C for 48 hours until constant weight was attained (Semuli, 2005).

3.5.1. Growth parameters

Days to maturity (DMt) - When the cabbage head is compacted and firm to the touch it is matured. The other indicator of maturity of head cabbage is the arrangement of wrapped leaves. When they are spread and the head is exposed it is usually matured. A very loose head is immature and should not be harvested (Semuli, 2005). Cabbage heads were harvested based on these indicators when 50 % of the samples were matured at the days of 91, 101 and 109 after transplanting.

Head height (HH) (cm) - Cabbage head height (HH) was measured from selected plant samples from the central rows of the plot and their mean were recorded. The measurement was done with ruler from the tip head to down the collar at maturity and was expressed in centimeter.

Head diameter (HD) (cm)- At harvest, randomly taken samples of cabbage heads from the central row were taken and the head diameter (HD) was measured at widest part using Caliper (model LEG ilox-250 mm, US patent) and was expressed in centimeter (Appendix plate 5).

Outer leaf number (OLN) - Total numbers of fully developed outer leaves from each sample head were counted at time of harvesting.

Outer leaf area (OLA) (cm^2) - Charles (2011) reported that leaf area can be 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 will be 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 greed square and the data were recorded as the average leaf area per plant.

Plant spread (PS) (cm) - Plant spread (PS) was measured using ruler from East to West and North to South direction (Purushottam, 2001). According to this the average plant spread was taken from the samples at time of harvesting.

3.5.2. Yield parameters

Whole plant fresh weight (WPFW) (kg/ plant) - Randomly selected sample plants were taken from the central rows of each plot and the whole plant parts were measured using the beam balance (Model WA310 rev-B aeadam equipment, made in China) (Appendix plate 6).

Head weight (HW) (kg/plant) - At time of harvesting (91, 101 and 109 days) after translating randomly selected samples were taken from each treatment and their head weight was measured using analytical balance (Model WA310 rev-B dam equipment, made in China).

Unmarketable yield (UMY) (t/ha) - Cabbage such as non-headed, split (burst), disease affected and under sized head (below 0.45 kg) were recorded as unmarketable NAARR (1986) and calculated on the basis of t /ha.

Total head yield (TY) (t/ha) - Total number of heads and their weight was 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 was taken and the whole part was chopped. 200 g sample was taken from the chopped cabbage and dried at 78 ^{0}C for 48 hours until constant weight was attained (Sumeli, 2005). Percentage dry matter content was calculated as the ratio between dried and fresh cabbage.

Harvest index (HI) - Harvest index (HI) 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 whole plant weight and only head weight separately and harvest index was taken as the ratio of head weight to total weight of the plant.

3.5.3. Soil analysis

Representative soil samples were taken using an auger at 0-20 cm depth from different places of experimental field before planting to make one composite sample. Soil samples were collected from each plot after crop harvest. The collected soil samples were air dried in wooden tray, ground and sieved. The soil analysis made before planting included total nitrogen, phosphorous, potassium, organic matter, soil pH, CEC and soil texture, and after harvesting of crop only nitrogen was analyzed. All the soil samples were analyzed at Zeway soil Laboratory.

3.5.4. Profitability analysis

For economic (profitability) evaluation, cost and return, and benefit: cost ratio was calculated according to the procedure given by CIMMYT (1998). B: C ratio was calculated as the relationship of net return to total cost. To estimate economic parameters, cabbage was valued at an average open market of 3.50 Birr per kg and all input and labor costs incurred were taken at local market price. Finally net return or profit was calculated with the following formula:

Net return (profit) =Gross field return - total cost incurred (CIMMYT, 1998).

C:B ratio =Net return / cost

Whereas C= cost

B= benefit

3.6. Data Analysis

Data were analyzed statistically using SAS version 9.2 and M-STAT statistical software computer package program (Montgomery, 2005). 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 intra row spacing and nitrogen application rate.

4. RESULTS AND DISCUSSION

4.1. Growth Parameters

4.1.1. Days to maturity

Days to maturity was very highly significantly **(***P<0.001*) affected by intra row spacing and nitrogen fertilizer rate (Appendix Table 1).

Increased nitrogen fertilizer from 0 to 150 kg/ha resulted in significant decrease in the days to maturity from 108 to 93 days. The earliest days to maturity (93 days) was observed at higher nitrogen fertilizer rate (150 kg/ha) where as the longest days to maturity (108) was recorded when nitrogen fertilizer was not applied (Fig.1). The higher nitrogen rate that shortened the days to maturity is probably due to higher nutrient presumed to have helped the cabbage plant for wrapped or head formation than lower rate of nitrogen. The current finding agrees with that of Westervel *et al*. (2003) that nitrogen rate and days to maturity was quadratic that cabbage received highest nitrogen rates (240 kg/ha) reached maturity up to four weeks earlier than those received no or low nitrogen rates. Khan (2002) also reported that if nitrogen is not in adequate amount cabbage would not form heads.

The earliest days to maturity (91 days) was observed at the wider intra row spacing (40 cm) but was extended (109 days) at the narrower intra row spacing (20 cm) (Fig. 2). The days to maturity was delayed by 18 days in the narrower intra row spacing as compared to wider spacing. Delayed days to maturity, in intra row spacing, probably was due to high competition for nutrients as a result of which the plant failed to form head earlier. According to these authors, lower nitrogen fertilizer and close intra row spacing delayed maturity. On the other hand, however, the present finding was not in-agreement with the works of Ogbomo (2009) who reported that days to maturity of cabbage was prolonged for plants grown with wider row spacing.

