INFLUENCE OF INTRA ROW SPACINGS ON YIELD AND YIELD COMPONENTS OF POTATO (*Solanum tuberosum* L.) VARIETIES AT HIGH LANDS OF GURAGIE ZONE, SOUTHERN ETHIOPIA

M.Sc. Thesis

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Jimma University

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Submitted to the Department of Horticulture and Plant Sciences, School of Graduate Studies Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture (Vegetable Science)

By

Gebeyehu Wondimu

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As thesis research advisor, I here by certify that, I have read and evaluated this thesis prepared under my guidance, by Gebeyehu Wondimu, entitled "Influence of Intra Row Spacings on Yield and Yield Components of Potato (*Solanum tuberosum* L.)Varieties at High Lands of Guragie Zone, Southern Ethiopia". I recommend that it can be submitted as fulfilling thesis requirement.

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As members of the Examining Board of the Final M.Sc. Open Defense, we certify that we have read and evaluated the thesis prepared by Gebeyehu Wondimu. We recommend the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Horticulture (Vegetable Science).

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DEDICATION

This thesis is dedicated to my beloved wife Manbeza Worku, daughter Eden Gebeyehu, son Esayas Gebeyehu, family and genuine friends who paved me the way towards education and for nursing me with affection and love and for their wholehearted partnership in the success of my life.

STATEMENT OF THE AUTHOR

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

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LIST OF ABBREVIATIONS

AEZ’s	Agro-Ecological Zones
ARDSP	Apiculture Research and Development Strategy Program
ASE	Agri-Service Ethiopia
BOA	Bureau of Agriculture
CIP	International Potato Center
EARO	Ethiopian Agricultural Research Organization
ESE	Ethiopian Seed Enterprise
FAOSTAT	Food and Agricultural Organization of the United Nation Statistics
JUCAVM	Jimma University Collage of Agricultural and Veterinary Medicine
LA	Leaf Area
LAI	Leaf Area Index
MoARD	Ministry of Agriculture and Rural Development
NGO’s	Non-Governmental Organizations

BIOGRAPHICAL SKETCH

Gebeyehu Wondimu was born in September 1972 in Limmu and Bilbilo Woreda, Arsi Zone, Oromia, Ethiopia. He attended his elementary school at Bokoji, Elementary and Junior Secondary School from 1977 to 1986. He pursued his secondary school education at Bokoji Senior Secondary School from 1987 to 1989 in Arsi Zone. He joined the then Jimma College of Agriculture in 1990 and graduated with a Diploma in General Agriculture in July 1993. After graduation, he was employed by the Ministry of Agriculture as an extension agent at Gumer Woreda Agricultural Development Office. He also served as the head of Office of Agricultural Marketing in Geta Woreda of Guragie Zone. He joined the summer program of Horticulture BSc Degree at Jimma University College of Agriculture and Veterinary Medicine in 2005 and graduated in November 2007. In September, 2008 he rejoined the Jimma University College of Agriculture and Veterinary Medicine to pursue M.Sc Degree in Horticulture under regular program of School of Graduate Studies through government sponsorship.

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TABLE OF CONTENTS

Contents Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

Tables **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES IN THE APPENDIX

Appendix tables **Page**

INFLUENCE OF INTRA ROW SPACINGS ON YIELD AND YIELD COMPONENTS OF POTATO (*Solanum tuberosum* L.) VARIETIES AT HIGH LANDS OF GURAGIE ZONE, SOUTHERN ETHIOPIA

BY

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ABSTRACT

A 4x4 factorial experiment arranged in randomized complete block design with three replications was conducted at Geta Woreda, Guragie Zone, Southern Ethiopia from December 2009 to April 2010 cropping season to assess the effects of intra-row spacing and variety on yield and yield components of potato (Solanum tuberosum L.). Four intra-row spacings (20, 25, 30 and 35 cm) and four potato varieties (Gudenne, Jalenne, Gera and Guassa) were used in the experiment. The results revealed that Jalenne and Guddene produced the highest marketable tuber yield; 31.69 t ha^{-1} and 29.72 t ha^{-1}, respectively and the least was from Gera, 26.15 t ha^{-1}. Variety Jalenne planted at 20 cm intra-row spacing recorded the highest LAI (11.54) and the lowest was recorded from Gera planted at 35 cm. The total tuber yield was significantly and positively associated with stem number ($r = 0.71^{**}$), marketable tuber number ($r = 0.31^{*}$) and marketable tuber yield ($r = 0.99^{**}$) whereas significantly and negatively correlated with unmarketable tuber number ($r = -0.42^{*}$), and unmarketable tuber yield ($r = -0.46^{*}$). In general, from the obtained results, it can be concluded that intra-row spacing, variety, and their interaction had valid effects on tuber yield significantly for variety Gudenne at 30 cm intra-row spacing in the study area. Thus, Gudenne variety planted at 30 cm intra-row spacing has been identified best in terms of yield and in using the scarce land of the area efficiently and effectively. Since this experiment was conducted only for one season, to come up with conclusive result, further investigations need to be conducted in line with irrigation methods and frequency, fertilizer types and rate, simultaneously at both major growing seasons (belg and meher) of the study area.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is originated in the highland of Andes in South America. In terms of quantities produced and consumed worldwide, potato is the most important vegetable crop (FAO, 2005). The crop is grown in majority of countries more than any other crops, and in the global economy, it is the fourth most important crop after rice, wheat, and maize (Stephen, 1999). Among the root and tuber crops, potato ranks first in volume produced and consumed, followed by cassava, sweet potato and yam (FAO, 2008).

The relatively high carbohydrate and low fat content of the potato makes it an excellent energy source for human consumption (Dean and Jones, 1994). The tuber is known to supply carbohydrate, high quality protein, a substantial amount of essential vitamins, minerals and trace elements (Horton and Sawyer, 1985). Moreover, the potato crop provides more nutritious food per unit land area, in less time, and often under more adverse conditions than any other food crops. It is said to be one of the most efficient crops in converting natural resources, labor and capital in to a high quality food with wide consumer acceptance (Bowen, 2003)

The crop is introduced to Ethiopia in 1859 by the German botanist called Schimper (Pankirust, 1964; Horton, 1987). Cultivation was limited to potatoes growing voluntarily in fields in the colder highlands until wider adoption of the potato occurred at the end of the nineteenth century in response to a prolonged famine (Gebremedhin *et al.*, 2001). Among African countries, Ethiopia has possibly the greatest potential for potato production; 70 percent of the arable land of the country (mainly of highland areas above 1500 m) is believed to be suitable for potato production (Berg *et al.*, 1998). Since the highlands are also home to almost 90 percent of Ethiopia's population, the potato could play a key role in ensuring national food security (MoARD, 2006; Bayeh *et al*, 2008).

Ethiopia is one of the principal potato producing countries in Africa and probably displays a unique position for having the highest potential area for cultivating potatoes (Mulatu *et al.*, 2005). It is endowed with suitable climatic and edaphic conditions for the production of high yield and quality potatoes (Demo and Pandey, 2009). Highest yield could be obtained in the central, southern, southeastern, southwestern and northwestern parts of the country (Save the Children-UK, 2007). The crop is grown all year round where frost and irrigation water are not limiting.

