EFFECT OF INTER AND INTRA ROW SPACING ON SEED AND WARE TUBER YIELD OF POTATO (*Solanum tuberosum* L.) AT BAKO, WESTERN ETHIOPIA

MSc Thesis

Bikila Akassa Dibaba

December, 2012

Jimma University

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By

Bikila Akassa Dibaba

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APPROVAL SHEET

JIMMA UNVERSITY

SCHOOL OF GRADUATE STUDIES

As thesis research advisor, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Bikila Akassa entitled **"Effect of Inter and Intra row Spacing on Seed and Ware tuber Yield of Potato (*Solanum tuberosum* L.) at Bako Western Ethiopia"**. We recommend it be accepted as fulfilling the thesis requirements.

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Name of chairperson	Signature	Date
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Internal Examiner	Signature	Date

DEDICATION

This work is dedicated to my wife Lidiya Oljira my daughter Achisa Bikila, my son Nahum Bikila and Yemisirach Bikila, my mother Terefech Werke and my father Akassa Dibaba for their great sacrifice, ceaseless support and encouragement.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for writing it have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. Degree at Jimma University College of Agriculture and Veterinary Medicine and it is deposited at the University's Library to be made available to borrowers under the rules of the Library. I solemnly declare that this has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Name Bikila Akassa

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Date of submission 16/11/2012

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BIOGRAPHICAL SKETCH

Bikila Akassa was born on April 7, 1962 at Horoguduru Wollega zone, Western Oromia, Ethiopia, from his father Akassa Dibaba and mother Terefech Werke. He attended his primary school from 1972 to 1975 at Sute Dagar and his secondary and high school from 1976 to 1981 at Shambu. He joined Addis Ababa University, Debrezeit Agricultural College in 1982 and completed with Diploma in Plant Science (Crop Production and Protection) in 1983. Then he was employed in Institute of Agricultural Research (IAR), where he has been working at Bako Agricultural Research Center (BARC) in Horticulture research division. He joined Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) in 2004 and completed his undergraduate study with a B.Sc.degree in Horticulture in 2008. He rejoined JUCAVM in September 2010 to pursue his post-graduate study leading to MSc degree in Horticulture (Vegetable Science). He is working for in horticulture research team, Oromia Agricultural Research Institute (OARI) Bako Agricultural Research Center.

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ABBREVIATIONS AND ACRONYMS

BARC	Bako Agricultural Research Center
CIP	International Potato Center
CSSE	Crop Science Society of Ethiopia
EARO	Ethiopia Agricultural Research Organization
EIAR	Ethiopia Institute of Agricultural Research
FAOSTAT	Food and Agricultural Organization of the united nation statistics
HARC	Holleta Agricultural Research Center
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
MOARD	Ministry of Agricultural and Rural Development of Ethiopia
OARI	Oromia Agricultural Research institute

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EFFECT OF INTER AND INTRA ROW SPACING ON SEED AND WARE TUBER YIELD OF POTATO (*Solanum tuberosum* L.) AT BAKO, WESTERN ETHIOPIA

ABSTRACT

A study was conducted to determine the effect of inter and intra row spacing on seed and ware tuber yield of potato (Solanum tuberosum L.*) in 2011 at Bako. The objective was to identify best spacing for high seed and ware potato tuber yield. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications in 6x3 factorial arrangements. Six inter row (60, 65, 70, 75, 80 and 85cm), and three intra (20, 30 and 40cm) spacing were used. Some parameters were significantly influenced by the interaction of inter and intra row spacing. Delayed emergence (16 days) was recorded at 60x40cm and 70x30cm. At 85x40cm delayed maturity (91 days) was observed. The tallest (83cm) plants were recorded at 80x40cm; while the shortest (57cm) was obtained from 60x30cm. Highest total tuber yield (38.39t/ha) and marketable (37.02t/ha) were recorded at 65x20cm, whereas the lowest total tuber yield (20.81t/ha) and marketable (20.17t/ha) were obtained from 85x40cm. The highest unmarketable tuber yield (1.68t/ha) was recorded at 60x20cm; while the lowest (0.55t/ha) was observed at 70x40cm. Average tuber weight (933g/plant) was obtained at 85x40cm; while the lowest (408g) was at 75x20cm. Result of higher total tuber number (54,880/ha) at 60x20 cm and lower (22,940/ha) at 75x40cm was obtained. Similarly higher (38,400/ha) marketable tuber number at 65x20cm and lower number (16,350/ha) at 70x20cm was observed. Also average tuber number (19/plant) was obtained at 65x20cm.Maximum (82and 78) under sized in number at 65x20cm and 60x30cm,but lowest number (39) at 85x40cm was recorded. Higher small sized in number (86) at 60x20cm and 65x20cm and maximum small number (77) at 60x30cm and lowest number (26) at 75x30cm was resulted. Higher medium sized number (88) at 65x20cm, but the lowest (36) at 70x30cm was observed. More under sized tuber weight (530gm) per plot resulted at 60x20cm, lowest weight (177gm) was from 80x20cm.Maximum small sized tuber weight per plot (1.8kg) at 65x20cm and weight of (1.7kg) resulted at 80x40cm in addition weight of (1.62kg) at 60x20cm.But lower size tuber weights (293gm) at 75x20cm.Other parameters were not significantly influenced. Parameters positively correlated were, total tuber yield with plant canopy (r=0.3*), tuber number (=0.46**), tuber weight (r=0.37**). Marketable tuber yield and tuber number (r=46**) and weight (r=0.37**).Unmarketable yield with tuber number (r=0.42**) and total yield (r=0.42**).Total marketable number/hectare with tuber number (r=0.67**), tuber weight (r=0.5*), while total tuber number with tuber number (r=0.65*), weight (r=0.46**).Days to maturity with plant height (r=0.34*), tuber weight (r=0.34).From the experiment conducted interaction gave good result that benefit farmers, potato producers and users of the study area, that 65cm by 20cm for seed,80cm by 40cm for ware potato production. The result was a one year data, further study may consider for reliable conclusions.*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the family *Solanceae* or the night shade family and the genes *Solanum*. The major species grown worldwide is S*olanum tuberosum,* a tetraploid with chromosome number of 12 and with the genomic formula of 2n=4x= 48. Potato is an herbaceous annual that grows up to 100 cm tall and produces a tuber. It is unique and different from other crops because edible food materials are stored in underground parts and is called tuber. Potato is commonly propagated asexually through tubers and grows as erect or semi erect with stems as single or branched (FAO, 2008).

Potato was introduced to Ethiopia in 1858 by a German Botanist, Schimper (Pankhurst, 1964). For many years since its introduction, potato production was limited to homestead as a garden crop. A gradual rise in production occurred at the end of the 19^{th} century, when there was a long famine in Ethiopia. Since then potato became a very important garden crop in many parts of Ethiopia. In the mid-1970s, the total potato acreage was estimated to be 30000 ha with an average yield of about 5 t/ha (Gebremedhin *et al.*, 2008).

Potato as a major source of inexpensive energy and produces more food per unit of time than any other major crops. It is also an excellent source of complex carbohydrates, production of food energy and food value per unit area (Mulatu *et al.*, 2005; Asefa and Alemayu, 2011). Potato contains significant amounts of vitamin B and C and other minerals (potassium, phosphorous, iron, magnesium) and water (80%), dry matter (20%), carbohydrate (16%), protein (2%), lipids (1%), and ash (1%). Moreover, potato used in many industries such as French fries, chips, starch, and alcohol production (Gebremedhin *et al.,* 2008). Potato indeed could become an important food crop, as it can be planted in dry areas not suitable for other crops and a potential crop for producers. It is mainly produced on fertile soils but also grown on sandy soils both under irrigation and rainfed conditions (Sadowska *et al.,* 2004).

Potato produces more nutritious food more quickly than other major crops. Up to 85% of the plant is edible, compared to around 50% of cereals. The potato is gaining popularity with consumers, especially marketed in towns, driven by the growing demand for convenience food to which the potato lends itself so well (Agele *et al*., 1999).

In certain countries, notably the Netherlands, Denmark and USA considerable quantity of potato are used for the preparations of a large grained starch which is used by the textile industries, in manufacture of adhesives, in the preparation of modified starch products such as amyl pectin and for the preparation of glucose and dextrin. Potato flour is the oldest commercially processed product which is used for baking and pulped and fermented to produce alcohol (Miller *et al.,* 2006).

Potato pulp which is obtained as a byproduct in the manufacture of starch can be used to feed either livestock (including pig) in wet or dried pulp form(Adam ,2005). In addition to its clear importance for food and feed, the tubers also represent the starting material for the next generation of plants, which is called seed tuber (Stevenson *et al.,* 2001).

Potato is generally one of the most important food plants of the world and is cash crop of great importance (Hawakes, 1990). Potato is the world's number one non-grain food commodity with a production reaching a record of 325 million tons in 2007. The consumption is expanding strongly in developing countries which accounted for more than half of the global harvest and have valuable cash crop for millions of farmers (FAO, 2008).

It is a short duration crop that can yield as high as 30-35 tons of starch based produced per hectare in 90-120 days. A single medium sized potato contains about half the daily adult requirements of vitamin C, which other staples such as rice and wheat have none (FAO, 2008). Potato is very low in its fat content; just five percent of the fat content in wheat, and one fourth of the calories of the bread (Tsedeke, 2006). Boiled potato has more protein and nearly twice the calcium than maize. Its protein content is around 2.1% (on fresh weight basis) which is a fairly high quality as compared to other root and tuber crops, especially in amino acid pattern is reported to much human requirements (FAO, 2008).

The per capita consumption of potato varies from country to country and generally, daily consumption of potato tuber depends on age, eating habits, and daily activities of consumers (Lister and Munro, 2000). According to Gebremedhin *et al*. (2008) the capita calorie consumption of potato in Ethiopia in 2000-2002, for instance, was estimated at 9.0/day also evidence of the growing consumption of potato in the country.

According to FAO (2003), potato consumption in developing countries had increased from 9kg in 1961-1963 to 14kg in 1995-1997. These averages are still a fraction of per capita consumption levels of 86 and 63 kg/year in Europe and North America, respectively, suggesting the possibilities of future increment in per capita consumption (Otroshy, 2006).

The total area under potato production or cultivation in Ethiopia was about 51,000 hectares with an average productivity of 8 ton per hectare. Currently the total area under production reaches 69,784 hectare and the production estimated to be 5,723,325 quintals (CVR, 2009). The productivity of the crop in the country is low as compared to the world average of 17 ton per hectare and 11 ton in Africa (Jalleta, 1997; Adane *et al*., 2010).

Farmers in western parts of Ethiopia are using different spacing (below or above the national recommendation) depending on the purpose of planting either for consumption or seed tuber. Hence, it is important to maintain appropriate plant population per unit area to have high yield, quality, marketable size and good quality seed tuber of potato (Abdisa *et al.*, 2001). Even though different research was done in different parts of the country about potato plant density, the condition was not studied in the western area to determine the effect of inter and intra-row spacing on yield and yield components of potato variety Jalane. Girma (2001) and Abraham (2009) indicated production management problems, especially lack optimum plant population for maximum yield, better growth and quality.

Spacing used between ridges and plants for the production of ware and seed potato tuber was one of the most important among the constraints contributing to low yield of potato in western parts of the country especially at Bako area (Country report, 2003). The agro ecologies where farmers thrive to grow potato are characterized by diverse conditions, they vary considerably in soil type, fertility conditions, intensity and duration of rainfall (EARO, 2004). To ensure high yield, crop management operations have to take in to account the poor crop management practice observed in most farmer fields (CVR, 2009).