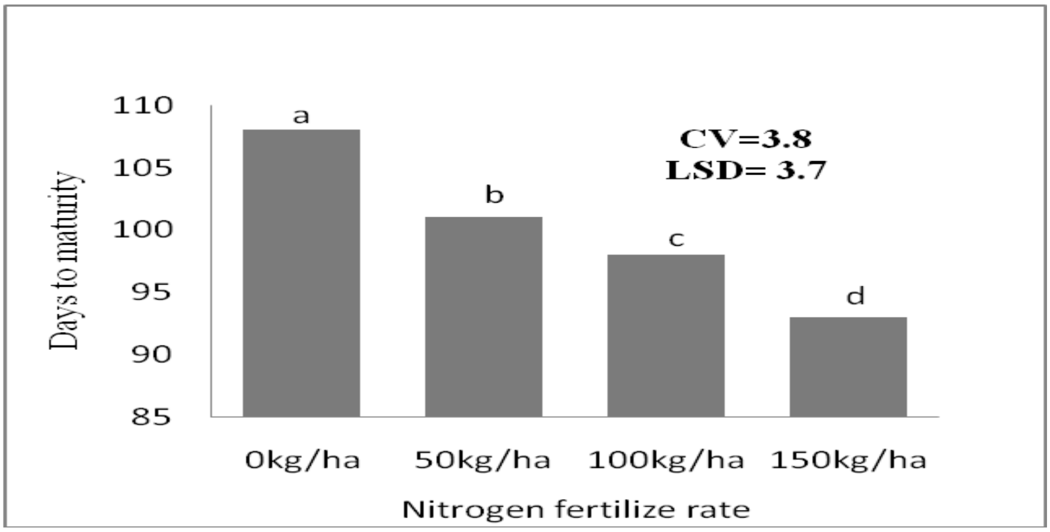

Figure 1. Effect of Nitrogen fertilizer on days to maturity.

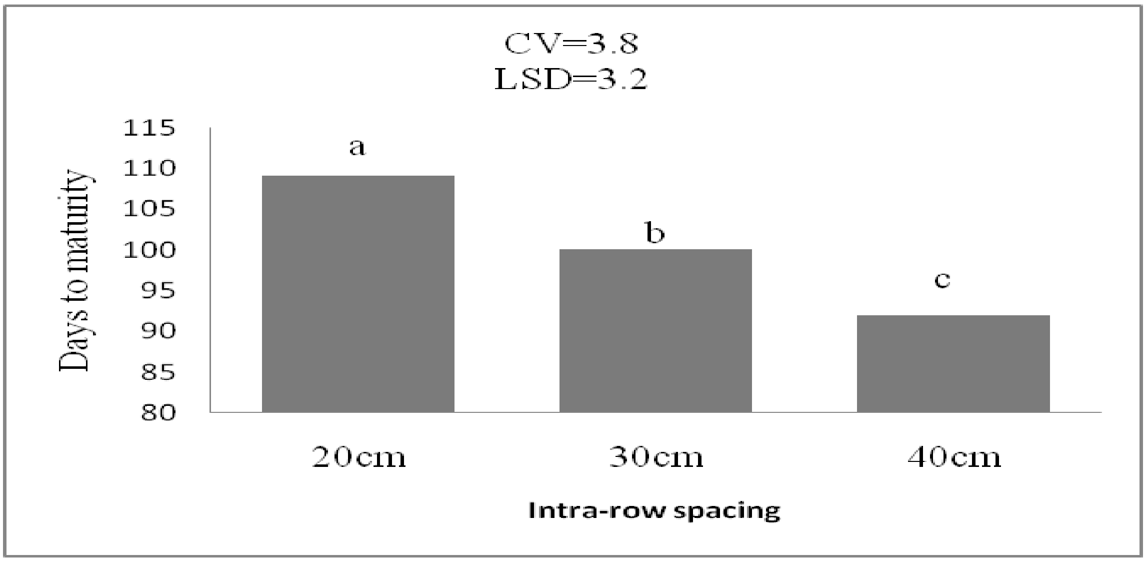

Figure 2. Effect of intra-row spacing on days to maturity.

4.1.2. Plant spread

Plant spread was very highly significantly (*P<0.001*) affected by nitrogen fertilizer rate and significantly (*P<0.05*) affected by intra row spacing. Interaction between nitrogen fertilizer level and intra row spacing was not significant (Appendix Table 1).

Increasing fertilizer rate from zero to 150 kg/ha increased plants spread from 42.5 cm to 51.8 cm. The widest plant spread (51.8 cm) was obtained at higher nitrogen fertilizer rate of 150 kg/ha, however it was not significantly different from plant spread (48.23 cm) recorded at 100 kg/ha. The narrowest plant spread (42.49 cm) was observed from plants grown without nitrogen fertilizer (Table 3). Widest plant spread at higher nitrogen rate, is due to higher nitrogen levels favor the growth of plants leading to larger leaf area that cover the wider space.

The widest plant spread (49.6 cm) was obtained at the wider intra row spacing of 40 cm. But it is not statistically different from 30 cm intra row spacing. The narrowest plant spread (44.9 cm) was recorded at the closer intra row spacing (20 cm) which is also statistically not different from 30 cm intra row spacing (Table 3). Increased intra row spacing from 20 cm to 40 cm increased plant spread by 11%. The wider plant spread at wider intra row spacing is due to the positive effect of wider intra row spacing, where there is minimum competition for resources between plants compared to the closer intra row spacing, in that the photosynthetic efficiency of plants increased and the plants utilize the sufficiently available resources. The result is in-line with the work of Purushottoma (2001) who reported that closer spacing in cabbage is not enough for the proper plant spread of as compare to wider spacing. The present result also agreed with the work of Sarker *et al*. (2002) who observed wider plant spread at wider spacing than narrower spacing. This Investigation was also in conformity with the finding of Mochiah (2011) who reported that closer intra row spacing (30 cm) resulted in poor vegetative growth such as plant spread compared to the wider intra row spacing (50 cm).