According to Gebremedhin *et al*. (2001), in 1975, the area of cultivation was estimated at 30,000 hectares, with an average yield of approximately five tons per hectare. However, potato cultivation declined in the early 1980s, due partially to widespread infestation of late blight, *Phytophthora infestans* (Tesfahun *et al*., 2004). Starting from 1991, potato production has resumed its upward trend. Gebremedhin *et al*. (2001) further stated that the area of cultivation had reached 36,000 ha in the early 2001; with average yield around eight tons per hectare. An increasing trend in potato production might be partly due to the continuing increase in population and subsequent decline in the average size of farm land holdings per household, hence pressure on agriculture to become more labor intensive and productive. With 384,046 tons production from 48,113 ha of land with national average of 9.8 t/ha, Ethiopia is the 11^{th} top potato producing country in Africa (FAOSTAT, 2010).

The fresh produce contains about 80% water and 20% dry matter, about 60 - 80 % of the dry matter is starch. On a dry weight basis, the protein content of potato is similar to that of cereals and is very high in comparison with other roots and tubers (Kabira and Berga, 2006). Potato contributes significantly to the quality and quantity of the diet because of its high vitamin C and protein content, however, the potato is low in fat (Haverkort *et al*., 1990).

The crop also rich in several micronutrients and vitamins, especially vitamin C when eaten with its skin; a single medium sized potato of 150 g provides nearly half of the daily adult requirement (100 mg) (FAOSTAT, 2008). The potato is a moderate source of iron, and its high vitamin C content promotes iron absorption. It is a good source of vitamins B_1, B_3 and B_6 and minerals such as potassium, phosphorus, iron and magnesium. Potatoes also contain dietary antioxidants, which may play a part in preventing diseases related to ageing, and dietary fiber (Mulatu *et al.*, 2005). Potato a nutritious food which produces high dry matter and protein per unit area, being a short duration crop it can be grown year round. Based on the above facts, nowadays attention has been given for potato production and improvement at national and international levels. Potato plays a beneficial role in world food production, owing to its status as a cheap and plentiful crop which can be raised in a wide variety of climates and localities (IYP, 2008).

The highlands of Ethiopia are the most populated areas of the country containing the majority of the agricultural work force required for the sector. With the continuing increase in population and decline in size of farm land holdings, the major labor force has to move to the labor intensive cropping system to sustain rural development and food production (MoARD, 2006).

Potato is ideally suited to places where land holding capacity per household is highly limited and labor is abundant (Berga *et al.*, 1994). Geta Woreda of Gurage Zone is one of the highlands of Ethiopia where potatoes are produced as a staple food and cash crop. In the Woreda, potato is the second staple food crop next to enset. According to the assessment result of Agriculture and Rural Development Office of Geta Woreda, about 15,000 tons of potato was produced in 2009/2010 cropping season.

In contrary to the diversified uses of the potato crop there are lots of production and productivity bottlenecks which are hindering the smooth expansion. Among these, limitations of improved agronomic and crop protection technologies and lack of improved varieties for all agro ecology zones; are the dominant restrictive factors of the sector. Farmers around the study area produce potato using the local cultivars and with non uniform planting density due to the lack of recommended intra- row spacing.

The optimum intra-row spacing in potato production plays a great role in determining yield and yield components. Ahmed (1989) found that closer spacing (20 cm) gave higher yields than wider spacing (30 cm). Rahemi *et al.* (2005) reported that the effect of intra-row spacing was significant on yield of potatoes and the 20 cm intra row spacing in comparison with 30 cm spacing showed 13.9, 59.8 and 30.39% increase in yield. Rahemi *et al*. (2005) also reported that intra-row spacing of 20 cm intra row spasing increased total tuber number and weight, and tuber weight per plant and the marginal return rate increased by 13% when intra-row spacing decreased from 35 to 25 cm. The EARO (2004) determined that there is a little difference in yield between intra-row spacings of 25 and 30 cm for all varieties released so far in Ethiopia and the 30 cm intra-row spacing accepted as standard. Besides the above varying trends of optimum intra-row spacings, the plant population and arrangement of the intra-row spacing vary considerably depending on agro ecology, season, soil type, cropping system, variety and purpose.

The studies conducted so far to determine plant population have very limited scope in coverage of many of the factors mentioned above and the extent of their effect on yield. This study was therefore conducted with the objective of investigating the effect of different intra-row spacing on yield and yield components of some potato varieties under Geta Woreda condition and accordingly to identify suitable plant population and variety for better yield and yield components of potato.

2. LITRATURE REVIEW

2.1. Status of Potato Production in the World, Africa and Ethiopia

The world potato sector is undergoing major changes. Until the early 1990s, the major potato producers and consumers were 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 raised from less than 30 million tones in the early 1960s to more than 321 million tones in 2007 (CIP, 2008).

As estimated by FAOSTAT (2010), the land covered by potato in the World, Africa and Ethiopia in the year 2009 was 18, 326, 242; 1,705, 500 and 48,113 ha which gave a yield of 329,556,911; 20,163,381 and 384,046 tons, respectively. Potatoes are widely regarded as a secondary crop, and annual per capita consumption is estimated at just 5 kg. However, potato growing is expanding steadily. FAO estimates that the world production has increased from 280,000,000 tons in 1993 to around 329,556,000 tons in 2009 (FAOSTAT, 2010).

2.2. Factors Affecting Potato Growth, Yield and Quality

The yield of potatoes, as many crops, is dependent on many factors; the amount of minerals in the soil, plant spacing, cultivars, environmental factors like temperature, soil moisture, cultural practices varieties and pests (Rahemi *et al*., 2005).

2.2.1. Environmental factors

2.2.1.1. Temperature

Temperature has influential effects on the tuberization stimulus. Haverkort *et al.* (1990) pointed out that potato is best adapted to cool climates such as tropical highlands with mean daily temperatures between 5 and 18 ^{o}C as encountered in its center of origin. Higher temperatures favor foliar development and retard tuberization. In addition, heat stress leads to a higher number of smaller tubers per plant, lower tuber specific gravity with reduced dry matter content, and usually to a paler skin color of the tubers. Vreugdenhil (2007) reported that the highest relative growth rate of potato obtained at low temperature and low irradiance. They further explained; high temperature and low irradiance combination had the opposite effect, producing the lowest net assimilation and relative growth rates. Both tuber number and weight were markedly reduced by high temperature. Low irradiance in combination with high temperature produced virtually no tubers.

The rate of development of sprouts days to emergence depends on soil temperature. Vreugdenhil (2007) stated that emergence was linearly related to mean soil temperature and relatively independent of diurnal fluctuations up to an optimum of 22-24 ^{o}C and emergence was inhibited above this optimum level. The author also reviewed studies on the effect of 20 ^{o}C and 30 ^{o}C root zone temperatures on root growth and root morphology of six potato clones and reported significant genotypical differences in the responses of potato roots to 30 ^{o}C were observed, indicating the potential for selecting heat tolerant potato clones. In both heat tolerant and heat sensitive clones, the size of the root system was reduced by a 30 ^{o}C root zone temperature explained by a reduction in the cell division followed by cessation of root elongation.