Understanding potato plants basic structure and growth patterns so as to make appropriate and timely management decision that result in maximum harvest yield and high quality tubers is most important (Jacson, 1985; Geremew *et al*., 2010). Such issues can be addressed by identifying appropriate spacing between plants and rows (Makara, 2003). Potato seed tubers are easily perishable and difficult to transport huge quantity from place to place (Hawkes, 1990). In Ethiopia there is no any institution that multiplies and distributes potato seed tubers to the farmers. Thus farmers are forced to use inferior size tubers from their own harvest or from other areas where farmers have access to irrigation. This practice has resulted in buildup of disease which caused low yield of potato (Tesfaye, 2008).

Plant spacing affects seed cost, plant development, yield and quality of the crop (Bussan *et al.*, 2007). In practice plant spacing in potato crop is manipulated through the number and size of tuber planted (Allen and Wurr, 1992). Many studies have been conducted to establish the optimal combination of seed size and planting distance for a certain environment (Barry *et al.*, 1990). The results indicated that increasing plant density increased total yield which on the other hand decreased the percentage of large potato tubers. The possibility of securing high yield depends much upon maintenance of optimum number of plants per unit area and their spatial arrangement in the field (Endale and Gebremedhin, 2001).

Farmers in the study area have no standardized management practices for seed and ware potato production system (CCE, 2006). They are using different spacing (below or above the recommended one). From potatoes produced for ware, they select mechanically damaged, defected, small sized and generally poor quality tuber seeds (CIMMYT, 1998). This indicates that there is a need to develop spacing recommendations for both ware and seed potato production (CCE, 2009). The major production problems of root and tuber crops in general and potato in particular in the western part are shortage of good quality seed tubers of improved cultivars, over sized tubers, lack of appropriate agronomic practices including plant density, crop rotation, absence of row planting (Berga *et al.*, 1994; Girma *et al*., 2006; Gebremedhin *et al*., 2008).

There are different potato varieties released by different Federal, regional and higher learning institutions that need further evaluation for their performance across different ecologies, soil and moisture level of the area in order to provide information for farmers (Alemu and Ermias, 2000 ; CVR, 2009). Jalane is one of the potential potato varieties for Bako area which has been released by Holleta Agricultural Research Center in 2002 (CVR, 2009). It is being used by small scale farmers and investors (OARI, 2002; Gebremedhin *et al.,* 2006). It has high tuber potential and is accepted by farmers and other end users. However, no research was done to determine effects of inter and intra row spacing on seed and ware potato production for this variety. The present research was therefore initiated to determine optimum plant population for maximum yield and good quality.

This study was conducted with the following objectives:

General objective:

To determine effects of inter and intra row spacing on seed and ware potato tuber

Specific Objectives:

To determine the best spacing combination for high tuber yield and appropriate seed tuber production.

2. LITERATURE REVIEW

2.1 World Potato Production

The world potato sector is undergoing major changes. Until the early 1990s, most potatoes were grown and consumed in Europe, North America and countries of the former Soviet Union. Since then there has been a dramatic increase in potato production and demand in Asia, Africa and Latin America, where output rose from less than 30 million tons in the early 1960s to more than 165 million tons in 2007. FAO data showed that in 2005, for the first time, the developing world's potato production exceeded that of the developed world (FAO, 2008).

Based on FAO statistics report of 2008, potato yield in the world was 325.3 million tons, that of developing countries was 165.4 million tons and developed countries 159.8 million tons. Similar to this, potato yield varies per continents: Asia 137,343,664 tons (15.7t/ha), Europe 130,223,960 tons (17.4t/ha), North America 25,343,305 tons (41.2t/ha) Africa 16,706,573 tons (10.8t/ha) and Latin America 15,682,943 tons (16.3t/ha). According to FAO (2008), the top five potato producing countries in the world are China 72,040,000 tons, India 26,780,000 tons, Russia federation 36,784,200 tons, Ukraine 19,102,300 tons and United state 20, 373,267 tons.

According to FAO (2008), China is the biggest potato producer, and almost a third of all potatoes are harvested in China and India. Potato is the only crop which can be planted in all regions of China. Based on the FAO statistics it was 4.9 million hectare and this was about 26.14 percent of the total globally planted area. The total production of potato in China was over 70 million tones and it accounts for 22.4 per cent of the global potato production. The Average yield of potato in China is 14.34 t/ha which was lower than the world's average yield 16.74 (17ton/ha).

The planted potato has been increasing during the past ten years because of the important role of potatoes in food security, poverty alleviation and higher economic returns compared to other crops.

Potato has become a major carbohydrate source in the diet of the people of developed countries. More importantly; hundreds of millions of people in the developing countries depend on potatoes for their survival, making a substitution contribution to meeting the needs for food. Consumption increased from average of 9kg/person to over 14kg/person now a day. The crop is fundamental in the diets of population in countries like South America, Africa, and Asia (Rahenie *et al*., 2005).

Boiled potato is popular form of utilization of potato in Ethiopia; it is now extensively used in the wide arrays of traditional stew (wet) preparations in both rural and urban areas. Potato is substituting pulse crops that are commonly used for these purposes. Potato consumption has expanded to include chips, crisps and mixture preparations with other vegetables which are becoming popular in urban areas in recent years (FAO, 2010).

Potato is one of the major food crops grown in the highland and mid altitude areas in western Ethiopia serving as the food and source of income for farmers during food shortage and when grains are depleted from stores; also reliable crop during short and erratic rainfall conditions (Girma *et al.,* 2004).

Accelerated and sustainable development of the potato sector is essential both to guarantee the food security of the world's growing population and as a source of added value to drive economic development in countries dependant on agriculture (Mandefro *et al.,* 2002). Potato is already making to development and food security in Africa, Asia and Latin America, where potatoes have become an important staple food and cash crop (FAO, 2008).

2.2 Potato Production in Africa

Potato arrived late in Africa, around the turn of the 20th century. In recent decades production has been in continual expansion, rising from two million tons in 1960 to 16.7 million tons in 2007. Potatoes are grown under a wide range of conditions, from irrigated commercial farms in Egypt and South Africa to intensively cultivated tropical high land zones of Eastern and Central Africa, where it is mainly a small farmers crop (FAO, 2008).

According to FAO (2008), in African the harvested area was 1, 541, 498, hactares, the quantity produced 16,706,573 tons and yield was 10.8 tons per hectare. The top producing countries in Africa in ton per hectare are Egypt 24.8, Malawi 11.9, South Africa 34.0, Morocco 24.2, Algeria 21.1, Rwanda 9.0, Nigeria 3.1, Kenya 6.7, Uganda 7.0, Angola 5.1 and Ethiopia 7.2.

2.3 Potato Production in Ethiopia

FAO (2008) stated that among African countries, Ethiopia has possibly the greatest potential for potato production. 70% of its arable land, mainly in high land areas (above 1500 m) is believed to be suitable for potato production. Since the highlands are also home to almost 90% of Ethiopia's population, potato could play a key role in ensuring national food security and as estimated the production has increased from 280,000 tons in 1993 to around 525,000 tons in 2007. Potato is widely grown in the highlands and mid altitude areas of the country, requiring sufficient moisture at early stages especially in the first 5-6 weeks. This crop needs sandy and fertile soil with good seed bed preparation (CVR, 2009).

In 1975, national potato research was started to develop and disseminate new production technologies. In a decade, the crop was grown more widely; a swift rise in acreage to 50000 ha was reported in the mid-1980s. Development of appropriate production technologies through research facilitated the expansion of potato production in the country. Since the inception of the national potato research, a large germplasm introduced and considerable efforts were made to improve traditional production practice. In the course of time potato became a very important non-cereal staple in Ethiopia (EARO, 2004; Mulatu *et al*., 2005). Ethiopia is endowed with suitable climatic and edaphic conditions for potato production that favors the potato farming system in to four seasons namely belg (short rain), Maher (long rain), residual crop and irrigation production. In many areas belg (January –June) crop supplied with irrigation constitutes the bulk potato production. This is due to favorable market during this season (Berga *et al.,* 1994; Bezabi and Mengistu, 2011).

However, the national average yield was estimated at 10.5 t/ha which was very low by any standard compared to the world average of 17 t/ha (CSA, 2008; FAO, 2008). One of the contributing factors to this low yield was inadequate application of proper agronomic management practices particularly plant density determination.

2.4 Potato Production in Western Ethiopia

Potato one of major food crops cultivated in the high lands and mid altitudes of western parts of Ethiopia serving as food and source of income to farmers, especially during the seasonal food shortages and/or when grains deplete from store. It is also a reliable crop during short and erratic rainfall conditions. Potato is a crop of growing importance in the region because of population increase at higher rates and its comparative advantage in terms of high yielding per unit area and within short period of time especially under highland agro-ecological conditions (Grima *et al*., 2006). The major potato producers in western parts are the highlands of Jeldu, Gedo, and Shambu and Arjo areas.

In western parts of Ethiopia, planting was started in March and May while harvesting in July to October. Potato intercropped with maize, linseed, rapeseed, faba bean, haricot bean, which is dependable on agro ecology (Gebremedhin *et al.,* 2008).

2.5 Cultural Requirements

The potato is considered a cool season vegetable crop, although it possesses only moderate frost tolerance. Best yields are typically obtained in climates where the average growing season temperature about 15-20 ^{0}C (Zamil *et a*l., 2010). The root system on the potato plant is not extensive and ample soil water is necessary either from rain or supplemental irrigation. Potato plants require a well drained soil so that the roots have adequate oxygen. The most attractive tuber shape and skin appearance are achieved with light, sandy soils or with muck soils (Tisdale *et al.*, 1995).

Seed tubers that are planted too deep will be slow to emerge and may be more subject to attack by various diseases (Tamiru, 2005). Very shallow planting of seed tubers may result in inadequate soil moisture around the seed piece and in production of tubers so close to the soil surface that greening caused by exposure to light is more of a problem. Planting should be deeper on lighter soils than on heavy ones (Thornton *et al*., 1996).

Many growers like to plant seed tubers relatively deep and then cover them with only a shallow layer of soil. More soil covering will then be added as the plant develops. A good rule of thumb is never to have more than 10cm of soil above the tip of the developing sprout (Ngungi, 1982).

Soils should be ridged up along the potato row to provide extra cover for the developing tubers. This tends to reduce the number of tubers that stick out of the soil and are exposed to light (Alexander *et al*., 2001). Even diffused light filtering down through the cracks in the soil will cause tubers to turn green and to develop a bitter flavor. Tubers that turn green in the field are called ‘sun burned’ and are unfit for consumption (Negi *et al.,* 1995). Secondary benefits of ridging up the soil are that it facilitates harvest and provides weed control (Allen *et al.,* 1992; Gebremedhin *et al*., 2008; Suman, 2010). The rate of nitrogen fertilization, a key consideration in managing fertility, because of excessive applications delays maturity and reduces the partitioning of dry matter to the fibers (Ewing, 1997).

2.6 Effect of Inter and Intra –Row Spacing on Yield and Yield Components

Plant density (inter and intra- row spacing) is very important aspect of potato production since it significantly affects number of tubers per plant and per stem, mean tuber weight, tuber yield and size grading (Haase *et al*., 2007). According to Khajehpour (2006), increase in plant density decreases mean tuber size probably because of plant nutrient reduction, increase in interspecies competition and large number of tubers produced by high number of stems.

Alvin *et al* (2007) also reported that plant density strongly affected yield, both by number and weight, and more tubers and yield per square meter were expected in higher plant densities. Burhan (2007) indicated that total yield increases with increasing plant density while percentage of large tubers decreased. However, the optimal planting density differs depending on the environmental conditions and cultivars. Also Georgakis *et al.* (1997) reported that by increasing plant density, the tuber yield was increased. Similarly Karatyllidies *et al.* (1997) concluded that plant density strongly affected yield, both by number and by weight and more tubers and yield per square meter were expected in higher plant density.