Table 3. Effect of nitrogen fertilizer rate and intra row spacing on maturity, plant spread, leaf number, leaf area, head height and head diameter

Treatments	PS (cm)	OLN	OLA (cm^2)	HH (cm)	HD (cm)
A. Nitrogen fertilizer rate (kg/ha)					
0	42.49^{a}	10.18^{a}	217.78^{a}	12.9^{a}	11.13^{a}
50	46.26^{b}	12.54^{b}	292.44^{b}	14.21^{b}	12.68^{b}
100	48.23^{bc}	13.17^{b}	393.78^{c}	15.20^{b}	14.42^{c}
150	51.86^{c}	13.69^{b}	463.33^{d}	16.67^{c}	16.61^{d}
LSD (5%)	3.8	1.42	35.11	1.04	1.12
C.V%	7.7	11.7	10.7	7.2	8.4
B. Intra row spacing(cm)					
20	44.96^{a}	11.4^{a}	269.92^{a}	13.5^{a}	12.36^{a}
30	47.08^{ab}	12.02^{a}	337.25^{b}	14.9^{b}	13.71^{b}
40	49.61^{b}	13.80^{b}	418.33^{c}	15.7^{b}	15.06^{c}
LSD (5%)	3.1	1.22	30.41	0.9	0.97
C.V%	7.7	11.7	10.0	7.20	8.40

Means followed by different letters per column differ significantly ($P < 0.05$) as established by LSD test.

DMt= days to maturity, PS=plant spread, OLN=leaf number, OLA=leaf area, HH=head height, HD=head diameter

4.1.3. Outer leaf number

Outer leaf number was very highly significantly ($P<0.001$) affected by nitrogen fertilizer rate and intra-row spacing, however, their interaction effect was not significant (Appendix Table 1). Increasing fertilizer from 0 to 150 kg/ha increased leaf area by 30%. The highest leaf number (13.7) was recorded at 150 kg/ha of nitrogen fertilizer rate but not significantly different from 50 and 100 kg/ha. The lowest leaf number (10.2) was recorded with no nitrogen fertilizer. Semuli (2005) reported that the leaf count has the tendency to increase in response to increasing nitrogen application. The current finding is in-line with the finding of Ghanti *et al*. (1982) who reported that nitrogen devours more vegetative growth with more number of leaves and larger leaf area. Mariyam (2007) also reported similar result that the leaf number of lettuce was affected by nitrogen fertilizer rate and the highest leaf number was recorded at higher rate of fertilizer.

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). However the latter was not statistically different from 30 cm intra row spacing (Table 3). Increasing intra row spacing of cabbage from 20 cm to 40 cm increased leaf number by 21%. Sarker *et al*. (2002) also indicated significant increase in leaf number per plant of cabbage with the increase of spacing from 60x45cm to 60x60 cm.

4.1.4. Outer leaf area

The outer leaf area was very highly significantly (*$p<0.001$*) affected by both nitrogen fertilizer level and intra row spacing, their interaction, however, was not significant (Appendix Table 1). Increasing nitrogen fertilizer rate increased leaf area of cabbage. The largest outer leaf area (463.3 cm^2) was recorded at higher nitrogen fertilizer rate (150 kg/ha) whereas the smallest (217.8 cm^2) was recorded at no nitrogen fertilizer treatment (Table 3). The highest leaf area of cabbage at higher fertilizer rate was probably due to the characteristics of nitrogen fertilizer that promote vegetative growth. This result is similar with the finding of Semuli (2005) who reported that leaf area increased in linear fashion with increasing nitrogen application for the whole growing period. The current finding also agrees with the findings of Mariyams (2007) who reported that the highest leaf area of lettuce was recorded at higher rate of nitrogen fertilizer. Kipkosgei *et al*. (2003) also reported improvement in vegetative growth as a result of increasing nitrogen fertilizer.

The largest outer leaf area (418.3 cm^2) was recorded at wider intra row spacing of 40 cm while the smallest (270 cm^2) was at closer intra row spacing of 20cm (Table 3). The larger outer leaf area at wider spacing was probably due to the presence of minimum competition, plants absorbed the sufficiently available resources and more light increased their photosynthetic efficiency that further increased the vegetative growth and ultimately resulted in increased leaf area at the wider intra row spacing. Aquino *et al*. (2004) also indicated that reduction of spacing resulted in a decrease of mass of fresh average head, leaf area, of the external and crop maturity.

4.1.5. Head height

Head height was very highly significantly (*P<0.001*) affected by both nitrogen fertilizer level and intra row spacing. However, the interaction of both factors was not significant. The highest head height (16.7 cm) was recorded at highest (150 kg/ha) nitrogen fertilizer level while the lowest (12.9 cm) was recorded at zero nitrogen fertilizer level (Table 3).Therefore increasing nitrogen from zero to 150 kg/ha increase head height by 33%. The higher head height at higher nitrogen level was probably due to the characteristics of nitrogen that favored vegetative growth of plants. This result confirmed the result of Semuli (2005) who reported that for trimmed head, nitrogen at 150 kg/ha recorded higher head height than 100 kg/ha and 50 kg/ha.

The highest (15.7cm) head height was recorded at widest intra row spacing (40 cm) which was not significantly different from 30 cm intra row spacing. But the smallest head height (13.5 cm) was recorded at narrower (20 cm) intra row spacing (Table 3). This shows that increasing intra row spacing increase head height. The increased plant height at wider spacing is relatively more available nitrogen and other plant nutrients per plant than close spacing. Mujeeb *et al*. (2007) indicated that lower plant height was recorded at close spacing in cauliflower. This finding was also compatible with the result of Semuli (2005) who reported that higher head height was recorded at 50 cm spacing than 30 cm spacing.

4.1.6. Head Diameter

Head diameter was very highly significantly (*P<0.001*) affected by both nitrogen fertilizer rate and intra row spacing. However, interaction of both factors was not significant.

The largest (16.6 cm) head diameter was recorded at highest (150 kg/ha) nitrogen fertilizer rate whereas the smallest (11.1cm) head diameter was observed at no nitrogen fertilizer treatment. This shows that increasing fertilizer rate from zero to 150 kg/ha increased head diameter by 50%. This is because of that the nitrogen favors more leaf number and leaf area which form the diameter. The higher number of leaves and larger leaf area form bigger diameter of cabbage. Semuli (2005) also indicated that higher head diameter (17.6 cm) was recorded at the higher nitrogen rate than lower nitrogen rate of which head diameter was 16.1 cm. He also stated that increase in diameter was attributed to the fact that nitrogen favored more vegetative growth with more number of leaves and larger leaf area.