Tuberization stimulus favors both tuber initiation and tuber enlargement. The optimum soil temperature for initiating tubers ranges from 16 to 19 °C (Western Potato Council, 2003). Reynolds and Ewing (1989) examined the influence of four air and soil day-night temperature treatments on root, tuber, and shoot growth in growth chambers: (cool air (19/17 ^{o}C), with cool or heated soil (20/18 °C or 32/31 °C); and hot air (34/30 °C), with hot or cooled soil (32/27 °C or 19/17 °C)). Cooling the soil at high air temperatures neither relieved visible symptoms of heat stress on shoot growth nor increased the degree of induction tuberization by the leaves. Heating the soil at cool air temperatures had no apparent detrimental effect on shoot growth or induction of tuberization by the leaves. Under high soil temperatures, stolonization was substantially compromised and there was no underground tuber development. In one experiment, stolons grew up out of the hot soil and formed aerial tubers above the soil surface in the cool air. The induction of tuberization by the leaves was affected mainly by air rather than soil temperature, but the signal to tuberize might be blocked by high soil temperatures. According to Mares *et al*. (1985), it is expected that the effect of high soil temperature on growing tubers would be similar to that of exogenously applied gibberellins, inhibiting tuberization. Tuber development declines as soil temperatures rise above 20 °C and tuber growth practically stops at soil temperatures above 30 °C. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favor development of large tubers (Western Potato Council, 2003).

Little research is available on the effect of soil temperature during tuber growth on potato grade and quality. Kincaid *et al*. (1993), assessing the influence of the interaction between water management and soil temperature on potato quality, observed that the critical period for tuber quality appears to be from mid-June to mid-July, based on measured soil temperature differences, frequent sprinkler irrigation reduced soil temperatures, along with the incidence of sugar-end tubers.

Yamaguchi *et al*. (1964) found that yield, specific gravity and starch content of Russet Burbank and 'White Rose' tubers were higher, and the sugar content lower when grown at soil temperatures between 15 and 24 ^{o}C, than when grown at higher temperatures. Ewing and Struik (1992) reports that in many areas the sequence of temperatures that most often brings economic damage to potato crops is warm temperatures early in the season, followed by cool temperatures that induce strong tuberization, followed in turn by another period of high temperatures. Such temperature oscillations lead to heat sprouts, chain tubers, and secondary growth of tubers. Apparently the fluctuations in tuberization stimulus cause tuber formation to alternate with more stolon like growth.

2.2.1.2. Moisture

Potato tuber response to soil moisture conditions begins before tuber set. MacKerron and Jefferies (1986) have shown that increased duration of water stress before tuber initiation reduces tuber set per stem. Where *Verticillium* wilt is present, there are advantages to keeping soils a little dry early in the season before tuber initiation (Cappaert *et al*., 1994; Eldredge *et* *al*., 1992). Jones and Johnson (1958) described the reduction in potato yield caused by water stress and Shock *et al*. (2003) reported that this yield reduction and overall stress effect varies potato varieties. Kleinkopf (1979) found that 'Russet Burbank' was more sensitive than the 'Butte' variety in forming misshapen tubers under water stress

Fluctuations in water that stress the potato plant during tuber development can be result in greater proportions of misshapen tubers of lower market grade. Corey and Myers (1955) determined that the proportion of misshapen tubers was directly related to moisture stress. Pereira and Villa Nova (2002) studied the effect of three irrigation treatments on tuber yield and grade and reported that fully irrigated potatoes had higher yields, better grade and fewer physiological defects.

Tuber physiological disorders such as brown center, hollow heart, and translucent end, as well as secondary growth, growth cracks, bruise susceptibility, and heat necrosis have been associated with water stress and/or wide variations in soil moisture content (Eldredge *et al*., 1996; Hooker, 1981; Hiller, *et al*., 1985; Mac Kerron and Jefferies, 1985; Rex *et al*., 1987; Shock *et al*., 1992). When induction to tuber is interrupted, the tubers show secondary growth, especially when the plant is exposed to irregular water supply. At stolon tip swelling, the plant of cell division changes, and there is an increase in radial cell expansion (Vanesse *et al*., 1999).

Wet soil is conducive to most tuber-rotting pathogens and excessive soil moisture following planting can promote seed piece decay and erratic plant. Excess soil moisture also encourages the incidence of blights, rots, and wilts, particularly prolonged excess soil water conditions. Therefore, avoiding over-irrigation, or even keeping soils a little dry early in the season before tuber initiation may reduce the amount of root infection. On the other hand, avoiding excessive plant water stress during the tuber bulking growth stage, which usually coincides with the warmest part of the season, may help decrease the severity of early die (Cappaert *et al*., 1994).

2.2.2. Cultural practices

Cultural practices such as type of planting material, earthing up, irrigation frequency and method, soil fertility and disease and insect pests greatly affect potato growth, yield and quality (Knowles *et al*., 2003).

Proper earthing up is one of the most important agronomic practices that affect yield and quality of potato tuber. In a growing cultivation, the tuber must be covered with an appropriate soil layer. This process conducted for the tubers protection from the direct light (which cause greening), high temperature (which cause second growth) and the insect injury such as potato moth. Bohl (2010) also reported that earthing up had significant effect on tuber number and average tuber weight per hill and tuber yield per ha and in all the cases the earthen plots gave the highest value compared to the non earthen plots.

Irrigation management practices can affect disease severity. The increased humidity from irrigation will have greater effects where the macroclimate is humid or sub-humid and be of less importance where it is drier. For potato grown in hot areas, sprinkler irrigation can cool the environment, with possible reductions in physiological defects. However, different irrigation methods can contribute to the occurrence of diseases and pests on the crop depending on site-specific weather pattern (Mustonen, 2006).

Potato vines that remain wet for long periods create a microenvironment conducive to early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), white mold (*Sclerotinia sclerotiorum*), and blackleg (*Rhizoctonia solani*) (Curwen, 1993). The timing of these diseases and associated crop losses vary regionally with yearly weather patterns, and can be affected by irrigation methods, which increase or decrease the duration of high humidity in the crop canopy.

Consistently rainy summer or fall weather promotes late blight (Stevenson, 1993). Irrigation that tends to keep the foliage wet may contribute to this developing risk. Potatoes cultivated under drip irrigation can receive a relatively low volume of irrigation water for a long time near the pivot, favoring late blight occurrence. Johnson *et al*. (2003) showed that the incidence of late blight tuber rot significantly increased as the amount of irrigation water applied increased, and was significantly greater within 30 cm of the pivot than at greater distances. Long duration sprinkler irrigation also favored late blight (Shock *et al*., 2003).

Long periods of leaf wetness or high relative humidity within the potato canopy favor infection by white mold (Powelson *et al*., 1993). Avoiding light, frequent irrigation of coarse-textured soils, and avoiding heavy, less frequent irrigation of fine-textured soils can diminish the risk of white mold. Simons and Gilligan (1997) found irrigation to increase the incidence of stem canker, stolen canker, and black scurf to a limited extent although the effect of season tended to be more pronounced on these defects than any of the agronomic treatments tested. While avoiding developing high humidity in the canopy, adequate soil moisture is essential not only for potato yield and quality but also for pest management strategies.

2.2.3. Disease and insect pests

Late blight, early blight, scab and bacterial wilt are major diseases of the potato crop that affect growth, yield and quality of the tubers. Moreover, cutworms, mites and potato tuber moth are major insect pests of potato (Vander Zaag, 1992). Adequate soil moisture helps to reduce the attack of cutworms (*Spodoptera litura*) and mites (*Tetranychus* spp and *Tenuipalpidaee* spp). Potato tuber moth (*Phthorimaea operculella*) and its larvae are repelled by soil moisture. Soil moisture also reduces formation of cracks in the soil, which allow the entry of potato tuber moth and its larvae (Grewal and Jaiswal, 1990).