Endale and Gebremedhin (2001) stated that the benefit from optimum combination of plant population and spacial arrangement to optimize tuber size and in turn, making appropriate spacing of the seed tubers is an essential factor to enhance productivity.

Competition occurs when two or more plants are growing in an environment and the combined demands of the plants exceed the supply of one or more of the limiting factors for the growth and development (Winch, 2006). In extreme case of a crop growing in the absence of competition, its individual yield gives an indication of maximum yield possible per plant. Tubers on the same plant compete each other for assimilate (Panda, 2010). Berga and Caesar (1990) reported that stem number per plant and tuber number per plant are positively related, however average tuber weight increased with wider spacing. Optimizing of plant density therefore is one of the most important agronomic practices of potato production and management as it affects the seed cost, plant development, yield and quality of the crop (Bussan *et al*., 2007).

Burton (1989) reported that if the spacing is too close, the individual plant will suffer from the competition and crop may be impaired or weakened, but if it is too wide the yield per hectare may be reduced because of insufficient number of plants per hectare. Increasing plant population influences the stem height with increasing density and height. With this there is much decrease in the auxiliary branching which in turn decreases the photosynthetic potential and associated yield. Berga *et al*. (1994) reported that with wider spacing the average tuber weight increase where as in a closer spacing total tuber number increases.

A study at Haramaya, evaluated the effect of three row width (60,70,80cm) in combination with in four in-row distance (10, 20, 30 and 40 cm) at three seed tuber size (25-35, 35-45, 45-55mm) using variety AL-624. The wider row width with wider in row distance (80x40cm) gave highest yield (34t/ha) whereas 60x20cm gave lowest yield (22.2t/ha). Taking into account the difference in field operation, a row width by in row distance of 75x30 to 40 was recommended for ware and 60x10 to20cm for seed production (Berga *et al.*, 1994).

In contrary, the number of tuber set by plants determined by plant population in relation to number of stem per unit area, spacing, variety and environment. The yield of seed potato can be maximized at higher plant population (closer spacing) or by regulating the number of stems per unit area and to certain extent by removing the haulm earlier darning the maturity (O'Brien and Allen 2009).

At Holetta in 1995 study was done on three varieties Awash, Tolcha and Menagasha with four row width (45,60,75,90 cm) and four in-row distance (20,25,30,35 cm) using a medium sized (35-45mm) tubers. In all varieties the highest total yield were obtained from in row distance of 20cm and row width of 75cm.Yield was consistently and significantly improved for in row spacing of 10, 20 and 30cm as row width increased from 45 to 75cm (Gebremedhin *et al*., 2008).

Similar studies conducted at Adet using inter row spacing (45, 60, 75cm) and the same intra row (30cm).From this research 60x30cm for seed and 75x30cm for ware potato production were recommended. Another study which used spacing combination of inter row 75, 80 and 90cm and intra row30,40 and 50cm on the other hand 75x30cm spacing was recommended for ware potato production (Tesfaye, 2008).

Finally, they indicated that greater number of tubers with size grades of 30-40mm and greater than 45-50mm diameter were obtained from 60 and 75cm inter-row spacing, respectively. In addition, wider spacing greater than 60cm inter- row distance was found to increase tuber size and dry matter yield per tuber. Therefore the use of 75cm as inter-row spacing was found to contribute to the production of suitable tuber size of greater than 50mm diameter. However, the use of 60cm inter-row spacing was found to be ideal for seed tuber potato production (Gebremedhin *et al*., 2008; Tesfaye, 2008).

According to Berga *et al.* (1994), further increase in both ways: inter and intra row spacing resulted in yield decline and the rate was higher with increasing row width and in-row distance at the same time.

Spacing for potato depends on the intended end use, if the deliberation for seed; narrow spacing is advisable to harvest good number of seeds with medium sized tubers. On the contrary if marketable or large size tubers needed a wider spacing is recommended (Girma *et al.*, 2004). But this has to be confirmed by conducting a designed study and generate up-to-date necessary information for farmers or users.

The optimum intra row spacing in potato production plays a great role on yield and yield components. Ahmed (1980) found that closer spacing (20cm) gave higher yields than wider spacing (30cm). Rahemi *et al. (*2005) also reported that intra row spacing was significant on potato yield and 20cm intra row spacing in comparison with 30cm spacing showed 13.9, 59.8 and 30.39% increase in yield. Intra row distance of 20cm increased total tuber number and weight, and tuber weight per plant.

According to EARO (2004) report, there is a little difference in yield between intra row spacing of 25 and 30cm for all varieties released so far in Ethiopia and the 30cm intra-row spacing accepted as standard. Besides to the above varying trends of optimum spacing, the plant population and arrangement of inter and intra row spacing vary considerably depending on agro-ecology, season, soil type, cropping system, variety and purpose of planting (Suman, 2010).

2.7 Yield Component

Yield development in potato known to be the result of physiological process leading to the formation of yield components (De La Morena *et al*., 1994). There are stem numbers per plant or per unit area, tuber numbers per plant or per unit area and average tuber weight**.**

The yield components in potato have been reported to develop sequentially (Adam, 2005). The sequential system of yield development of the potato involves interaction among individual yield components in which later developing components are formed to be dependent up on developing ones (De La Morena *et al*., 1994).

2.7.1 Number of main stem per plant

The potato plant commonly consists of varying stems, each stem forming roots, stolen and tuber behaving like an independent plant (Beets, 1982). It is usually propagated by using underground storage organs, known as tubers. Which show wide range of variation and posses a variable number of growing points (buds) arranged in groups (eyes) over their surface (Otroshy, 2006). According to Margaret *et al.* (2007), the plant has two kinds of stems, the above ground and one whose terminal portion swells to form the tubers as it accounts starch and sugars from photosynthesis in leaves (Babasheb, 2004).

The number of eyes per tuber was reported to be dependent on the size of tubers. Varietal difference was also reported to influence eye number per tuber. Although variety, tuber size or other factors exert their influence the number of eyes on the tuber surface, there seems to be only one eye on a tuber that develops into stems and also differences exist between eye types (apical or lateral) in their yield potential (Rajadurai, 1994).

The increase in the number of main stems per hill lead to increase in the total and marketable yield since stem density influence both total production, as well as tuber size at harvest (Prasad and Kumer, 2008). Similar results were also reported by Burhan (2007) where total yield and marketable tuber yields expressed close relationship with number of main stem or above ground stems. The author indicated that high number of stem per plant to favor tuber production influencing the growth of haulm and the number of tuber per plant.

The number of stems per plant reported to be under the influence of variety, seed (tuber) size, physiological age of the seed, storage condition and the number viable sprout at planting, sprout damage at the time of planting and growing condition **(**De La Morena *et al*., 1994**)**. According to Leyla and Halis (2009) number of main stem per plant was not significantly affected by in-row spacing and number of main stems per unit area significantly decreased with wider in-row spacing.

2.7.2 Seed tuber production of potato

The usual means of propagation for seed and ware potato production throughout the world is by the vegetative seed tuber which may be planted whole as in most of Europe or after cutting in to pieces as in North America or parts of Spain (FAO, 1980). Seed tubers vary in their size and predominantly water (80%) and do not keep even at lower temperature from one crop year to other (Allen and Wurr, 1992).

According to Gebremedhin *et al.* (2008) intra row spacing of 10 and 20cm with between row spacing of 75cm were preferred for seed potato production. Further study was undertaken in 1995 and 1996 at Holetta on red soil to determine the optimum intra row and between row spacing. From the result, for seed production the highest total yields were obtained from the in row distance of 20cm and row width of 75cm.

The optimal plant density in one location not apply at other location, because of regional variation in weather and soil type mean that further trials are needed at each site to validate general recommendations (Lemma, 1992). The plant density helps to calculate crop productivity in relation to the availability of environmental resource expected during the growing season (Azam-Ali., 2002).

2.7.3 Tuber number

The number of tuber set by plants determined by plant population in relation to number of stem per unit area, spacing, variety and environment (Nempal *et al.*, 2006). The yield of seed potato can be maximized at higher plant population or by regulating the number of stems unit area and to certain extent by removing the haulm earlier during the maturity (Allen *et al*., 1992; Gobeze *et al*., 2004).

Tuber sets are number of tubers formed per plant and the plant initially produce small tubers but only 5 to 15 tubers typically reach maturity. The number of tubers that achieve maturity related to available moisture and nutrition (Havar, 1990). Optimum moisture and nutrient levels early in the growing season are critical to the maintenance and development of tubers (Rai, 2005). Number of tubers set per plant greater at lower temperature than higher temperatures, where as a higher temperature favors development of large tubers (Western Potato Council, 2003).

The number of tubers set per plant largely governs the total tuber yield as well as the size categories of potato tubers. Increasing the stem density by planting larger seed tubers resulted in increased tuber number per plant despite the reduction in the number of tubers per stem (Zamil *et al*., 2010). Wurr *et al.* (2001) reported stem density over a wide range either by planting larger seed tubers or more seed tuber for most varieties resulted in increasing number of tubers per unit area.

Total tuber number and the number of seed size tubers (smaller-tuber) increased with closer spacing. In contrast, the number of ware potatoes (large tubers) was greater with wider spacing as it can be seen from larger average tuber weight (Tamiru, 2005). Berga *et al.* (1994) reported that intra row spacing should depend on the intended use of the crop, closer intra row spacing of 10 or 20cm would be advantageous for seed and larger seed tubers from wider intra row spacing of 30 or 40cm are better for ware potatoes.

2.7.4 Average tuber weight

According to De La Morena *et al.* (1994) average tuber weight has been reported to be the most important yield component contributing to the total tuber yield. Tuber weight affected by variety and growth conditions. Environmental factors that favor cell division and cell expansion such as optimum water supply, mineral nutrition, etc reported to enhance tuber size (Reeve *et al*., 1973).

Variety with higher average tuber weight in addition to its late maturity might also be more efficient in dry matter partitioning to tubers than variety with lower average tuber weight (Saluzzo *et al.*, 1999). Berga and Caesar (1990) reported that stem number per plant and tuber number per plant positively related, but Ali (1997) reported that average tuber weight increased with wider spacing and increased in density probably causes the increase in competition between and within plants and leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight (Khan, 1993).

2.8 Yield

2.8.1 Total tuber yield

Factors limiting crop yield both in quantity as well as quality could be categorized into main headings: the management practices, the soil up on which the crop grows, the genetics make up of the crop and the climate conditions during the growth of the crop (Tisdale *et al.*, 1995).

The optimum growth condition could increase tuber yield and the tuber yield increase was almost linear during the tuber bulking phase of plant development. The highest stem density increases leaf area early in the season and hence light interception, this in turn improves early tuber growth, but it may be counter balanced by increase in leaf senescence that reduces photosynthesis and slow tuber growth (Ronald, 2005).

High plant population per hectare was reported to increase total tuber yield, which is due to more tuber produced at the greater plant population per hectare but tuber size and individual plant yield decreases (Khalefalla, 2001). The yield of tuber per plant increased significantly with increase in plant spacing but the yield of tuber per hectare did not follow the same trend (Sultana and Siddique, 1991).

2.8.2 Marketable tuber yield

The primary essential in potato production is its fitness to the targeted purpose, in commercial terms, its marketability obtain the maximum yield consistent with economy of production (Burton, 1989), hence marketability describes the proportion of tubers that are suitable for the end use. According to this report a balance must be retained by spacing whereby the proportion of tuber yields that suits the marketable at its maximum.