Khan (2002) also indicated that maximum head diameter in cabbage was observed with maximum fertilizer input. The highest head diameter (15 cm) was recorded at wider (40 cm) intra row spacing, while the smallest (12.4 cm) head diameter was recorded at narrower (20 cm) intra row spacing (Table 3). This is because of the availability of more nutrients, light, and moisture to the plants. Sarker *et al*. (2002) also reported that head diameter is significantly affected by spacing and that wider spacing has larger head diameter. The finding of Dragan (2007) also showed that head diameter generally increased with increasing plant spacing.

4.2. Yield Parameters

4.2.1. Whole plant fresh weight

Whole Plant fresh weight was very highly significantly ($P<0.001$) affected by nitrogen fertilizer rate and intra row spacing however, the interaction of both factors was not significant (Appendix Table 2).

The highest whole plant fresh weight (2.5 kg) was recorded at the highest nitrogen fertilizer level (150 kg/ha) even though it is not statistically different from 100 kg/ha of fertilizer level. The lowest plant fresh weight (1.3 kg/plant) was recorded at zero fertilizer level (Table 4). This shows increasing fertilizer level increased biomass of cabbage. The current finding is 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 plant fresh weight (2.2 kg/plant) was recorded at wider intra row spacing (40cm) which is not statistically different from 30cm intra row spacing. But the lowest (1.8 kg/plant) plant fresh weight was recorded at narrower intra row spacing (20 cm) (Table 4). This result agrees with the finding of Staflella and Fleming (1990) who confirm linear increase of total plant weight with increase in within row spacing.

Table 4. Effect of nitrogen fertilizer rate and intra row spacing on whole plant fresh weight, total yield, marketable head yield, and marketable and unmarketable yield

Treatments	WPFH (kg)	HW (kg)	TY (ton)	MY (ton)	UY (ton)	DM (%)	HI	NAH (%)
A. Nitrogen fertilizer rate(kg/ha)								
0	1.30^{a}	0.56^{a}	38.3^{a}	33.78^{a}	4.78^{a}	8.7a	0.72a	0.11a
50	1.9^{b}	0.97^{b}	65^{b}	60.22^{b}	4.5^{a}	8.6a	0.77b	0.14b
100	2.40^{c}	1.0^{c}	74^{c}	71.33^{bc}	2.67^{b}	8.3b	0.79c	0.19c
150	2.47^{c}	1.2^{d}	80^{d}	78.2^{c}	2.05^{b}	7.9b	0.8c	0.22d
LSD (5%)	0.28	0.07	5.3	4.9	1.21	0.13	0.015	0.01
CV%	13.9	8	8.3	8.3	19	1.5	2	8.3
Intra row spacing(cm)								
20	1.78^{a}	0.7^{a}	69^{a}	ns	5.8^{a}	ns	0.75a	0.15a
30	2.^{b}	0.95^{b}	63^{b}	ns	3.5^{b}	ns	0.77b	0.16b
40	2.23^{b}	1.22^{c}	60^{b}	ns	1.2^{c}	ns	0.79c	0.18c
LSD (5%)	0.24	0.07	4.6	-	1	-	0.013	0.01
C.V%	13.9	8	8.3	-	19		2	8.3

Means followed by different letters per column differ significantly (*P < 0.05*) as established by LSD test.

WPFW= whole plant fresh weight, HW= head weight, TY= total yield, UMY= unmarketable yield, MY = marketable yield, DM= dry matter, HI= harvesting index, NAH= nitrogen after harvest.

4.2.2. Head weight

Cabbage head weight was very highly significantly (*P<0.001*) affected by the interaction between nitrogen fertilizer and intra row spacing (Appendix Table 2). The highest head weight (1.5 kg/plant) was obtained at the combination of higher nitrogen fertilizer rate of 150 kg/ha and wider intra row spacing of 40 cm (Fig. 3), but statistically it was not different from the combination of 100 kg/ha nitrogen fertilizer with 40cm intra row spacing. The lowest head weight (0.45 kg/plant) was found at the combination of no nitrogen fertilizer and narrower spacing (20 cm), which was statistically similar with zero nitrogen fertilizer level and a spacing of 30 cm.

The current result agrees with the finding of Purushottam (2001) who confirmed that plant spacing and significant influence on head weight. The formation of bigger heads at wider spacing was because of availability of more nutrients, light and moisture to the plants.