2.2.4. Variety

The potential of potato growth, yield and quality is mainly determined by its genetic makeup and mostly governed by the environment (Barry *et al*., 1990). Potato varieties have varied response to the growing environment such as soil type (Falconer and Mackay, 1996). Endale *et al*. (2005) reported the occurrence of more tuber crack on Menagesha variety than Genet under vertisol condition of Ginchi and explained the variation in tuber growth cracking probably attributed to the genetic difference between the two varieties. Ahmed *et al*. (2000) reported that potato varieties significantly differ in tuber yield potential and resulted in different amount of yield under similar agro climatic condition. .Varieties that shed their leaves (early varieties) before others (late ones) maintained a higher radiation-use efficiency, and vice versa. However, in the absence of water limitation, water-efficient potato genotypes generally perform less than 'water spending' types (Vreugdenhil, 2007). Haverkort *et al*. (1992) also reported that potato varieties differ in maturity class. Ewing and Struik (1992) also reported that tubers of different potato varieties vary in size, skin and flesh colour and skin texture.

In Ethiopia, several varieties are under cultivation including those released from research centers and introduced at different times. There is no sufficient information on time of introduction, origin, quality and adaptation of the introduced potato varieties (Gebremedhin et al., 2001)

The yield, taste and better market price are the factors that were used to select potato varieties and/or cultivars (Gebremedhin *et al*., 2001). Some local varieties grown in Geta Woreda are 'Nech Abeba', 'Key Abeba', 'Agea' and 'Durame' which are susceptible to *P. infestans* and most farmers given up potato production from the main cropping season(June to September) due to the threats of the disease and shifted to the *belg* season and/or irrigated system.

2.2.5. Plant population

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

Competition occurs when two or more growing in an environment and the combined demands of the plants exceed the supply of one or more of the limiting factors for growth and development (Winch, 2006). In extreme cases of a crop growing in the absence of competition, its individual yield gives an indication of the maximum yield possible per plant.

Tubers on the same plant compete each other for assimilate. This competition depends on number of main stem per hill or per unit area (Moorby, 1978). Berga and Caesar (1990) also reported that stem number per plant and tuber number per plant are positively related, however, average tuber weight increased with wider spacing. Burton (1989) observed a strong intra row competition with closely planted potato tubers and yields decreased due to mutual shadowing of leaves resulting in high leaf area index reducing the total radiation intercepted and net assimilation. Optimizing of plant density is one of the most important agronomic practices of potato production managements, because it affects the seed cost, plant development, yield and quality of the crop (Bussan *et al*., 2007). In practice, plant density in potato crop is manipulated through the number and size of the seed tubers planted (Allen and Wurr, 1992).

Burton (1989) reported that if the spacing is too close the individual plant will suffer from 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 in that with an increasing density, height increases and with this there is much decrease in the axillary branching, which in turn decreases the photosynthetic potential and associated yield. Berga *et al*. (1994) reported that with wider spacing the average tuber weight increased whereas closer spacing total tuber number increased.

Yield of potato is strongly affected by the size of the leaf area and the duration of photosynthesis (Van Oijen, 1991; Boyd *et al*., 2001). Allen and Scott (1980) reported an increase in yield with increased plant population and this attributes to the increased ground cover which enables more light interception, consequently influencing photosynthesis. It is therefore, very likely that substantial increases in rate of land coverage and there by tuber yield could be achieved by dramatically increasing stem density, either by increasing size of the seed tuber or the number of plants per unit area. The formation of optimum-sized leaf area and maintaining the plant’s productivity for as long as possible are vital for obtaining high potato yields (Marschner, 1995; Van Delden, 2001). The rate of photosynthesis is highest in leaves that have just reached their maximum leaf area and plants at closer spacing allow the leaves to cover the ground as early as possible and thus favor more photosynthesis (Vander zaag, 1992).

The rate of photosynthesis depends on the leaf area, which itself depends on the growing conditions and plant population per a given area (Reich *et al.*, 1998). However, a larger mass of top leaves (canopy) may be an indicator of a larger leaf area, a higher rate of photosynthesis or a higher yield only when the leaves are not overshadowed and all the necessary components are provided. The vigorous growth of haulms or the density of the plants after canopy closure will cause overshadowing of many of the leaves, especially those on the lower section of the plant (Tooming, 1977, 1984). As light intensity decreases, a greater number of the lower leaves switch from net producers to net consumers of photosynthetic products. The production of organic matter from the whole plant therefore decreases and the tuber yield may be negatively affected (Boyd *et al*., 2001).

Leaf area index (LAI) indicates the ratio of the assimilative area of the leaf and the surface area (Eremeev, 2007). For optimal photosynthetic rate it is necessary that LAI should be 3.0 for as long a period as possible, otherwise the use of photosynthetically active radiation (PAR) and thus the production of organic matter, decreases (Winch, 2006).

Many studies have been conducted to establish the optimal planting density for a certain environments (Entz and La Croix, 1984; Barry *et al*., 1990; Strange and Blackmore, 1990; Kleinhenz and Bennett, 1992; Negi *et al*., 1995; Creamer *et al*., 1999 and Bussan *et al*., 2007).

Total yield increases with increasing plant density while percentage of large tubers decreased (Ifenkely, 1975). However, the optimal planting density differs depending on the environmental conditions and cultivars. As a general rule, the higher plant densities are recommended for early potato production systems in the Mediterranean type of environments since, out-season production of potato crop limits its growth and yield potential (Caliskan 1997; Mauromicale *et al*., 2003) of large seed tubers can be advantageous under certain circumstances such as soil and weather at planting are unfavorable, if the growing season is short and there is a risk of frost or drought during the first part of the growing season (Beukema and Vander zaag, 1990).

High plant population per hectare was reported to increase total yield, specific gravity and reduce the incidence of hollow heart. Yield increases were due to more tubers produced at the greater plant population per hectare but tuber size and individual plant yield decreases (Khalafalla, 2001).

The number of tuber set by plants is determined by stem density, spatial arrangement, cultivar and the growing season (Wurr *et al*., 2001). There are strong relationships between tuber yield and stem density (Bleasdale, 1965; Jarvis, 1977) and between tuber yields distribution in different size grades and stem density (Wurr, 1974). Thus, control over stem numbers is a fundamental requirement if growers are to control tuber size to meet market requirements. The best way of manipulating tuber number is by manipulating optimum spacing and size of the seed tubers.

The plant population and arrangement of the intra-row spacing that potato farmers in Ethiopia use vary considerably depending on agro ecology, season, soil type, cropping system, variety and purpose. In areas with shallow soils planting at wider spacing is used to get enough soil for earthing up. The studies conducted so far to determine plant population have very limited scope in coverage of many of the factors mentioned above and the extent of their effect on yield (Gebremedhin *et al*., 2001).

The study at Holetta showed the effects of intra-row spacing on tuber size and yield. In all varieties the highest total yield was obtained from the 20 cm intra-row spacing. In a situation where the number of tuber is of greater importance, as in seed production, the narrow intra-row spacing (20cm) is preferred (Gebremedhin *et al*., 2001). Based on the fixed relative variability and the close relationship between yield and average tuber size, tuber size distributions can easily be predicted once tuber numbers do not further change drastically. The position of the large tubers depends on the environmental conditions and the micro-environment around each individual stolon (Struik *et al*., 1991; Struik and Wiersema, 1999).

Total tuber number and the number of seed-size tubers (smaller-tuber) increased with closer spacing. In contrast the number of ware potatoes (larger potatoes) was greater with wider spacing as it can be seen from larger average tuber weight. Bohl (2010) also reported that intra-row spacing had a significant effect on tuber yield; the closest intra-row spacing (10 cm) gave the highest yield (19.10 t/ha) whereas the widest intra-row spacing (40cm) yielded the lowest (12.00 t/ha). Berga *et al*.(1994) have been concluded that intra-row spacing should depend on the intended use of the crop; closer intra-row spacing of 10 or 20 cm would be advantageous for seed and larger seed tubers from wider intra-row spacing of 30 cm to 40 cm are better for ware potatoes.