According to Khalefalla (2001), close spacing of 15-25cm was found to give better proportion of marketable yield than wider spacing of 35cm. Both plant spacing and seed size are reported to have considerable effects on the ratio of marketable tuber per plant, marketable tuber weight and number of stem per plant. In line with this, Kantona *et al*. (2003) observed a greater increase in marketable yield of onion as plant density increased. Plant density and plant arrangement have revealed pronounced influence in plant development, growth and the marketable yield of many vegetable crops (Bryan and Stoffella, 1988).

Obtaining high marketable yield is a key point to obtain high demand from the market for what is produce. For this, the best agronomic practices like plant density are among the factors for determining marketable yield and decreasing unmarketable yield production

(Geremew *et al.,* 2010). According to this report, the highest marketable yield of tomato (607.9q/ha) was obtained at closer spacing of 40x30cm, whereas the lowest marketable yield (475.85q/ha) was recorded from the widest spacing (100x30cm).

2.9 Quality Traits of Potato

2.9.1 Potato tuber size categories

Among the Ethiopian small holder farmers in all areas, it is common practice to save tubers for seed that are too small and inferior to be sold for consumption (Mulatu *et al*., 2005; Endale *et al.,* 2008). Small sized tubers delayed emergence and low sprout vigor and number, because of low food reserve (Palag, 1985). Also they might be a progeny of an infected mother plant as infected plants usually give small tubers (Strick and Wireseme, 1999). However, there are areas where many farmers use medium sized tubers for seed, for instance 72% of farmers in districts of Degem, 66% of farmers in Jeldu and 63% of farmers in Banja (Adane *et al.,* 2010).

Tuber size was reported to be an important aspect of potato production. The production of potato tuber of a requisite size may be of much economic value both for seed and human consumption (Mulubrhan, 2004). According to the author, the market demand for shapes and sizes of tuber varies, thus the size of tubers required by consumers depends upon the ease of handling for household purpose and also upon the accepted level of peeling loss.

Seed tuber size is generally influenced by the performance of the potato crop like emergence, seedling vigor, subsequent plant growth and final yield (Van Deldan, 2001). According to Bohi *et al.* (2000) larger seed tuber had given higher total yield than the smaller ones. When the number of tubers per stem was high, inter-tuber competition reduced the average tuber size. Also they indicated that varieties that set many tubers per stem require significantly lower stem densities for graded yield than for total yield.

Wider spacing may produce few tubers as it gave rise to few stems that could lead to high number and possibly misshapen tuber while, closer spacing improved quality and salable yield (Burton, 1989). Productivity per unit area is determined by the number of tubers produced per stem and the number of stems per hectare (Beukema and Vander Zaag, 1990). The number of stems per hectare influenced by the planting density and the number of sprouts that form each seed tuber.

2.9.2 Tuber specific gravity g/cm^3

Specific gravity of raw potatoes is widely accepted by the potato processing industry as a measure of total solids, starch content and other qualities (Story and Davies, 1992). High uniform specific gravity in potato tubers important to the grower and the processor because they affect the quality and yield of processed product. They also affect processing costs because the oil absorption rates during frying are related to dry matter levels (Hogy and Fangmeier, 2009).

Specific gravity (SG) is an expression of density, the most widely accepted measurement of potato quality. There is a very high correlation between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids (Tekalign and Hammes, 2005). Higher specific gravity contributes to higher recovery rate and better quality of the processed product (Storey and Davies, 1992). The specific gravity of potato tuber is determined by weighing the sample in air and then in water.

The specific gravity may vary over a wider range within one variety of potato due to other environmental and field management factors (Klalafalla, 2001). Yield increases were due to more tubers produced at the greater plant population per hectare. But tuber size and individual plant yield decreases. High yielding of potato were obtained from tubers of high specific gravity, but variety and season have its own effects that 1.05 low specific gravity and 1.10 was high specific gravity.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at Bako Agricultural Research Center (BARC) during 2011 main cropping season. The center is located in the western parts of Ethiopia at a distance of 260km away from Addis Ababa. It lies at latitude of $9^0$6’N and longitude $37^0$9’E and at an altitude of 1650 meters above sea level. Bako Agricultural Research Center has a humid climate with annual mean minimum and maximum temperature 13.5 and 26.9^0C, respectively. The area receives average annual rainfall of 1424 mm extending from May to November with the maximum precipitation in the months of June to August (OARI, 2002).

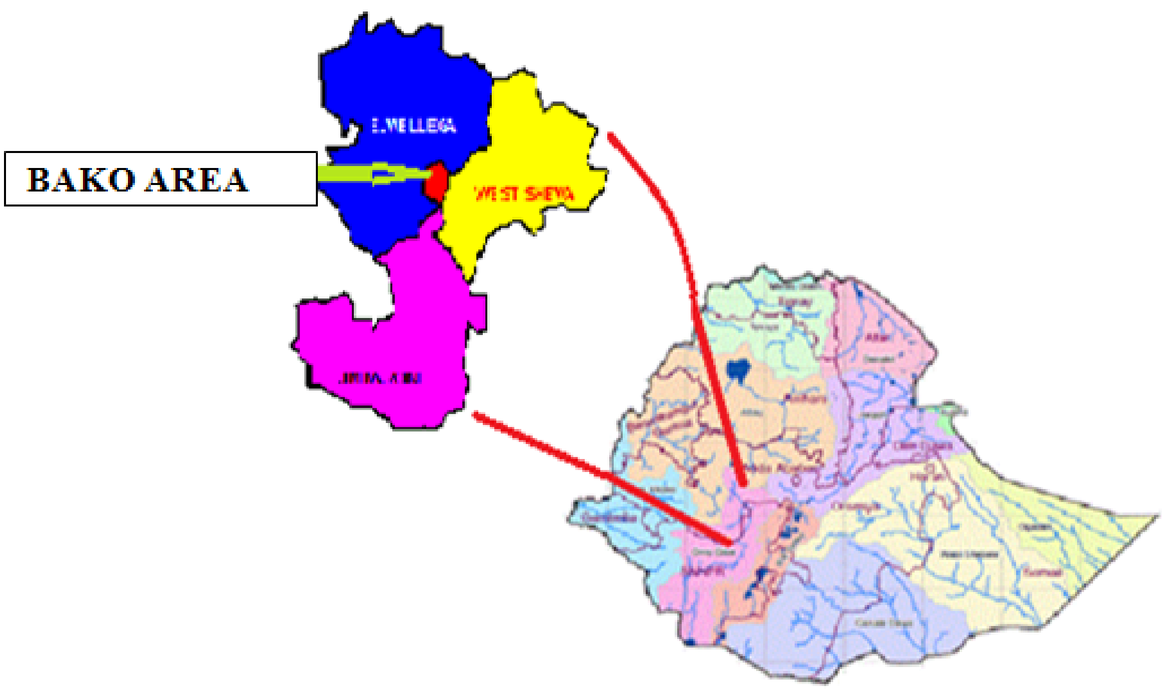

Fig.1. Map indicating experimental location

The soil of the area is characteristically reddish brown Nitosols, which is slightly acidic with a pH of 4.8. The cropping system around the study area dominated by diversified mixed farming system with high production of cereals (maize, teff, and sorghum), among horticultural crops vegetables (hot pepper, tomato, onion, potato, cabbage, garlic, and shallot) and fruits (mango, banana, avocado, and papaya) are the major crops growing in the study area (CCE, 2009). In Oromia Regional State, particularly in the western part of the region, potato is a dominant crop and plays an important role in generating cash income and as part of the daily diet of the people. There are also high demands and attractive prices for quality seed and ware potatoes (Asfaw *et al*., 1997; CSA, 2006).

Bako area is generally known in mixed crop and livestock farming system (OARI, 2002). Different local and improved potato varieties are growing in the area both under rain fed and irrigation. Among the improved potato varieties, Jalene is growing widely and has got acceptance by farmers due to its high yielding and resistance to disease and pest and acceptability by consumers.

Table1: Description of physicochemical characteristics of Bako soil

pH	Ec%	Silt%	Clay %	Ec	Base saturation	TN%	OC%	P/ppm	K Available
4.8	40	26	34	22.6	35	0.154	1.74	7.48	105

Source: Bako Agricultural Research Center (2009)

3.2 Experimental Materials and Treatments

There were 18 treatment combinations, consisting of six inter row spacing (60, 65, 70, 75, 80 and 85cm) and three intra row spacing (20, 30 and 40cm). In Ethiopia 75cm inter row and 30cm intra row was the recommended spacing for released potato varieties grown. Three levels down and two levels up were taken to determine the optimum inter row and intra row spacing.

The potato variety, Jalene (CIP37792-5) was released by Holleta Agricultural Research Center (HARC) in 2002 (MOARD, 2003). Currently it is one of the best varieties selected by the farmers in the study area. The planting material for the study was obtained from Bako Agricultural Research Center (Shambu seed multiplication sub site).

Table 2: Yield and other characteristics of *Jalene* variety used for the study

year of release	adapt altitude (masl)	adapt rainfall (mm)	days 50% flower	days to maturity	Plant Height (cm)	yield at research qt/ha	yield on farm	breeder
2002	1600-2800	750-1000	50	90-120	66	403.3	291.3	EIAR/ HARC

Source: CVR (2003)

3.3. Experimental Design

The experiment was laid out in 6 x 3 factorial arrangement using Randomized Complete Block Design (RCBD) with three replications. The length of each experimental plot was 3 meter and the width was 3.5 meter that was adjusted according to the inter row and intra row spacing's capacity. Each plot contain four or five rows with different plot size of (3x3m, 3 x2.8m, 3.25x2.8m, 3.25x3m,3.5x3m,3.5x2.8m, 3.2x3m, 3.2x2.8m, 3.4x3 and 3.4x2.8m) and different number of plants per row as 15, 10 and 8 with 20 m, 30cm, 40cm intra row spacing, respectively and only the middle rows were harvested. Spacing used for path was 0.5 and one meter between plots and blocks, respectively.

3.4 Experimental Procedures

Site selection and land preparation was done before planting. Medium sized and well sprouted tubers were planted on well prepared ridges on June 2011 at a different spacing as per the experimental design. The treatment received 165 kg per hectare UREA and 195 kg per hectare DAP (EARO, 2004). DAP was applied during planting and UREA was applied in split form during planting and after planting. Other management practices like weeding, hoeing, earthing up, were applied according to EARO (2004) recommendation.

3.5 Data Collected

To avoid the border effect, the pre- and post-harvest observations were recorded from harvestable rows only. Data (for all characters) were collected from ten randomly taken plants. However, days to emergence, flowering and days to maturity, was taken from the all harvestable plants with in a plot.

3.5.1 Growth response variables

A. Days to emergence: Number of days from planting up to the plant emergence was recorded at 50% of emergence.

B. Days to 50% flowering: The number of days from planting to 50% flowering of plant populations in each plot.

C. Days to maturity: Number of days from planting to the date at which more than 50% of senescence of haulms was expressed as the days to maturity.

D. Plant height (cm): The height of ten sample plants per plot was measured at maximum growth stage, from the base of the stem to shoot apex in centimeters.

E. Plant canopy (cm): Average width of ten individual plants canopy measured twice, east – west and north south from the broadest portion of the canopy.

F. Number of main stems per plant: Number of main stem was recorded when the plants attained full flowering and stem branching at the ground level of ten plants per plot.

3.5.2 Yield response variables

A. Tuber yield per plant (g): Mean fresh tuber yield (g/plant) was taken from ten plants per plot.

B. Marketable yield (ton/ha): produced from middle row healthy tubers greater than 20 millimeter diameter and weighed in kg/plot and converted to t/ha.