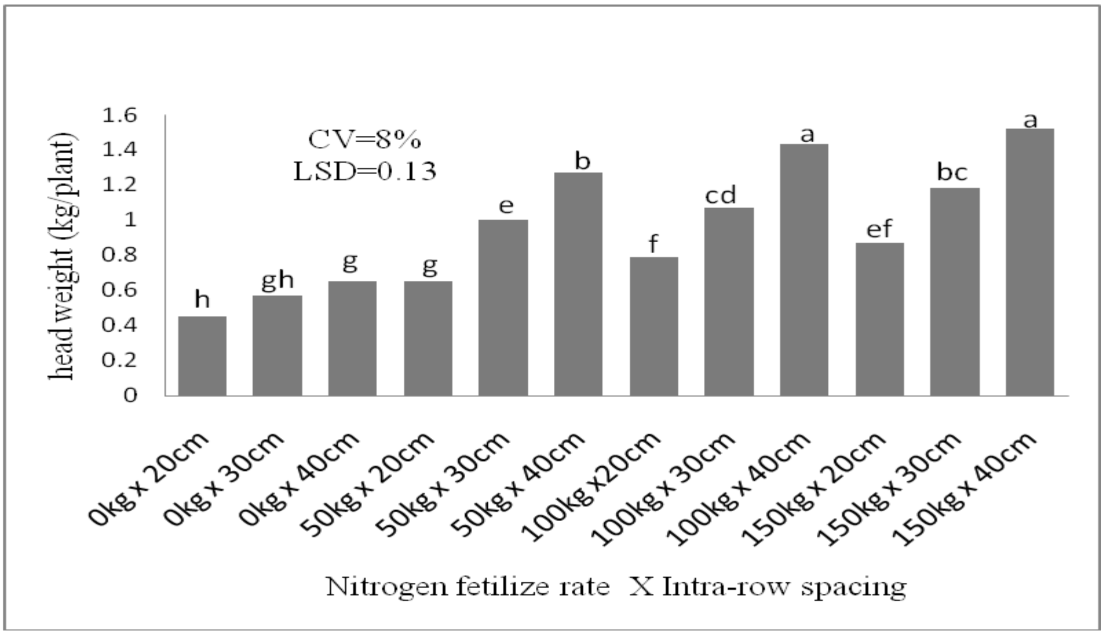

Figure 3. Effect of interaction between nitrogen fertilizer rate and intra row plant spacing on head weight of cabbage.

4.2.3. Total cabbage yield (t/ha)

Total cabbage yield was very highly significantly (*P<0.001*) affected by nitrogen fertilizer levels and intra row spacing, however, the interaction of intra row spacing and nitrogen fertilizer was not significant (Appendix Table 2).

The highest gross cabbage yield (80 t/ha) was recorded at highest nitrogen fertilizer rate (150 kg/ha) where as the lowest yield of cabbage head (38.3 t/ha) was recorded at zero nitrogen fertilizer level (Table 4). Increasing nitrogen fertilizer from zero to 150 kg/ha would increase cabbage head gross yield by 110%. The maximum yield from 150 kg/ha nitrogen was attributed mainly to increase in head mass. This result is compatible with the finding of Parmar *et al.* (1999) who reported significant increases in cabbage head yield at higher nitrogen level. Semuli (2005) also stated that, higher total cabbage yield (79.3 t/ha) was recorded at 150 kg/ha than 50 kg/ha of nitrogen.

Regarding intra row spacing the highest gross cabbage yield (69 t/ha) was recorded at the narrowest intra row spacing of 20 cm .The lowest cabbage yield (60 t/ha) was recorded at wider intra row spacing (40 cm) but statistically not different from 30 cm intra-row spacing (Table 4). It was observed that even though the larger and heavier individual cabbage heads were obtained at wider spacing (40 cm), the maximum yield per unit area was obtained at narrower spacing (20 cm). The higher gross yield per hectare at closer spacing was possible due to more number of plants per unit area. Dragam *et al*. (2007) reported that although in cabbage higher plant density reduced head size and head weight a greater number of head per unit area increased total yield. Semuli (2005) indicated that as intra row spacing increased the total yield for both trimmed and untrimmed head decreased. Although in cabbage high plant density reduced head size and head weight a greater number of heads per unit area increased total yield. This may be due to more number of plants per unit area at closer spacing.

4.2.4. Marketable yield

Cabbage marketable yield was very highly significantly ($P<0.001$) affected by nitrogen fertilizer level. Intra-row spacing and interaction between nitrogen fertilizer level and intra row spacing did not affect marketable yield (Appendix Table 2).

The highest marketable yield (78.2 t/ha) was recorded at higher nitrogen fertilizer level (150 kg/ha) but not statistically different from 100 kg/ha. On the other hand the lowest head yield (33.8 t/ha) was obtained from cabbage grown without nitrogen fertilizer (Table

4). This shows that increasing nitrogen fertilizer from zero to 150 kg/ha increased marketable cabbage yield. The yield obtained from the current finding is high when compared to the national average of 7 t/ha. This is because the spacing, nitrogen fertilizer application and other agronomic practice my optimum in this current finding than the practical situation in country. Similar observation on cabbage marketable yield was reported by Ghannti *et al.* (1982) where yield character such as head diameter and gross mass of heads and number of marketable heads increase with increasing the level of nitrogen up to 200 kg/ha. This result agrees with the finding of Hill (1990) who confirm that the highest marketable yields 126.6 and 123.6 t/ha were produced at closer spacing with fertilizer rate of 200 and 300 kg/ha respectively.

4.2.5. Unmarketable yield

Unmarketable yield was significantly *(P<0.05)* affected by the interaction between intra row spacing and nitrogen fertilizer rate. Intra row spacing and nitrogen fertilizer rate also affected unmarketable yield (Appendix Table 2).

The lowest unmarketable yield (0.83 t/ha) or 1% was recorded with the interaction of higher nitrogen fertilizer level (150 kg/ha) and wider intra row spacing (40 cm) whereas the highest unmarketable yield (8 t/ha) or 17.7% was recorded with interaction of no fertilizer and narrow intra row spacing (20 cm) (Fig. 5). This could be due to the synergic effect of intra row spacing and nitrogen fertilizer level that at narrower intra row spacing and lower fertilizer level 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 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 yield. The other reasons for unmarketable yield were pests (Aphids), burst and rotten. The result agrees with the finding of Khatiwada (2001) who confirms that higher number of unmarketable plant is higher at 45x20 cm than 45x30 cm spacing. Singn (1996) also observed that with the decreasing in plant spacing from 60 to 30 cm, there was a significance reduction in number of marketable head (less than 0.5kg) per unit area. The reductions were associated with higher plant density in the closer spacing. Staflella and

Fleming (1990) also indicated that low plant population has increased cabbage head size but reduced marketable yield per hectare.