Besides of the importance of determining optimum intra-row spacing in potato production, the intra-row spacing fixed by different authors at different locations and seasons greatly vary due to the variations in potato cultivars and the growing environment. Rahemi *et al*. (2005) determined the 20 cm intra-row spacing as optimum for potato production. However, EARO (2004) recommended 30 cm as the standard intra-row spacing for potato production in Ethiopia.

Besides the above varying trends of optimum intra-row spacing, the plant population and arrangement of the intra-row spacing vary considerably depending on agro ecology, season, soil type, cropping system, variety and purpose (Rahemi *et al*., 2005).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The study was conducted in 2009/10 under irrigated condition at Geta Woreda, Guragie Zone, SNNPR; 235 km south-west from Addis Ababa, Ethiopia. The experimental site is located at an altitude of 2800 meters above sea level, 80^0 24’N latitude and 38^0 24’E longitude. The area is characterized by having an average annual rainfall of about 1350 mm, the mean maximum and minimum temperature of 23 ^{0}C and 7 ^{0}C, respectively. The physical and chemical properties of the soil of the study area are given in Appendix Table 5 (Personal communication).

3.2. Experimental Materials and Treatments

The experiment consisted of 16 treatments resulting from a factorial combination of two factors with, intra-row spacing at four levels and variety at four levels (Table 1).

Table 1. Details of the treatment combinations in the study area

Treatment	Description	Treatment	Description
T_1	Gudenne with 20 cm	T_9	Gera with 20 cm
T_2	Gudenne with 25 cm	T_{10}	Gera with 25 cm
T_3	Gudenne with 30 cm	T_{11}	Gera with 30 cm
T_4	Gudenne with 35 cm	T_{12}	Gera with 35 cm
T_5	Jalenne with 20 cm	T_{13}	Guassa with 20 cm
T_6	Jalenne with 25 cm	T_{14}	Guassa with 25 cm
T_7	Jalenne with 30 cm	T_{15}	Guassa with 30 cm
T_8	Jalenne with 35 cm	T_{16}	Guassa with 35 cm

T_1 to T_{16} represent the number of treatments

Table 2. Average yield and some other characteristics of potato varieties released by EARO that were used in the study 2009/10

Variety	Year of release	Area of adaptation		Maturity days	Yield (t/ha)		Releasing research center(s)
		Altitude (m a.s.l)	Rain fall (mm)		Research field	Farmer's field	
Gera	2003	2700-3200	800-1000	>120	25.93	23.64	Sheno and Holeta
Guassa	2002	2000-2800	1000-1500	110-115	22.40	20.50	Adet and Holeta
Gudenne	2006	1600-2800	750-1000	120	29.20	21.00	Holeta
Jalenne	2002	1600-2800	700-1000	90-120	44.80	29.13	Holeta

Source: EARO (2008)

There were 16 treatment combinations, consisting of four varieties (Gudenne, Jalenne, Gera and Guassa) and four intra-row spacing (20 cm, 25 cm, 30 cm and 35 cm). 30 cm intra-row spacing is the standard recommended for released potato varieties of Ethiopia. Two levels down and one level up were taken in determining the optimum intra-row spacing. The base for taking these intra-row spacing was the severe farm land shortage per household in the study area in order to answer the objective of the study by determining the optimum intra-row spacing for potato production in the study area to utilize the limited farm land effectively and efficiently.

The varieties were obtained from Holeta Agricultural Research Center. Well sprouted and medium sized tubers were selected for the experiment and planted on beds and spaced with 75 cm between rows and 20, 25, 30 and 35 cm intra-row spacing based on the laid out treatment combinations.

3.3 Experimental Design

The experiment was laid out in 4 x 4 factorial arrangements using a Randomized Complete Block Design (RCBD) with three replications. The width of each experimental plot was 3.75 meters and the length was adjusted 2.40 m. Each plot has five rows of which each row holds

12, 10, 8 and 7 plants per row for the 20, 25, 30 and 35 cm intra-row spacing, respectively. The distance between blocks and plots was one meter.

3.4. Management of the Experiment

The treatments received 165 kg/ha Urea and 195 kg/ha DAP (EARO, 2004). All the DAP and half of Urea fertilizers were applied during planting and the remaining half Urea was applied 45 days after 50% sprouting. Other management practices: weeding, hoeing, watering, and earthingup (Appendix Plate 1, 2 and 3) were provided as per EIAR recommendations (EARO, 2004).

3.5. Data Collected

Data were collected on vegetative growth and yield components. The following parameters were recorded for five randomly selected plants per plot.

Days to emergence: The number of days from tuber planting to tuber emergence was recorded at 50% emergence.

Days to 50% flowering: The number of days from tuber planting to plant flowering was recorded at 50% flowering.

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

Leaf area index (LAI): Fully opened and a representative sample of physiologically active green leaves were taken from randomly selected plants. From each plant only single stem was randomly taken and leaves stripped off from five different positions of the stem and the average leaf surface area was measured using an automatic leaf area meter, and multiplied by total leaves on the stem. The sum of all leaf surface area was divided by the ground area that a plant occupied (Bleasdale, 1965).

Plant height (cm): It was measured using ruler from the soil surface to the tip of the plant at full maturity.

Number of stems per hill: It was measured at maturity and expressed as number of stems per hill.

Total number of tubers per hill: It was measured at harvest and expressed as number of tubers per hill.

Marketable tuber number per hill: It was recorded at harvest by counting tubers which are healthy and greater than 20 mm in diameter, and expressed as number of tuber per hill (Endale and Gebremedhin, 2001).

Unmarketable tuber number per hill: It was recorded at harvest by counting tubers which are rotten, greened and less than 20 mm diameter, and expressed as unmarketable tuber number per hill (Endale and Gebremedhin, 2001).

Total tuber yield per hill: It was recorded after harvest and expressed in gram using a sensitive balance of model BP-16000-S with a precision of 0.01 and county in gram.

Marketable tuber yield per hill: It was recorded at harvest by weighing tubers which are healthy and greater than 20 mm in diameter, and expressed as weight of marketable tubers per hill.

Unmarketable tuber Yield per hill: It was recorded at harvest by weighing tubers which are rotten, green and less than 20 mm in diameter, and expressed as weight of unmarketable tubers per hill.

Marketable yield (t/ha): Tubers which were healthy and medium sized were weighed in kg/plant bases and converted into ton per hectare.

Unmarketable Yield (t/ha): Rotten, green and with least tuber size were weighed in kg/plant and converted into ton per hectare.

Total yield (t/ha): The total tuber yield (kg/plant) were weighed and converted into ton per hectare.

3.6. Statistical Analysis

The mean values of all the above parameters were subjected to Analysis of Variance (ANOVA) using the SAS package (SAS, 2002, version 9.2). Least Significant Difference (LSD) procedure was used to determine differences between treatment means whenever the treatments were significantly different. Linear correlation was applied for all parameters to establish a relationship between response parameters.

4. RESULTS AND DISCUSSION

The results recorded on yield and yield components of the potato varieties; Guddene, Jalenne Guasa, and Gera as affected by different levels of intra-row spacing are presented and discussed as follows.