C. Unmarketable tuber (ton/ha): rotted, cracked, under sized (<20mm diameter), insect affected were reasons for unmarketability and data was expressed in t/ha

D. Total tuber yield (ton/ha): The sum of marketable and unmarketable tuber yield, the total yield kg/plot converted to t/ha.

E. Average tuber number per plant: Ten plants were randomly selected per plot and harvested. Tubers were counted and converted to average tuber number per plant.

F. Marketable tuber number per ha: the number of marketable tuber produced from middle row counted at harvest (>20mm diameter and converted to number per hectare).

G. Total tuber number per ha: Counted tuber per plot was converted to hectare.

3.5.3 Quality response variables

3.5.3.1Tuber size categories

The harvested tubers were cleaned and sorted into size categories per plot using caliper. Tubers below diameter of 20mm were considered as unmarketable and the rest of tubers were small size (20-30mm), medium size (30-40mm) and large size (>40mm). Based on these tuber size categories data on number and weight recording was made.

A. **Under size tuber number per plot:** Number of tubers with less than 20mm diameter.

B. **Small size tuber number per plot:** Number of tubers within the range of 20 to 30mm diameter.

C. **Medium size tuber number per plot**: Number of tubers in range of 30 to 40mm diameter.

D. **Large size tuber number**: Number of tubers with diameter greater than 40mm.

E. **Under size tuber weight per plot (g):** Tubers having less than 20 mm diameter.

F. **Small size tuber weight per plot (g**): Tubers with tuber diameter in the range of 20-30mm

G. **Medium sized tuber weight per plot (kg**): Tubers within the range of 30-40mmdiameter.

H. **Large size tuber weight per plot (kg**): Tubers having diameter above 40mm.

3.5.3.2Tuber specific gravity in g/cm^3

At harvest, a representative tuber sample from each plot was taken and washed and then tuber specific gravity was determined by weighing in air and under water method.

$$SG = \frac{\text{weight of tuber in the air}}{[(\text{Weight in air}) - (\text{weight in water})]}$$

3.6 Data Analysis

The collected data on different growth, yield and quality parameters were checked for normality and meeting all ANOVA assumptions. The mean values of all the above parameters were subjected to Analysis of Variance (ANOVA) and correlation using SAS Computer soft ware version 9.2 (SAS Institute Inc.,2008). When ANOVA showed significant differences, mean separation was carried out using LSD (least significant difference) test at 5% level of significance.

4. RESULTS AND DISCUSSION

Data on growth response variables yield and yield components, and selected parameters of potato that are influenced by different levels of inter-row and intra row spacing were recorded during the course of the study. The results are presented and discussed sequentially as follows.

4.1 Yield Response Variables

4.1 .1 Days to emergence

Interaction of inter and intra row spacing (Table 3 and Appendix Table 8) showed very highly significant difference (*P*< 0.0001) with respect to days to emergence.

Treatment combination of inter row spacing (60cm) and intra row spacing (40cm) and 70x30cm took longer days (16days) for emergence and treatment combination 70x20cm, 75x30cm, 75x40cm, 80x30cm and 85x40 emerged in shorter days or within 12 days after planting. Days to emergence is hardly affected by cultural practices like spacing, earthing up or depth of planting the tubers.

Table 3: Interaction effect of inter and intra row spacing on days to emergence

Inter row	Intra row(cm)	Days to emergence
60	20	15.00^{b}
	30	13.66^{c}
	40	16.00^{a}
65	20	15.00^{b}
	30	13.00^{d}
	40	14.00^{c}
70	20	12.00^{e}
	30	16.00^{a}
	40	15.00^{b}
75	20	13.00^{d}
	30	12.00^{e}
	40	12.00^{e}
80	20	14.00^{c}
	30	12.00^{e}
	40	13.00^{d}
85	20	14.00^{c}
	30	13.00^{c}
	40	12.00^{e}
LSD (5%)		0.49
CV (%)		2.2

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.1.2 Days to 50% flowering

Days to 50% flowering was significantly ($P< 0.05$) affected by inter row spacing. The inter row spacing (80cm) took longer time (58 days) to reach its 50% flowering whereas the inter row spacing (60cm) took relatively shorter period (51.55 days) to reach this flowering stage (Table 4). But intra row spacing did not show significant effect on days to 50% flowering at all. The interaction effect of inter and intra row spacing did not show significant variation with respect to this variable (Appendix Table 8).

Table 4: Inter and Intra row spacing (cm) effect on potato days to 50% flowering

Treatment	Days to 50% flowering
Inter row (cm)	
60	51.55^{c}
65	53.33^{bc}
70	54.44^{abc}
75	56.22^{abc}
80	58.22^{a}
85	57.55^{ab}
LSD (5%)	4.47
Intra row (cm)	
20	53.83
30	56.16
40	55.66
LSD (5%)	NS
CV (%)	8.97

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.1.3 Days to maturity

Days to maturity was significantly (*P*< 0.05) influenced by the interaction between inter and intra row spacing (Table 5 and Appendix Table 8).

Treatment combination of 70 x 30cm and 75 x 20cm matured earlier (81days) as compared to potato planted at the other spacing combinations. The results of this experiment are in line with the findings of Tesfu and Charles (2010) who reported that increasing plant density fastened days to maturity. A treatment combination of 80 x 40cm and 85 x 40cm on the other hand were found to mature 91 days after planting (Table 5). As the number of plant per unit area reduced by increasing the inter and intra row spacing the availability of nutrients, light and space that the plants need to grow is also increasing and this is further resulted in more vegetative growth of the potato plant that extended days to maturity. The days to reach maturity are relevant parameter for potato producers in order to develop planning for production season, marketing etc.

Table 5: Interaction effect of inter and intra row spacing on days to maturity and plant height

Inter row(cm)	Intra row (cm)	Days to maturity	Plant height(cm)
60	20	81.66^{fg}	60.66d^{ef}
	30	83.33^{d-g}	57.33^{f}
	40	88.33^{a-d}	61.66^{def}
65	20	88.00^{a-e}	67.33^{bcd}
	30	88.33^{a-d}	66.33^{b-e}
	40	84.66^{c-g}	66.00^{b-e}
70	20	85.66^{b-g}	58.66^{ef}
	30	80.66^{g}	66.00^{b-e}
	40	84.66^{c-g}	72.33^{b}
75	20	81.00^{g}	64.33^{c-f}
	30	87.00^{a-f}	64.00^{c-f}
	40	84.33^{c-g}	64.00^{c-f}
80	20	84.66^{c-g}	66.00^{b-e}
	30	89.33^{abc}	70.00^{bc}
	40	90.66^{ab}	82.66^{a}
85	20	82.66^{efg}	67.00^{bcd}
	30	89.33^{abc}	64.66^{b-f}
	40	91.33^{a}	70.00^{bc}
LSD (5%)		5.39	7.95
CV (%)		8.97	7.25

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.1.4 Plant height (cm)

Interaction of inter and intra row spacing significantly (*P*<0.05) influenced plant height (Table 5 and Appendix Table 9). Superior plant height (82.66cm) was observed in the combination of 80cm inter and 40cm intra row spacing, whereas, relatively shorter plant height (57.33cm) was obtained in the treatment combination of 60 x 30cm inter and intra row spacing.

The increase in height may be due to better availability of nutrients, water, and sun light since plants in wider spacing have less competition and grow more shoots. But, densely populated plants show intensive competition which leads to decrease in plant height. The result of the current experiment confirms the findings of Zamil *et al*. (2010) who reported that the widest spacing enhances growth and height of the plant which was significantly different from narrow spacing. The current finding is also supported by a study undertaken by Endale and Gebremedhin (2001) who reported significant effect of spacing on plant height, as a result of availability of wider inter row spacing for growth factors.

4.1.5 Plant canopy (cm)

The analysis of variance for inter and intra row spacing showed that there were significant statistical differences (*P*<0.05), between the treatments there plant canopy. Inter row spacing of 65cm and 85cm indicate wider, 48.55cm and 47cm canopy, while intra row spacing of 40cm has wider (46.94cm) canopy. But the combination of row and plant spacing showed no significant differences (P >0.05).

Table 6: Inter and Intra row spacing effect on plant canopy (cm) and number of stem

Treatment	Plant canopy	Number of main stem
Inter row(cm)		
60	42.88^{b}	3.00^{ab}
65	48.55^{a}	3.00^{ab}
70	41.77^{b}	2.88^{b}
75	43.66^{b}	3.11^{a}
80	46.33^{b}	3.00^{ab}
85	47.00^{a}	3.00^{ab}
LSD (5%)	4.75	0.18
Intra row(cm)		
20	43.27^{b}	3.00a
30	45.88^{ab}	2.94a
40	46.94^{a}	3.00a
LSD (5%)	3.36	0.12
CV (%)	10.93	6.31

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.1.6 Number of main stem

The number of main (primary) stem or branches showed no significant difference ($P > 0.05$) over replication with the combination of row and plant spacing but affected by both treatments (Table 6).

Number of main stem or branch per plant was not influenced by plant spacing as reported by different workers Vander Zaag *et al*. (1990). But stem number increased as a result of either by planting lesser tuber size or more tuber number per unit area pre plant storage (Sturz *et al*., 2007).

4.2 Yield Parameters

4.2.1 Average tuber yield

The interaction effect of inter and intra row spacing showed statistically significant ($P < 0.05$) differences on average tuber yield in gram per plant and per plot (Table 7 and Appendix Table 4).

The maximum yield per plant, 933g was obtained from inter row spacing of 85cm combined with intra row spacing of 40cm (Table 7). This revealed that using wider spacing decreased the yield per hectare but resulted in increased yield per plant. Contrary to the higher yield, inter and intra row combination of 75x20cm 70x20cm and 60x40cm resulted lowest yield 408 , 410 and 425 grams, respectively.

The present result is in corroboration with the findings of Sultan and Sindduque (1991) who reported significant increase in tuber yield per plant /hill/with the increase in plant spacing, however, the yield of tubers per hectare did not follow similar trend

Table 7: Interaction effect of inter and intra row spacing on tuber yield

Inter row(cm)	Intra row(cm)	Av.tuber yield/hill (g)	Marketable yield(t/ha)	Unmarketable tuber (t/ha)	Total yield(t/ha)
60	20	683.3[c-f]	29.8[bcd]	1.86[a]	31.66[bcd]
	30	652.0[def]	22.28[fgh]	1.11[bc]	23.39[fg]
	40	425.7[i]	21.86[gh]	0.94[c-f]	22.80[fg]
65	20	796.7[bc]	37.02[a]	1.37[b]	38.39[a]
	30	617.0[fg]	29.56[cde]	0.67[fgh]	30.23[cde]
	40	776.7[bcd]	25.33[efg]	1.09[bc]	26.42[ef]
70	20	410.0[i]	22.47[fgh]	0.87[c-f]	23.34[fg]
	30	443.7[hi]	22.19[fgh]	0.73[e-h]	22.92[fg]
	40	567.0[fgh]	22.71[fgh]	0.55[h]	23.26[fg]
75	20	408.3[i]	23.62[fgh]	0.94[c-f]	24.56[fg]
	30	471.0[hi]	25.58[d-g]	0.97[cde]	26.55[ef]
	40	506.7[ghi]	28.69[de]	1.07[cd]	29.76[cde]
80	20	758.7[b-e]	33.33[abc]	0.89[c-f]	34.22[abc]
	30	637.7[ef]	29.46[cde]	0.69[e-h]	30.15[cde]
	40	842.0[ab]	34.16[ab]	0.94[c-f]	35.10[ab]
85	20	686.0[c-f]	26.51[def]	0.8d[e-h]	27.31[def]
	30	651.0[def]	26.16[d-g]	0.87[c-h]	27.03[def]
	40	933.0[a]	20.14[h]	0.64[gh]	20.78[g]
LSD (5%)		129.1	4.54	10.86	4.86
CV (%)		12.43	10.24	10.58	10.58

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.2.2 Marketable tuber yield (t/ha)

Analyses of variance showed significant ($P < 0.05$) differences for the interaction effect of inter and intra row spacing on marketable potato tuber yield (Table 7 and Appendix Table 3). Significantly maximum marketable yield (37.02 t/ha) was obtained at the combination of inter row spacing of 65cm and intra row spacing of 20cm. This highest marketable yield was recorded at closer spacing which is attributed to more tubers produced at the higher plant population per hectare.