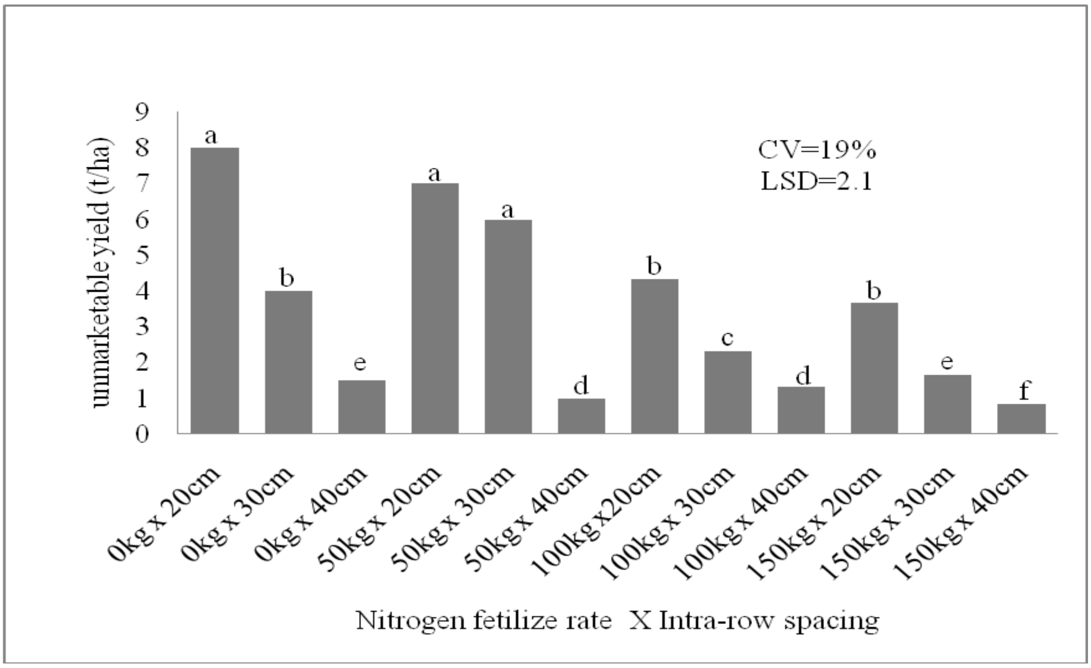

Figure 4. Effect of interaction between fertilizer rate and plant spacing on unmarketable yield of cabbage.

4.2.6. Dry matter

Cabbage dry matter is very highly significantly (*P<0.005*) affected by nitrogen fertilizer levels. Main effect of intra row spacing and interaction of nitrogen fertilizer and intra row spacing did not affect dry matter (Appendix Table 3).

The highest dry matter percentage (8.7%) of cabbage plant was recorded at no nitrogen treatment even though it is not significantly different from 50 kg/ha. But lowest (7.79%) was recorded at highest nitrogen fertilizer level (150 kg/ha) (Table 4). This is probably due to associated with soften head tissue at higher nitrogen level. The current finding is also in line with the finding of Semuli (2005) who reported that the dry matter percentage decreased with increase in nitrogen rate. Everaarts and Moel (1998) also reported a decrease in cabbage dry matter percentage as nitrogen rate increased. Solo (1999) indicated that dry matter content of heads and leaves of cabbage at harvest were slightly lower when nitrogen rate was high.

4.2.7. Harvest index

Cabbage harvest index was very highly significantly ($P<0.001$) affected by nitrogen fertilizer rate and intra row spacing. The interaction of nitrogen fertilizer level and intra row spacing did not affect harvest index (Appendix Table 3).

The highest harvest index (0.8) was recorded at higher nitrogen fertilizer rate (150 kg/ha) which was not statistically different from 100 kg/ha nitrogen fertilizer rate. The lowest harvest index (0.7) was recorded at no fertilizer treatment. 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. This shows that harvest index increased with increase in nitrogen fertilizer. Sarke *et al*. (2002) also reported that higher harvest index was obtained from the higher rate of fertilizer.

The highest harvest index (0.7) was recorded at wider intra-row spacing followed (0.8) by 30 cm intra row spacing. This is probably due to that at wider intra row spacing the cabbage crop can get enough nutrient that make it higher head and other biomass.

4.3. Nitrogen after Harvest

The amount of nitrogen left in the soil after harvest was very highly significantly ($P<0.001$) affected by main effects nitrogen fertilizer level and intra row spacing. Combined effect of nitrogen fertilizer level and intra row spacing did not affect the level of nitrogen after harvest (Appendix Table 3).

The highest amount of nitrogen (0.22%) left in the soil was recorded at higher nitrogen fertilizer level (150 kg/ha) whereas the lowest (0.11%) was recorded at lower or zero level of nitrogen fertilizer (Table 4). Increasing nitrogen rate from 0 to 150 kg/ha increased soil total nitrogen by 100%. The nitrogen left in the soil at no nitrogen fertilizer rate and 50 kg/ha were decrease when compared with pre-planting nitrogen (0.19%) but increases in the case of 100 and 150 kg/ha of nitrogen rate. Increasing nitrogen level probably has increased post harvest total soil nitrogen. The current finding agrees with the report of Frezgi (2007) that increasing nitrogen level increased post harvest soil total nitrogen. Solo (1999) also reported that nitrogen after harvest tends to increase with increasing amount of fertilizer applied.

The highest amount of nitrogen left after harvest (0.18%) was recorded at wider spacing (40cm). The lowest nitrogen (0.15%) left was recorded at narrower intra row spacing (20cm) (Table 4). The nitrogen left in the soil decrease in all intra rows spacing when compared with the pre plant nitrogen (0.18%) in the soil. Frezgi (2007) reported that increasing intra row spacing from 60 cm to 75 cm increased soil total nitrogen left after harvest by 20%. The decrease of soil total nitrogen at higher plant density was probably due to the increased plant population that resulted in higher removable of nitrogen from the soil by the plants.

4. 4. Correlation Analysis among Growth and Yield components

The correlation study indicate that head weight was very highly and positively correlated with outer leaf area (r=0.89), head height (r=0.7) and head diameter (r=0.8). Similarly marketable yield was very highly and positively correlated with outer leaf area (r=0.71), head height (r=0.53) and head diameter (r=0.67) (Table 6). This indicates that the head weight and marketable yield per hectare of cabbage was increased due to increasing leaf area, head height and diameter. On the other hand unmarketable yield was very highly significant ($P<0.001$) and negatively correlated with outer leaf area (r=-0.68), head height (r=-0.6), head diameter(r=-0.6), whole plant fresh weight (r=-0.53), head weight (r= (0.63), marketable yield.