4.1. Growth Parameters

4.1.1. Days to emergence

Varieties showed significant ($p < 0.001$) difference in emergence date. However, intra-row spacing and interaction effects showed non significant difference in emergence date (Table 3 and Appendix Table 1). This could be due to the inherent genetic differences between the varieties. Vander zaag *et al.* (1992) also reported that plant spacing did not influence shoot emergence.

Table 3 Means for Days to 50% emergence, days to 50% flowering, plant height and maturity date as influenced by variety

Variety	Days to 50% emergence	Days to 50% flowering	Plant height (cm)	Days to maturity
Gudenne	16.50^{c}	59.58^{b}	52.81^{a}	95.58^{d}
Jalenne	15.91^{c}	58.91^{b}	52.01^{a}	97.75^{c}
Gera	20.75^{a}	67.50^{a}	40.36^{d}	106.00^{a}
Guassa	17.41^{b}	54.00^{c}	50.60^{c}	101.41^{b}
LSD (5%)	0.91	1.32	0.65	1.14
CV (%)	6.15	2.64	1.59	1.36

Means with in the same column having the same letter are not significantly different at $p<0.05$

This result is in agreement with NJF (2006) that revealed varieties tested for early maturity showed significant differences in emergence date. The effect of varieties (Table 3) revealed that Jalenne emerged earlier than others (16 days). While Gera emerged late (21 days). Also this result is inconsistent with Eremeev (2007) that reported days to emergence to vary significantly among potato cultivars which could be attributed to the variation in nutrient and hormonal composition.

4.1.2. Days to 50% flowering

Variety showed a very highly significant ($p<0.001$) difference in days to flowering. However, intra-row spacing and interaction effects showed non significant difference in days to flowering (Table 3). The result revealed that Guassa flowers earlier (54) and *Gera* took longer (68) days for days to flowering. This might be due to inherent genetic factors. This result is in agreement with the Vreugdenhil (2007) who stated that days required to flowering is highly dependent on gene factors and governed by so many environmental factors; mainly temperature and light. The number of days required to flowering is one of the important parameter for potato farmers due to the fact that, it enables the grower to forecast its harvesting scheme as well as the marketing plan (Khalafalla, 2001)

4.1.3. Days to maturity

The analysis of variance for variety showed a very highly significant ($p<0.001$) difference between varieties in days to maturity (Table 3). In comparing the four varieties, Guddene was the earliest to mature (96 days). On the other hand, *Gera* took the longest time to reach maturity (106 days). This result is in accord of the findings of Tekalign (2005). EARO (2004) also stated that days to maturity of potato varieties varied from 90 to 120 days and the variation is accounted by variety, growing environment and cultural practices. The number of days to reach maturity is the important parameter for potato producers in that, it enables the growers to develop a suitable production scheme, season, as well as the marketing plan (Khalafalla, 2001) However, effects of intra-row spacing and interaction effects are non significant for days to maturity.

4.1.4. Plant height

The Varietal difference was very highly significant ($p<0.001$) on plant height (Table 3). Among the four varieties, Gudenne is the longest in height (52.81 cm) and the shortest was *Gera* (40.36 cm). This might be attributed to growth nature of various varieties. This result is in conformity with Tafi *et al.* (2010) who reported the presence of wider variability among potato varieties in terms of plant height.

Intra-row spacing also showed a significant ($p < 0.05$) effect on plant height (Table 4).

Table 4. Means for Plant height as influenced by the main effect of intra-row spacing

Intra-row spacing (cm)	plant height (cm)
20	49.18^{ab}
25	49.41^{a}
30	48.63^{b}
35	48.56^{b}
LSD (5%)	0.65
CV (%)	1.59

Means with in the same column having the same letter are not significantly different at $p<0.05$

The longest height (49.41cm) was recorded in 25 cm intra-row spacing while the shortest height (48.56 cm) was recorded in intra-row spacing of 35 cm. This result is in accord with the findings of Endale and Gebremedhin (2001) who reported significant effect of spacing on plant height of potato with different intra-row spacings. However, the analysis of variance for the interaction effects of variety with intra-row spacing showed non significant effect on plant height.

4.1.5. Leaf area index

The interaction effect of variety with intra-row spacing was very highly significant ($p < 0.001$) for leaf area index (Fig.1).

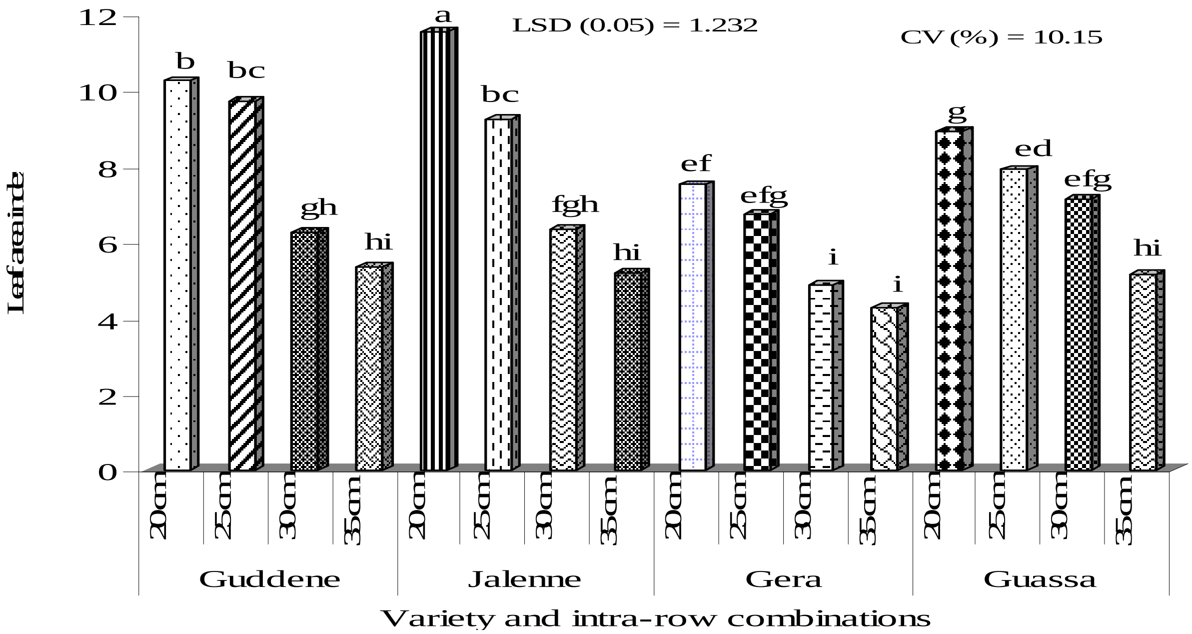

Fig.1. Leaf area index as influenced by the interaction effect of variety and intra-row spacing

The highest leaf area index was recorded for Jalenne planted at 20 cm intra-row spacing, whereas the lowest leaf area index was recorded for variety Gera planted at 35 cm intra-row spacing even though it was not statistically different from the leaf area index recorded for variety Gera planted at 30 cm intra-row spacing. According to Eremeev (2007), different potato cultivars have different LAI values and maximum LAI was attained by all cultivars at 75 days after planting.

This might be attributed to the presence of greater number of leaves recorded at closer spacing compared to the plants placed at wider spacing as well as the growth habit of different varieties. This result is in agreement with Burstall and Harris (1983) that reported the number of leaves at closer spacing is higher due to the presence of more number of plants at closer spacing than the sparsely populated plants.