This result agrees with the findings of many workers (Stoffela and Bryan, 1988; Khalafalla, 2001) who reported plant density effects on marketability of potato crop. Use of closer spacing appropriate as it yields better proportion of marketable tubers than wider spacing of 40cm. In addition, the combination of wider spacing of inter and intra row spacing (80x40cm) gave marketable yield of 34.16 t/ha (Table 7) which can be fit for ware potato production than for seed production. However, narrow spacing (65x20cm) resulted that higher marketable tuber (37.02t/ha) which is economical for seed production.

4.2.3 Unmarketable tuber yield (t/ha)

Interaction effect of inter row with intra row spacing showed highly significant ($P< 0.01$) variation on unmarketable tuber yield per hectare (Table 7). Among the interaction the highest unmarketable tuber yield of 1.68t/ha was recorded at the treatment combination of inter row spacing of 60cm and intra row spacing of 20cm. Opposite to this, the lowest unmarketable tuber yield of 0.55 t/ha was recorded in the treatment combination of 70cm inter and 40cm intra row spacing (Table 7).

Similar results have been reported by Beukema and Vanderzaag (1990) that plant density had a marked effect on unmarketable tuber yield and maximum unmarketable yield recorded from the narrow spacing due to higher inter plant competition which is associated with under sized tubers.

4.2.4 Total tuber yield (t/ha)

The interaction of inter and intra row spacing significantly ($P< 0.01$) influenced total tuber yield (Table 7 and Appendix Table 3).

The highest total tuber yield of 38.19 t/ha was obtained from the combination of inter row spacing of 65cm and intra row spacing of 20cm, while the lowest (21.22 t/ha) yield was recorded at the treatment combination of 85cm inter and 40cm intra row spacing. The increased yield was attributed to more tubers produced at higher plant population per hectare, because at closer spacing there is high number of plants per unit area which brings about an increased ground cover that enables more light interceptions, influencing photosynthesis. The present finding is supported by Karafyllids *et al*. (1997), who indicated that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and quality. Increase in plant density leads to decrease in mean weight and more tubers and yield per square meter are expected in higher plant density.

The wider inter and intra row spacing (80x40cm) interaction also gave higher yield (35.09 t/ha) which agree with the findings of Berga *et al.* (1994), who reported that wider inter and intra row spacing (80x40cm) gave highest yield (34t/ha) and the narrow spacing 60x20cm treatment gave the lowest yield (22.2t/ha). Therefore this combination fits for ware production of potato that meets the demands of consumers due to its reasonable size and weight.

As Beakema and Vander Zaag (1990) stated, yield of potato depends on many factors such as the amount of minerals in the soil, plant spacing, cultivar and management inputs (cultural practices). However, plant spacing had a marked effect on yield, revealing that increasing plant density increased tuber yield.

4.2.5 Average tuber number per plant

The analysis of variance indicated highly significant ($P < 0.01$) differences for the interaction effects of inter and intra row spacing on average tuber number per plant (Table 8). The maximum average tuber number per plant (18.66) was recorded at the treatment combination of inter row spacing of 65cm with intra row spacing of 20cm, while the lowest average tuber per plant (6.66) was revealed from the combination of inter row of 70cm and intra row spacing of 20cm. This shows that plant density is important aspect of potato production.

The current findings in consonance with the report of different workers that planting more seed tubers for most varieties resulted in increasing number of tubers per unit area, also planting with intra row spacing of 10 to 20cm would be advantageous (Berga *et al*., 1994; Wurr *et al.*, 2001).

Table 8: Interaction effect of inter and intra row spacing on tuber number

Inter row(cm)	Intra row(cm)	Average tuber/plant	Marketable tuber number /ha	Total tuber number/ha
60	20	15.00[b]	33770[a-d]	54880[a]
	30	14.66[b]	33770[a-d]	48700[abc]
	40	12.00[b-e]	31670[a-d]	45570[a-d]
65	20	18.66[a]	38400[a]	49630[abc]
	30	11.33[cde]	26500[a-d]	38230[a-e]
	40	14.00[bc]	31320[a-d]	41700[a-e]
70	20	6.66[h]	16350[d]	27700[cde]
	30	7.33[gh]	18350[cd]	26033[de]
	40	9.66[e-h]	18590[bcd]	29370[b-e]
75	20	7.33[gh]	25700[a-d]	38520[a-e]
	30	8.00[fgh]	23630[a-d]	36600[a-e]
	40	7.33[gh]	31190[a-d]	22940[e]
80	20	12.33[b-e]	36670[ab]	45830[a-d]
	30	11.00[c-f]	35900[abc]	45830[a-d]
	40	12.66[b-e]	37200[a]	50450[ab]
85	20	13.00[bcd]	35340[abc]	47580[a-d]
	30	10.33[d-g]	26380[a-d]	36530[a-e]
	40	12.00[b-e]	30670[a-d]	38590[a-e]
LSD (5%)		3.09	2.94	4.19
CV (%)		16.52	11.67	10.29

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.2.6 Marketable tuber number per hectare

Interaction of inter row and intra row spacing highly significantly ($P < 0.01$) influenced marketable tuber number of potato (Table 8). The maximum marketable tuber number (38,400) was obtained at inter row spacing of 65cm interacted with intra row spacing of 20cm, while the lowest marketable tuber (16,350) was obtained at the treatment combination of inter row spacing of 70cm and intra row spacing of 20cm (Table 8). The report by Kantona *et al.* (2003) confirms significant increase in number of marketable yield as plant density increases and this result fits for potato seed and ware production.

4.2.7 Unmarketable tuber number

Inter and intra row spacing significantly (*P*<0.05) influenced total unmarketable tuber number per hectare (Table10). Inter row spacing of 65cm gave higher number (77.88), while intra row spacing of 20cm has more number (64.22). But the combination of row and plant spacing showed no significant differences (P >0.05).

Table 10: Effect of inter and intra row spacing on total unmarketable tuber number/ha

Treatment	Unmarketable tuber number
Inter row(cm)	
60	77.88^{a}
65	63.66^{c}
70	66.00^{b}
75	54.22^{cd}
80	50.00^{d}
85	51.66^{d}
LSD (5%)	11.38
CV (%)	19.61
Intra row(cm)	
20	64.22^{a}
30	61.44^{ab}
40	56.05^{b}
LSD (5%)	8.04
CV (%)	19.61

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.2.8 Total tuber number per hectare

Total tuber number per hectare was significantly (*P*<0.05) affected by the inter row spacing and intra row spacing (Table 8). The maximum total tuber number per hectare (54,880) was recorded from the combination of inter row spacing of 60cm and intra row spacing of 20cm. In contrary the lowest tuber number per hectare (22,940) was recorded at inter row spacing of 70cm combined with 40cm intra row spacing.

In this study total tuber number per hectare increased as the narrow spacing used resulting in high number of plants per unit area. This result confirms the findings of Rahemi *et al.* (2005) who reported that intra row spacing of 20cm increased total tuber and weight per unit area.

4.3 Tuber Quality parameters

4.3.1 Tuber specific gravity (g/cm3)

The effects of both inter and intra row spacing showed that statistically there was no variation on specific gravity of tubers. But the value of 1.25 was recorded from 80cm of inter row spacing and was significantly different (P<0.05) (Table 10). The combination use of inter and intra row spacing exhibited non-significant (P > 0.05) differences among the treatments combinations in terms of specific gravity of tubers.

Table 10: Effect of inter and intra row spacing on specific gravity

Treatment	Specific gravity
Inter row(cm)	
60	1.0087^{b}
65	1.0087^{b}
70	1.0076^{b}
75	1.0010^{b}
80	1.0025^{a}
85	1.0009^{b}
LSD (5%)	0.14
CV (%)	13.83
Intra row(cm)	
20	1.0015
30	1.0010
40	1.0008
LSD (5%)	Ns
CV (%)	13.83

Means followed by the same letter(s) are not significantly different at p>0.05, Ns=non significant

4.3.2 Tuber size category in number per plot

4.3.2.1 Undersize tuber (<20mm) in number /plot

The analysis of variance showed that the interaction effects of inter row spacing and intra row spacing revealed significant (P<0.01) difference for under sized potato tubers (Table 11). Maximum undersized tuber number (82) was recorded at the interaction of 65x20cm and 60x30cm; however the lowest under size tuber recorded at 75x30cm and 85x40cm. This finding agrees with Boh *et al*. (2000) who reported that at higher tuber number per stem inter tuber competition reduced tuber size.

Table11: Interaction effect of inter and intra row spacing on under sized tuber number/plot

Inter row (cm)	Intra row (cm)	Undersize (<20mm)	Small size (20-30mm)	Medium size (30-40mm)
60	20	62.33^{bc}	86.33^{a}	81.00^{ab}
	30	78.33^{a}	75.66^{a}	61.33^{def}
	40	51.33^{c-f}	59.66^{b}	65.00^{c-f}
65	20	81.66^{a}	85.66^{a}	88.33^{a}
	30	56.33^{b-e}	59.00^{bc}	54.00^{fgh}
	40	56.33^{b-e}	56.33^{bcd}	58.66^{ef}
70	20	60.00^{bcd}	32.33^{gh}	43.33^{hij}
	30	58.33^{b-e}	36.33^{fgh}	36.00^{j}
	40	44.00^{fg}	36.33^{fgh}	41.33^{hij}
75	20	43.00^{fg}	37.33^{e-h}	44.00^{g-j}
	30	38.66^{g}	26.00^{h}	39.33^{ij}
	40	63.66^{b}	37.00^{fgh}	55.00^{fgh}
80	20	41.00^{fg}	47.00^{b-f}	73.33^{bcd}
	30	52.00^{b-f}	51.33^{b-e}	73.00^{b-e}
	40	48.66^{d-g}	46.66^{c-f}	76.00^{abc}
85	20	47.33^{efg}	45.33^{c-g}	81.00^{ab}
	30	51.33^{c-f}	44.66^{d-g}	51.33^{f-i}
	40	38.66^{g}	33.33^{fgh}	58.33^{fg}
LSD (5%)		12.28	14.08	14.44
CV (%)		13.69	17.03	14.43

Means followed by the same letter(s) are not significantly different at a probability level of 0.05

4.3.2.2 Small size tuber (20-30mm) in number /plot

The interaction effect of inter and intra row spacing on small sized tuber (20-30mm) showed statistically significant (P<0.01) difference for potato tubers (Table 11). Maximum small sized tuber number (86) was obtained at inter row spacing (60 and 65) and intra row spacing (20 and 30cm), while the smallest tuber number (26) was obtained at 75x30cm.

The research finding of Wurr *et al. (*2001) indicated that stem density over a wide range either by planting larger seed tubers or more seed tubers for most varieties resulted in increasing number of tubers per unit area which agrees with the result obtained at closer spacing tuber number increased.