This correlation indicates that cabbage production highly influenced by the growth parameters. So by optimizing nitrogen fertilizer and spacing we can regulate growth parameters which are important for head formation of cabbage.

Table 5. Correlation coefficient among growth, yield and quality parameters in cabbage

	OLA	HH	HD	WPFW	HW	MY	UMY	HI
OLA	1	0.74***	0.87***	0.8***	0.89***	0.71***	-0.68***	0.83***
Hh		1	0.76***	0.68***	0.7***	0.53***	-0.6***	0.78***
Hd			1	0.74***	0.8***	0.67***	-0.61***	0.81***
WPFW				1	0.83***	0.79***	-0.53***	0.8***
HW					1	0.67***	-0.63***	0.63***
MHW						0.78***	-0.67***	0.83***
MY						1	-0.23^{ns}	0.7***
UMY							1	-0.58***
HI								1
NAH								

***= very highly significance ns= non significance

OLA= outer leaf area, HH= head height, HD= head diameter, WPFW= whole plant fresh weight, HW= head weight, TY= total yield, UMY= unmarketable yield, MY = marketable yield, DM= dry matter, HI= harvesting index.

4.5. Cost Benefit Analysis

The economic analysis revealed that highest net returns of Birr 230,530.00 per hectare was recorded in the treatment that received 150 kg/ha nitrogen fertilizer with 20 cm intra-row spacing. However, the lowest net return (Birr 87,530.00 per hectare) was received with no fertilizer and 20 cm spacing (Appendix Table 5). The same treatments which recorded highest net return also recorded highest benefit: cost ratio of seven.

High net return from higher nitrogen fertilizer rate with narrow intra row spacing was due to high yield and the low net return was due to low yield. From the economic point of view, it was apparent from the above results that 150 kg/ha nitrogen fertilizer with 20 cm intra row spacing was more profitable than the rest of treatment combinations.

Table 6. Benefit and cost of cabbage as influenced by nitrogen fertilizer rate and intra row spacing.

Treatments combinations	Marketable yield (t/ha)	Yield loss (10%) (t/ha)	Adjusted Yield (t/ha)	Gross return (Birr/t)	Cost (Birr/t	Net return (Birr/t)	Benefit/cost (B:C)
0kg N x20cm	37	3.7	33.3	116550	29020	87530	3.0
50kg N x 20cm	58.6	5.86	52.74	184590	29120	155470	5.3
100kg N x 20cm	68.7	6.87	61.83	216405	30470	185935	6.1
150kg N x 20cm	83	8.3	74.7	261450	30920	230530	7.5
0kg N x 30cm	30	3	27	94500	29020	65480	2.3
50kg N x 30cm	65	6.5	58.5	204750	29120	175630	6.0
100kg N x 30cm	72	7.2	64.8	226800	30470	196330	6.4
150kg N x 30cm	78	7.8	70.2	245700	30920	214780	6.9
0kg N x 40cm	29.6	2.96	26.64	93240	29020	64220	2.2
50kg N x 40cm	66	5	61	213500	29120	184380	6.3
100kg N x 40cm	70	7	63	220500	30470	190030	6.2
150kg N x 40cm	75	7.5	67.5	236250	30920	205330	6.6

5. SUMMARY AND CONCLUSION

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 seed or plant population is arranged in the field of planting. This is due to the fact that the quantity of solar radiation, which penetrates a crop canopy greatly, depends on planting patterns or spacing and individual plant morphology**.**

Similar problems may occur in determining also nitrogen rate. It is apparent that supply of inorganic fertilizer inputs, basically nitrogen fertilizer is crucial for enhanced crop productivity and sustainable yield. However, the use of fertilizer for a particular area must be aligned with nutrient requirements of the target crop for optimum yield. Nitrogen response is directly linked to soil type, emphasizing that soils varying in fertility status react differentially to the applied fertilizers. Around Holeta, Central high land of Ethiopia has high potential for cabbage and the need of the farmers to produce it as cash crop and enhancing their income is increasing from time to time, but its productivity is low when compared with the world average. Various factors contribute for low productivity of cabbage including inappropriate agronomic practices (e.g. lack of optimum plant population per unit area, fertilizer rate etc.), pests and diseases. Especially the use of nitrogen fertilizer and spacing used by farmer here is a recommendation for other crops. Due to this the yield they obtain is very low.

Various workers indicated that agronomic practices such as plant population and rate of fertilizer per unit area are commonly determined by the crop variety and growing location. In the present research intra-row spacing and nitrogen fertilizer rate were taken up to determine their effect on yield and yield components of cabbage at Holeta condition.

The experiment was laid out in 3 x 4 factorial arrangement in randomized complete black design with three replications comprising three levels of intra-row spacing (20, 30 and 40 cm) and four levels of nitrogen fertilizer (0, 50, 100 and 150 kg/ha) using Copenhagen market cabbage variety.

The results of the experiment revealed that significant response of most yield and yield components to the main and interaction effects of intra row spacing and nitrogen application rate. The interaction effects of intra row spacing and nitrogen fertilizer rate affected head weight and unmarketable yield. The highest head weight and lowest unmarketable yield were recorded at highest nitrogen fertilizer levels and wider intra-row spacing.

Days to maturity showed highly significant variation in response to the main effect of intra-row spacing and nitrogen fertilizer rate. In the current study, days to maturity was prolonged from 93 to 108 days as nitrogen fertilizer rate decreased from 150 kg/ha to no fertilizer used. Similarly days to maturity was prolonged from 91 to 109 days as intra row spacing decreased from 40cm to 20 cm. Plant spread, head height and diameter, were also found to be affected significantly by the main effects. Wider plant spread (51.8cm), longer head height (16.7 cm) and wider head diameter (11.1cm) were recorded at higher nitrogen fertilizer rate (150 kg/ha). And also wider plant spread (49.6 cm), longer head height (15.7cm) and wider head diameter (15 cm) were recorded and wider (40 cm) intra row spacing.