The rate of gross photosynthesis is almost proportional to LAI (Vreugdenhil, 2007). In a closed canopy, however, leaf area extension is of minor importance compared to a young crop with sparse canopy coverage, because more light is intercepted at high LAI and further increase in LAI has only a marginal effect on photosynthesis. According to (Vander zaag, 1992) water deficit reduces leaf area or foliage growth and leaf area index.

4.1.6. Number of stems per hill

Variety and intra-row spacing showed a very highly significant ($p<0.001$) differences in number of stems per hill (Fig. 2).

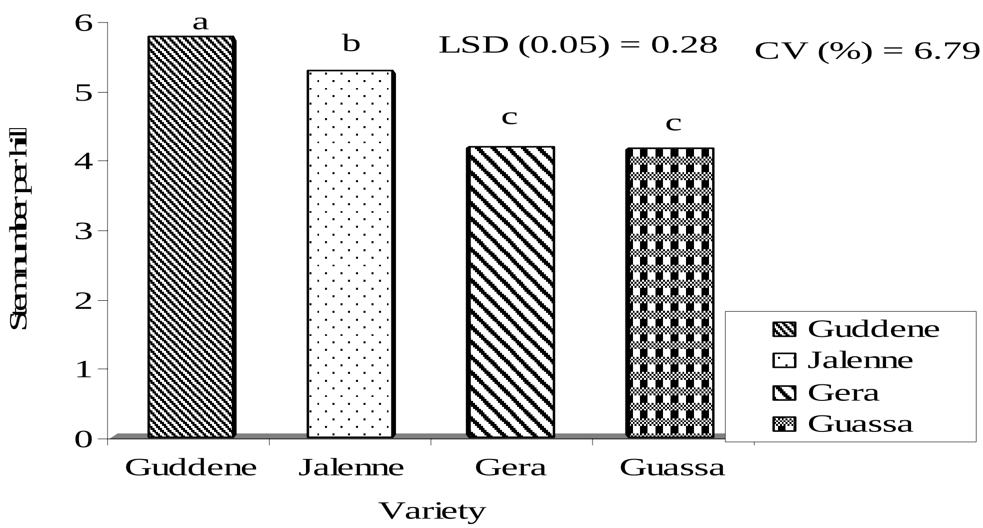

Fig. 2. Stem number per hill as influenced by variety.

However, the interaction effects of variety with intra-row spacing was non significant ($p>0.05$) for number of stems per hill. Maximum stem numbers (6) per hill were obtained from Gudenne variety and the lowest stem number (4) per plot was obtained from variety Guassa. The variation in stem number per plant among different potato varieties could be due to their inherent variation (Tekalign, 2005). This result is in conformity with Vander zaag *et al*. (1990) who reported stem number per hill variability among potato cultivars tested.

As far as the intra-row spacing is concerned, the highest number of stems per hill was recorded at 35 cm intra-row spacing and the lowest was at 20 cm intra-row spacing (Fig. 3).

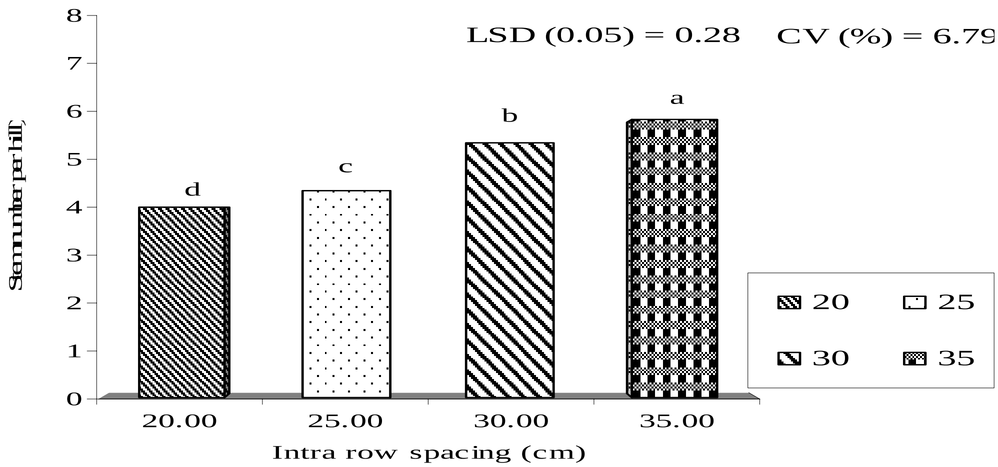

Fig.3. Stem number per hill as influenced by intra-row spacing.

This might be due to the minimal inter-plant competition for growth factors, such as moisture, soil nutrients and light. The result is in agreement with Berga and Caesar (1990) that reported as number of stems is affected by different intra-row spacing, eventhough in contradiction with Vander zaag *et al*. (1990) who reported numbers of main stems per plant were not influenced by spacing. Gulluoglu and Arloglu (2009) also reported that although number of main stems per plant was not significantly affected by intra-row spacing, number of main stems per unit area significantly decreased with wider intra-row spacing.

4.2. Yield Parameters

4.2.1. Number of marketable tubers per hill

Intra-row spacing showed a very highly significant ($p<0.001$) effect on number of marketable tubers per hill (Table 5). However, effects of variety and its interaction with intra-row spacing was non significant ($p>0.05$) for marketable tubers per hill (Appendix Table 3). Maximum marketable tuber number was obtained at intra-row spacing of 35 cm.

Table 5. Means for number of marketable and unmarketable tuber per hill as affected by intra rows spacing

Intra-row spacing (cm)	Number of marketable tuber per hill	Number of unmarketable tuber per hill
20	10.50[c]	6.75[a]
25	10.73[cb]	6.31[b]
30	11.31[b]	6.18[b]
35	12.28[a]	5.55[c]
LSD (5%)	0.62	0.35
CV (%)	6.67	7.04

Means with the same letter are not significantly different at $p < 0.05$

The lowest marketable tuber number (10.5) was recorded at 20 cm intra-row spacing. This might be due to the fact that plants at wider spacing practiced less competition for growth resources such as water, light and nutrients (Eremeev, 2007) whereas, plants that exhibit intense competition showed a decreased in tuber size which leads to less number of marketable tuber number.

Moreover, at closer spacing absence of air circulation resulted in development of disease and associated diseased plants which contribute more for un marketability (Midmore, 1988). Since the size of tubers produced at this planting density mostly have bigger sized tubers and the marketable yield per hill increased.

This result is in agreement with Khalafalla (2001) who reported marketable tuber number per hill increased with increase intra-row spacing and vice versa. Vander zaag *et al.* (1990) also reported that the share of large sized tuber (> 50 mm in diameter) increased from 91 to 95% as the intra-row spacing increased from 15 to 45 cm. Gulluoglu and Arloglu (2009) also reported that major yield components such as number of tuber per plant, mean tuber weight and tuber yield per plant significantly decreased as planting distance get closer due to increasing between plants competition. Bussan *et al.* (2007) reported that tuber production per plant are directly correlated with number of main stems per plant and significantly affected by distance between plants..

4.2.2. Number of unmarketable tubers per hill

Intra-row spacing showed a very highly significant ($p<0.001$) effect on number of unmarketable tubers per hill (Table 5). However, variety and its interaction with intra-row spacing was non significant on number of unmarketable tubers per hill.