4.3.2.3 Medium size tuber (30-40mm) in number /plot

The interaction effect of inter and intra row spacing on medium sized tuber (30-40mm) showed statistically significant (P<0.01) difference (Table 11). The higher tuber number (88.33) at 30-40mm obtained at inter row spacing of 65cm and intra row spacing of 20cm and lower tuber number (36) was obtained at 70x30cm interaction. According to Berga *et al. (*1994), intra row spacing depends on intended use of the crop that closer spacing is advantageous for seed tuber and wider spacing for ware tuber potatoes.

4.3.2.4 Large size tuber (>40mm) in number /plot

The combination of inter and intra row spacing on large size tuber had no significant (P>0.05) effect. But 65, 80, 85 cm row spacing showed greater number of larger tuber sizes. Intra row spacing showed significant effect (P < 0.05) on the number of tuber size category except for the intra row spacing of 40cm whose effect was significant (P<0.05) on the number of the larger tuber sized potatoes (Table 12). This research work result agrees with finding of Tamiru (2005) that the number of ware potatoes (large tuber size) was greater with wider spacing.

Table 12: Effect of inter and intra row spacing on large size tuber number /plot

Treatment	Lstn
Inter row	
60	41.44[b]
65	49.55[a]
70	30.55[c]
75	37.00[bc]
80	51.77[a]
85	51.00[a]
LSD (5%)	7.15
Intra row	
20	4.15[c]
30	4.97[b]
40	5.85[a]
LSD (5%)	0.7
CV (%)	17.15

Means followed by the same letter (s) are not significantly different at 0.5significance /probability level, Lstn=large size tuber number

4.3.3 Tuber size category in weight per plot

4.3.3.1 Under size tuber (<20mm) weight

Interaction effects of inter row spacing and intra row spacing revealed significant (P<0.01) difference for under sized potato tubers weight (Table 13). The maximum under size tuber weight (530g) for less than 20mm was registered at the interaction of inter row spacing (60cm) and intra row spacing (20 and 30cm). However, the lowest under size tuber weight (177g) was obtained at the interaction of inter row spacing (80cm) and intra row spacing (20cm). Different workers (Reeve *et al.,* 1973; De La Morena *et al.,* 1994) reported tuber weight to be affected by variety, growth condition or environmental factors.

Table13: Interaction effect of inter and intra row spacing on size of tuber weight/plot

Inter row(cm)	Intra row (cm)	Under size/g/plot (<20mm)	Small size/g/plot (20-30mm)
60	20	530[a]	1.63[a]
	30	530[a]	0.63[efg]
	40	363.3[b-e]	0.72[efg]
65	20	393.3[bc]	1.80[a]
	30	333.3[b-e]	1.14[cd]
	40	440.00[ab]	1.11[cd]
70	20	323.3[b-e]	0.63[efg]
	30	370.00[bcd]	1.51[ab]
	40	316.7[b-e]	0.94[de]
75	20	233.3[ef]	0.29[g]
	30	337.3[b-e]	0.48[fgh]
	40	416.7[abc]	0.75[ef]
80	20	177.00[f]	0.93[de]
	30	241.3[def]	1.28[bc]
	40	363.3[b-e]	1.70[a]
85	20	303.3[c-f]	0.42[gh]
	30	390.00[bc]	0.65[efg]
	40	248.3d[ef]	0.64[efg]
LSD (5%)		136.3	320.4
CV (%)		23.4	20.13

Means followed by the same letter (s) are not significantly different at 0.5significance /probability level.

4.3.3.2 Small size tuber (20-30mm) weight

Interaction of inter row and intra row spacing very highly significantly (P<0.001) affected small sized potato tuber weight (Table 13). Inter row spacing of 65cm combined with intra row spacing of 20cm gave 1.8kg/plot and 80x40cm followed by resulting 1.7kg/plot and 60x20cm also showed 1.6kg/plot weight. According to the report of Berga and Caesar (1990), stem number and tuber number per plant are positively related. This finding also revealed that plants having more stem number gave more tuber number.

4.3.3.3 Medium size tuber (30-40mm) weight

Interaction of inter and intra row spacing showed no significant (P>0.05) difference on tuber size category of medium weight (Table 14). However, inter row spacing (65cm and 80cm) revealed maximum (7kg/plot) tuber weight for medium sized tubers.

This finding is in conformity with work of Ali (1997) who reported increase in density caused due to increase in competition between and within plants and in turn decrease in availability of nutrients to each plant and consequently, resulted in decline of mean tuber weight.

Table 14: Effect of inter and intra row spacing on size of tuber weight/kg /plot

Treatment	Medium tuber/kg	Large tuber/kg
Inter row(cm)		
60	4.98^{b}	3.80^{b}
65	6.50^{a}	5.88^{a}
70	4.32^{b}	5.32^{a}
75	4.28^{b}	3.53^{b}
80	7.00^{a}	6.15^{a}
85	4.90^{b}	5.27^{a}
LSD (5%)	1.24	0.99
CV (%)	24.32	20.84
Intra row(cm)		
20	5.36	44.00
30	5.34	42.00
40	5.28	44.44
LSD (5%)	Ns	Ns
CV (%)	24.32	20.84

Means followed by the same letter(s) are not significantly different at 0.05probability level, Ns=non significant

4.3.3.4 Large size tuber (>40mm) weight

Inter row and intra row spacing was significant (*P*< 0.05) on the weight of larger potato tuber sized (Table 14). The larger tuber size was observed in inter row spacing of 65, 70, 80 and 85cm. The intra row spacing showed no significant (*P*> 0.05) difference with regard to tuber weight. Berga and Caesar (1990) reported that stem number per plant and tuber number per plant are positively correlated, but average tuber weight increased with wider spacing.

4.4 Correlation Analysis among Yield and Quality Parameters

The correlation coefficient among response variables (Appendix Table-10) revealed that, the potato parameters were significantly and positively associated with different characters of potato. Total tuber yield was positively correlated with plant canopy (r = 0.3*), tuber number (r = 0.46**), tuber weight(r = 0.37**) and both tuber size in terms of number and weight except that of under sized tuber. Marketable tuber yield was positively correlated with tuber number (r = 46**) and weight (r = 0.37**).

Also unmarketable tuber yield was correlated positively with tuber number (r=0.42**) and total yield (r = 0.42**). Total marketable tuber number per hectare was positively correlated with tuber number (r = 0.67**), tuber weight (r = 0.5*), while total tuber number was positively correlated with tuber per plant number (r = 0.65*), tuber per plant weight (r = 0.46**) small size tuber number(r=0.68***), medium size tuber number (r=0.86**) large size tuber number (r=0.57*). Days to maturity correlated positively with plant height (r =0.34*) tuber weight (r = 0.34), tuber flour (r = 0.36**). Plant height was positively correlated with tuber number (r = 0.63***).

5. SUMMARY AND CONCLUSION

Potato ranks first in volume produced and consumed followed by cassava, sweet potato and yam. Also potato is important source of nutritious food crop in different parts of Ethiopia, especially in western parts of the country including Bako area. However, the production and the productivity of potato are too low due to poor agronomic practices, poor quality seed, storage and marketing system.

Farmers in the study area apply different spacing which is above or below the recommendation used either for consumption or seed tuber. Therefore it is important to maintain appropriate plant population per unit area in order to get high yield, quality and appropriate size of tubers which meets the demand of the producer. In potato production selection of appropriate inter and intra row spacing favors to utilize the resource effectively and intensively for higher ware tuber yield and for quality tuber seed.

To address this problem the study was conducted at Bako with the objective of identifying optimum inter and intra row spacing for better yield and quality of seed and ware potato tuber (*Solanum tuberosum*L). The experiment was conducted using a RCBD with three replications in 6x3 factorial arrangements. Data on different variables were collected and the results of analysis of variance revealed that most potato variables were significantly affected by inter and intra row spacing as well as their combinations. Some variables were not significantly affected by the treatments and their combinations.

The inter and intra row spacing combination effects on days to emergence at 60x40cm and70x30cm, resulted longer days (16) where as shorter days (12) were revealed by other treatment combinations. Wider spacing showed longer days and narrow spacing shorter days on maturity and plant height.

Regarding to total and marketable tuber yield in ton per hectare was influenced by using narrow spacing. Also the high unmarketable tuber yield (rotted, diseased, undersized, cracked and deformed were recorded at narrow spacing. Considering the average tuber weight per plant per plot more yield was obtained at wider spacing.

Narrow spacing was resulted in more tuber number per hectare (54,880) and per plant (18.66) while wider spacing resulted in lower tuber number per hectare (22,940) and per plant (6.66). Marketable tuber number per hectare influenced by both 65x20cm and 80x40cm with maximum tuber number (38,400 and 37,200) but treatment 70x20cm resulted lower tuber numbers (16,350). In line to tuber size category more under and medium sized tuber number obtained at narrow spacing. Also in case of tuber size in weight that narrow spacing resulted in higher weight of under sized tubers.

Total tuber yield was positively correlated with plant canopy (r=0.3*), tuber number (r=0.46**), tuber weight (r=0.37**). Marketable tuber yield positively correlated with tuber number (r=46**) and weight (r=0.37**).Also unmarketable tuber yield correlated positively with tuber number (r=0.42**) and with total yield (r=0.42**).Total marketable tuber number per hectare positively correlated with tuber number (r=0.67**),tuber weight (r=0.5*),while total tuber number positively correlate with number (r=0.65*),weight (r=0.46**).Days to maturity correlated with plant height (r=0.34*) tuber weight (r=0.34) .Plant height positively correlated with tuber number (r=0.63***).

The result of this study demonstrated that yield in per unit area is inflected by different level of inter and intra row spacing. Narrow spacing (65 and 20cm) and 80 x 40cm were produced maximum total and marketable tuber yield per hectare than other spacing that can be used for seed and ware potato production for the study area. Therefore farmers and users who grow potato (Jalane variety) in the study area (Bako) can be benefited if they use this narrow spacing 20x65cm and wider spacing 40 x 80cm.

This result was one year or one season and one location therefore further study may consider assessment of inter and intra row spacing on seed and ware production of potato to draw reliable conclusions.

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7. APPENDICES

AppendixTable1: Long term (1992-2011) weather data of Bako Agricultural Research Center

Year	Rain fall(mm/annum	Average temp ^{O}c minimum	Ave Tem ^{O}c maximum	Relative humidity %

1992	1438	13.7	27.9	64.1
1993	1659	13.9	27.8	70.9
1994	1332	12.9	28.5	65.7
9195	1109	14.1	27.7	64.3
1996	1061	14.3	28.2	68.7
1997	1389	14.2	27.1	68.9
1998	1559	13.8	27.9	65.8
1999	1272	14.1	26.8	64.2
2000	1446	13.6	26.9	62.2
2001	1359	14.0	28.0	61.6
2002	1041	13.9	29.0	58.6
2003	1395	14.7	28.6	57.0
2004	1161	13.2	28.7	58.4
2005	1258	13.3	29.7	60.8
2006	1365	14.2	28.1	57.8
2007	1287	13.7	28.3	56.8
2008	1528	13.6	28.6	54.4
2009	1324	14.8	28.9	55.3
2010	1338	13.4	27.9	55.6
2011	1424	13.5	26.9	60.3

Source: Bako Agricultural Research center metrology section 2011.