Total fresh weight, marketable head weight and total yield were highly affected by intra row spacing and nitrogen fertilizer rate. Increased nitrogen fertilizer from 0 to 150 kg/ha increased the above parameters. Bigger total plant fresh weight (2.5 kg/plant), higher marketable yield (78.2 t/ha) and higher total yield (80 t/ha) were recorded at higher nitrogen fertilizer rate of 250 kg/ha. Similarly bigger total plant fresh weight (2.2 kg/plant) were recorded at wider intra row spacing (40 cm) where as higher total yield (69 t/ha) was recorded at narrower intra row spacing (20 cm). Cabbage dry mater percentage was also found to be affected significantly by the main effect of nitrogen fertilizer rate. Higher cabbage dry matter percentage (8.7%) was recorded at no nitrogen fertilizer rate levels. Hence, the percent of dry matter was lowest in cabbage from plants receiving highest nitrogen applications. Harvest index was also affected by nitrogen fertilizer rate and intra row spacing. Higher harvest index (0.8) was higher at higher nitrogen fertilizer level (150 kg/ha) and also higher harvest index (0.79) was recorded at wider intra row spacing. Similar to this effect, total nitrogen in post harvest soil was influenced by the main effects of inter-row spacing and nitrogen application. It increased with increased inter row spacing and nitrogen rate.

Correlation analysis also indicated that marketable yield was significantly and positively correlated with leaf area (r= 0.71***), head height (r=0.53***), head diameter (r=0.67***) plant fresh weight (r=0.79***) and head weight (r=0.67***). But unmarketable cabbage yield was very highly and negatively correlated with leaf area (r= -0.8***), head height (r=-0.6***), head diameter (r=-0.61***) plant fresh weight (r=-0.53***) and head weight (r=-0.3***). Hence, the result of correlation indicated that the yield of cabbage can be increased with increasing leaf area, head height and diameter, and head weight. On the contrary unmarketable yield can be reduced by improving leaf area, head height, head diameter, head weight and marketable yield.

Regarding profitability 20 cm intra-row spacing with 150 kg/ha nitrogen fertilizer was more profitable than other combinations followed by 30cm intra-row spacing and 150 kg/ha nitrogen fertilizer rate and 40 cm intra-row spacing with 150 kg/ha nitrogen fertilizer rates. Based on the present result, use of 150 kg/ha nitrogen and 20 cm intra-row spacing gave the highest marketable yield per hectare of cabbage when cultivated by irrigation on loam soil of total nitrogen 0.18% and pH 7.6. Therefore, farmers in Holeta area could be advised to use combination of 150 kg/ha nitrogen and 20 cm intra row spacing for profitable cabbage production.

Since the experiment was conducted at one location for only one season, further investigations may be suggested to be carried out at different seasons of the year, location, soil type and cabbage varieties so as to come up with precise and comprehensive recommendation.

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7. APPENDICES

Appendix Table 1. Mean squares of growth parameters of cabbage

		Mean square					
Source of variation	DF	DMt	PS	OLN	OLA	HH	HD
Block	2	8.5 ns	28.9 ns	1.1 ns	2625.5 ns	6*	1.6 ns
Nitrogen fertilizer	3	375***	137***	21.6***	105868.5***	22.7***	49.8***
Intra-row spacing	2	93.7***	65*	19*	66271.5***	13.7***	21.8***
Error	22	14.7	13.4	2.0	1290	1.1	1.3
SE±		3.8	3.7	1.4	35.9	1.0	1.1
CV (%)		3.8	7.7	11.7	10	7.2	8.4

*= significant, ** = highly significant, *** =very highly significant, ns = non significant, Df = degree of freedom, DMt= days to maturity, PS=plant spread, OLN=leaf number, OLA=leaf area, HH=head height, HD=head diameter

Appendix Table 2. Mean square of yield parameters cabbage

		Mean square								
Source of variation	DF	WPFW	HW	TY	MHY	MY	UMY	DM	HI	NAH
Block	2	0.07 ns	0.02*	91.8 ns	0.02*	98*	0.4 ns	0.02 ns	0.000003 ns	0.00007 ns
Nitrogen fertilizer levels	3	2.6***	0.7***	3078**	0.8***	3434**	16***	0.8***	0.01**	0.02**
Intra row spacing	2	0.65***	0.83***	213 ***	0.9***	54.5 ns	60***	0.04 ns	0.005***	0.004***
Spacing with fertilizer	6	0.06 ns	0.04 ***	24 ns	0.03**	23.4 ns	41**	0.04 ns	0.0005 ns	0.0002 ns
Error	22	0.08	0.006	28.9	0.005	25	1.5	0.21	0.0002	0.0002
SE±		0.29	0.08	5.4	0.07	5	1.2	0.13	0.02	0.01
C.V%		13.9	8.0	8.3	7.71	8.3	35.5	1.5	2	8.3

*= significant, ** = highly significant, *** = very highly significant ns = non significant, Df = degree of freedom, WPFW=whole head fresh weight, HW=head weight,TY=total yield, MHY= marketable head yield, MY= marketable yield, UMY=unmarketable yield DM= Dry matter, HI= Harvesting Index, NHA= Nitrogen after harvest.

Appendix Table 3. Laboratory soil nitrogen analysis

Treatments combinations	Percentage of nitrogen left in the soil after harvest
0kg N x 20cm	0.1
50kg N x 20cm	0.13
100kg N x 20cm	0.16
150kg N x 20cm	0.2
0kg N x 30cm	0.11
50kg N x 30cm	0.13
100kg N x 30cm	0.19
150kg N x 30cm	0.22
0kg N x 40cm	0.12
50kg N x 40cm	0.16
100kg N x 40cm	0.21
150kg N x 40cm	0.24

Appendix plat 4. Partial view of the experimental layout and site

Appendix plate 5. Diameter measurement of head cabbage using caliper.

Appendix Table 6. Weighing activity of head using sensitive balance