Appendix Table2: Mean monthly field rainfall, temperature and relative humidity of Bako during the study period (2001) annual

Month	Rain fall	Air tem ^{O}c	Air temp ^{O}c	mean	Relative

	Mm/annum	minimum	Maximum		humidity
January	15.9	12.0	28.0	20.0	58
February	2.0	11.0	29.7	20.35	50.9
March	58.8	14.3	29.9	22.10	53.9
April	68.1	14.8	30.1	22.45	52.4
May	222.2	15.2	28.3	21.75	58.5
June	295.0	15.1	24.8	19.95	64.8
July	224.1	14.6	23.9	19.25	69.3
August	294.0	14.9	23.3	19.0	75.6
September	131.3	14.9	25.2	15.5	65.9
October	53.2	12.6	23.6	18.1	84.9
November	60.0	12.3	27.7	20.0	59.8
December	0.0	10.5	29.0	19.75	54.5
Total	1424	162.2	323.5	242.85	723.5
Mean	----	13.5	26.9	20.2	60.3

Appendix Tables3: Effect of inter and intra row on potato tuber yield at Bako in 2011/2012

Source of variation	D F	Mean squares		
		Mty(t/ha)	Uty(t/ha)	Tty(t/ha)
Block	2	4.76	0.01	2.39
Inter(A)	5	135.49***	0.34***	140.58***
Intra(B)	2	59.44**	0.34***	64.33 **
AxB	10	37.01**	0.13**	36.57**
Error	34	7.50	0.03	8.58

***=very highly significant**=highly significant, *= significant, Ns= non significant, Mty = Marketable tuber yield, Uty= unmarketable tuber yield, Tty = total tuber yield,

Appendix Table 4: Effect of inter and intra row spacing on tuber average of ten plants per plot at Bako in 2011/2012

Source of variation	DF	Mean squares	
		Tnp	Twp

Block	2	7.46	15115.2407
Inter(A)	5	79.94***	169192.50***
Intra(B)	2	13.3518519*	41914.9630**
AxB	10	10.35*	35390.2074***
Error	34		

***=very highly significant**=highly significant,*= significant, Tnp= tuber number mean of ten plant, Twp=Tuber weight mean of ten plants.

Appendix Table 5: Effect of inter and intra row on tuber size by weight/ plot in 2011/2012

Source of variation	Df	Mean squares			
		Ustw/gm	Sstw/gm	Mstw/kg	Lstw/kg
Block	2	3079.40	86606.00	3.07	2.18
Inter(A)	5	48447.18***	1135310.22***	11.82***	10.57***
Intra(B)	2	8052.24NS	4198.22ns	0.027ns	13.00***
AxB	10	19674.26*	4198.22***	3.83ns	1.63ns
Error	34	6747.79	37279.73	4198.22	1.08

***=very highly significant,*= significant, Ns= non significant, Ustw=under size tuber weight (<20mm), Sstw =Small size tuber weight (20-30mm), Mstw= medium size tuber weight (30-40mm), Lstw=large size tuber weight (40-50mm)

Appendix Table 6: Effect of inter and intra row spacing on tuber size by number/ plot

Source of variation	Df	Mean squares			
		Ustn	Sstn	Mstn	Lstn
Block	2	0.16	7.01	27.79	22.72
Inter(A)	5	649.01***	2592.55***	1664.56***	675.82*
Intra(B)	2	176.05*	535.24**	1163.57*	24.88ns
AxB	10	401.50***	218.41*	236.12*	86.17ns
Error	34	54.77	71.97	75.73	55.80

***=very highly significant,**=Highly significant,*=significant, Ns=non signficant,Ustn= under size tuber number (<20mm),Sstn =Small size tuber number (20-30mm),Mstn= medium size tuber number (30-40mm),Lstn=large size tuber number (40-50mm)

AppendixTable7: Effect of inter and intra row spacing on tuber number/ plot and /ha

Source of variation	Df	Mean squares				
		Mtn/pt	Unt/pt	Ttn/pt	Mtnh	Ttnh
Block	2	343.62	286.46	130.88	40832189.05	677072329

Inter(A)	5	12774.20***	1026.55***	14155.36***	45437048401***	54054357959***
Intra(B)	2	4523.01*	310.35ns	7300.22*	11012388934*	13528448887*
AxB	10	976.32*	167.50ns	2139.22ns	3204778725*	4092768362*
Error	34	452.90	141.16	1038.98	1205448849.2	1811029639.3

***=very highly significant,*= significant, Ns=non significant, Mtn/pt=marketable tuber number per plot, Unt/pt=unmarketable tuber number per plot, Ttn/pt=total tuber number per plot, Mtnh=marketable tuber number per hectare, Ttnh=total tuber number per hectare.

Appendix Table 8: Effect of inter and intra row spacing on growth parameters

Source of variation	Df	Mean squares		
		De	Df	Dmt
Block	2	0.12	98.16	0.51
Inter(A)	5	8.02***	59.51ns	29.80*
Intra(B)	2	0.90*	59.51ns	73.40*
AxB	10	0.90***	38.94ns	31.14*
Error	34	0.09	24.57	10.55

***=very highly significant,*= significant, Ns=non significant, De=days to emergens, DF=days to 50%flowering, Dmt=days to maturity,

Appendix Table9: Effect of inter and intra row spacing on yield attributes

Source of variation	Df	Mean squares		
		Ph	Pc	Nb
Block	2	21.50	61.40	0.05
Inter(A)	5	162.47***	83.18*	0.04ns
Intra(B)	2	157.38*	64.12ns	0.05ns
AxB	10	49.70*	41.04ns	0.03ns
Error	34	22.99	24.62	0.03

***=very highly significant,*= significant, Ns=non significant, ph=plant height (cm), Pc=plant canopy (cm), Nb=number of main branch.

Appendix Table10.Simple correlation on growth, yield and quality parameters

	Mty	Uty	Tty	Ustw	Sstw	Mstw	Lstw	Mtnh	Ttnh	Dmt	Ph	Tnp	Twp	Tf	Ustn	Sstn	Mstn	Lstn
Mty	1	0.38 ns	0.98***	0.03ns	0.54***	0.67**	0.33**	0.09ns	0.14ns	0.02ns	0.33*	0.46**	0.37**	0.08ns	0.23ns	0.4**	0.58***	0.31*
Uty		1	0.42 **	0.46**	0.27ns	0.22ns	0.26ns	0.10ns	0.18ns	-.18ns	0.22ns	0.42**	0.09ns	-0.21ns	0.43**	0.56ns	0.4ns	-0.07ns
Tty			1	0.009ns	0.52**	0.66***	0.30*	0.32*	0.50*	0.01ns	0.3*	0.46**	0.37**	0.08ns	0.25ns	0.41**	0.59***	0.3*
Ustw				1	0.19ns	0.10ns	-0.10ns	0.41**	0.46**	-0.02ns	-0.31*	0.28ns	0.02ns	-0.24ns	-0.55***	-0.48**	-0.15ns	-0.003ns
Sstw					1	0.41**	0.32*	0.28*	0.48**	0.06ns	0.34*	0.42**	0.32*	0.09ns	0.33*	0.51***	0.37**	0.09ns
Mstw						1	0.41**	0.25ns	0.48**	0.09ns	0.18ns	0.44**	0.41*	0.13ns	0.31*.	0.39**	0.53***	0.38**
Lstw							1	0.33*	0.10ns	0.03*	0.55***	0.23ns	0.44**	0.39**	-0.05ns	-0.15ns	0.05ns	0.02ns
Mtnh								1	0.95**	0.11ns	0.15ns	0.67**	0.58***	0.36*	0.15ns	0.64***	0.09***	0.69***
Ttnh									1	0.05ns	0.04ns	0.65**	0.46**	0.22ns	0.21ns	0.68***	0.86***	0.57**
Dmt										1	0.34*	0.05ns	0.34*	0.36**	-0.10ns	-0.05ns	0.10ns	0.16ns
Ph											1	0.63***	0.16ns	0.36**	0.73***	0.72***	0.49**	0.23ns
Tnp												1	0.62***	0.05ns	0.3*	0.57***	0.66***	0.49**
Twp													1	0.07ns	-3.5ns	-0.09ns	0.31*	0.53**
Tf														1	-0.14ns	-0.11ns	0.17ns	0.24ns
Ustn															1	0.59***	0.24ns	-15ns
Sstn																1	64*	0.25ns
Mstn																	1	0.57**
Lstn																		1

=significant.**=highly significant,***=very highly significant, Mty=marketable tuber yield,Uty=unmarketable tuber yield,Tty=total tuberyield,Ustw=undersize tuber weight,Sstw=small size tuber weight,Mstw=mediumsizetuberweight,Mtnh=marketable tuber number inhectar,Ttnh=total tuber number in hectare.Dmt=days to maturity,ph=plant heght.Tnp=plant number ,twp=plant weight,Tf=tuber flour,Ustn=under size tuber number,sstn=small size tuber number,Mstn=medium size tuber number,lastn=large size tuber number.

Plate A: At full growth data recording;

Plate B: Potato at field evaluation

Plate C: Cutting potato stem for harvesting

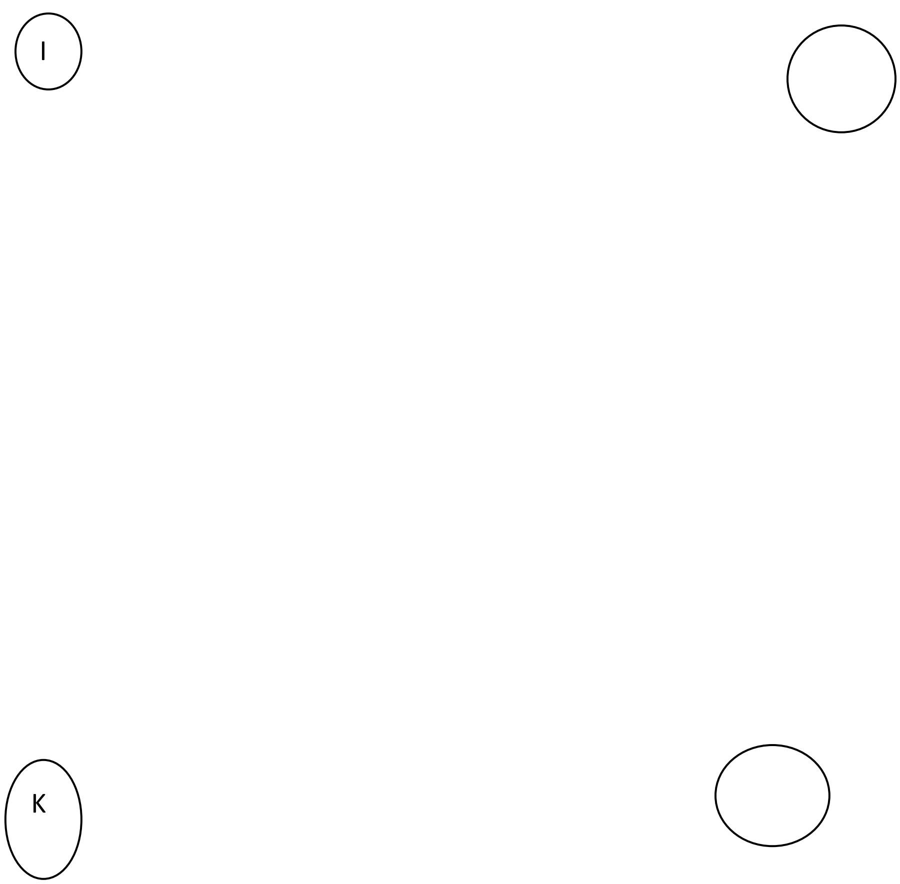
Plate D: Potato tuber per plant (hill)

Plate E: Potato tuber size grading collection

Plate F. Potato tuber weight data

Plate G: Potato tuber grading by size

Plate H: Potato data collection at harvesting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