The maximum and minimum unmarketable tuber number was recorded at 20 and 35 cm intra-row spacing, respectively. The result indicates that number of unmarketable tubers per hill decreases with increasing intra-row spacing, and vice versa. This might be due to the fact that at wider spacing the individual plants face less competition and resulted in big sized tubers which are marketable, whereas, at closer spacing due to more number of plants per unit area, the plants get severe competition and resulted in small sized and diseased tubers and associated with high unmarketable tuber number per hill. This result is in agreement with Khalafalla (2001) who reported unmarketable tuber number per hill increased with decreased intra-row spacing.

4.2.3. Total tuber number per hill

The effects of variety, intra-row spacing as well as their interaction were non significant on total number of tubers per hill (Appendix Table 3).

4.2.4. Marketable tuber yield

Highly significant ($p <0.001$) differences were observed on marketable tuber yield per hectare among the varieties and intra-row spacing (Table 6). However, the interaction effect was non significant. Higher marketable yield per hectare (32.65 t/ha) was obtained at 35 cm intra-row spacing and the lowest marketable yield per hectare (25.1 t/ha) was recorded from the 20 cm intra-row spacing. This could be due to the absence of intense inter-plant competition at wider spacing and the consequent result of healthy and large sized tubers that contribute the higher marketable yield. This result is in agreement with Vander zaag *et al.* (1990) that reported average tuber weight per plant was increased from 84 to 135 g as the intra-row spacing increased from 15 to 45 cm and there was a linear trend.

Table 6. Means for marketable, unmarketable and total tuber yield as influenced by variety and intra-row spacing

Variety	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)
Gudenne	29.72[ab]	4.40[ab]	34.12[ab]
Jalenne	31.69[a]	3.78[c]	35.47[a]
Gera	26.15[c]	4.68[a]	30.83[c]
Guassa	28.71[b]	4.05[bc]	32.76[bc]
LSD (5%)	2.04	0.38	2.06
CV (%)	8.39	10.47	7.43
Intra-row spacing (cm)			
20	25.10[c]	4.79[a]	29.95[b]
25	27.03[b]	4.29[b]	31.32[b]
30	31.42[a]	4.12[b]	35.54[a]
35	32.65[a]	3.72[c]	36.37[a]
LSD (5%)	2.04	0.38	2.06
CV (%)	8.39	10.74	7.43

Means with the same letter are not significantly different at $p<0.05$

The highest marketable yield was obtained from Jalenne (31.69 t/ha) whereas the lowest marketable yield per hectare (26.15 t/ha) was recorded for Gera. This could be due to the genetic variation among cultivars and respective response. This result is in agreement with the work of (Endale *et al*., 2001) who stated that varieties showed different requirements for different growth parameters and maximum tuber number and yield for different cultivar potatoes.

4.2.5. Unmarketable tuber yield

The effects of variety and intra-row spacing were highly significant ($p < 0.01$) and very highly significant ($p < 0.001$) on unmarketable tuber yield per hectare, respectively (Table 6). However, there was non significant interaction effect. The lowest unmarketable tuber yield (3.72 t ha^{-1}) was obtained at 35 cm intra-row spacing, whereas the highest unmarketable tuber yield (4.79 t ha^{-1}) was recorded at 20 cm intra- row spacing. This could be due to the presence of intense inter-plant competition at closer spacing and the consequent result of much small sized tubers that contribute to the higher unmarketable yield. This result is in agreement with the findings of Beukema and Vander zaag (1990) who pointed out that intra-row spacing had a marked effect on unmarketable tuber yield and the highest unmarketable yield recorded from the closer spacing due to higher inter-plant competition and associated small sized tubers. Rex *et al.* (1987) also reported that average tuber size is decreased because of increased inter-plant competition with closer spacing and resulted is high unmarketable yield per ha.

The least unmarketable tuber yield (3.78 t/ha) was obtained from Jalenne whereas, Gera produced the highest unmarketable tuber yield (4.68 t/ha). This result is in agreement with the findings of Rahemi *et al.* (2005) who reported that any varietal difference with planting density variation could influence biomass accumulation and subsequently marketable and un marketable tuber yield.

4.2.6. Total tuber yield

Intra-row spacing showed a very highly significant ($p < 0.001$) effect on total tuber yield per hectare (Table 6). However, the interaction effect was not statistically significant. Tubers planted at 30 and 35 cm intra-row spacing produced the highest and statistically similar yield per ha. Whereas the lowest yield per ha was recorded at 20 cm intra-row spacing but not statistically similar with 25 cm intra-row spacing. Even though the wider spacing gave relatively higher yield than the closer spacing, as compared to the higher tuber yield per individual plant base, the lower spacing gave higher yield per ha. This is due to the compensation effect of plants per hectare than the wider spacing, which results in higher yields of tuber per hectare (Burton, 1980).

The increased yield was attributed to more tubers produced at the higher plant population per hectare although average tuber size was decreased because of increased inter-plant competition at closely spaced plants leading to more unmarketable tuber yield. This result is in agreement with Mahamood (2005) who reported that the yield increments were attributed to more tubers produced at the higher plant population per hole although average tuber size was decreased because of increased inter-plant competition with close spacing. Rex *et al.* (1987) also reported that yield increment is attributed to more tubers being produced at the higher plant population per hectare although average tuber size is decreased because of increased inter-plant competition with closer spacing.

The highest yield recorded from the wider spacing could be explained by the presence of large sized tubers than the closer spaced because of the absence or limited competition among plants. According to the present result, the total marketable tuber number was higher at wider intra-row spacing than the closer ones (Table 5). This result is in conformity with Vander zaag *et al*. (1990), who stated that the final tuber yields per stem increases sharply with wider spacing.

The effect of variety was highly significant ($p < 0.01$) for total tuber yield per hectare (Table 6). The highest tuber yield (35.47 t/ha) was recorded for Jalenne whereas the lowest total tuber yield (30.83 t/ha) was for Gera and this could be due to genetic variation among the potato varieties. This result is in agreement with EARO (2008) which stated that Jalenne and Gera gave 44.80 t/ha and 25.90 t/ha tuber yield, respectively on research field.

4.4. Correlation Analysis among Yield and Quality Parameters

The correlation coefficients among response variables (Table 7) revealed that, the total tuber yield of potato was significantly and positively associated with plant height ($r = 0.31^{*}$), stem number ($r = 0.71^{**}$), marketable tuber number ($r = 0.31^{*}$) and marketable tuber yield ($r = 0.99^{**}$). This shows that total tuber yield favored by stem number, marketable tuber number and marketable tuber yield. When stem number increase, the plant canopy and associated leaf area increases leading to more carbon assimilation to the optimum level. The presence of high marketable tuber number and yield contributes much to the total yield because of the increase in individual tuber size and weight. Bleasdale (1965), Jarvis (1977) and Wurr (1974) reported a strong relationship between tuber yield and stem density, between tuber yield distributions in different size grades and stem density. Vander zaag *et al.* (1990) also showed a highly strong correlation between yield and stem number up to the optimum limit.

Days to tuber initiation showed highly and positively significant correlation with maturity date (r = 0.74**) and with days to flowering (r = 0.58**). It seems that delay in tuber initiation prolongs the growth period and the days to flowering. Thus, the period of tuber initiation is a determinant factor for the days to flowering and maturity. However, Ene Obong, (2007) reported a significant negative correlation between tuber yield, days to tuber initiation, and days to maturity under a cool mid-altitude area.

Total number of tubers was highly significantly and positively associated with marketable tuber number (r = 0.81**). This could be explained by production of more tuber number at wider spacing. This result is in conformity with Wiersema (1987) that reported the increase in intra-row spacing resulted in more number of tubers per plant. Eremeev (2007) also stated that the number of tubers per plant has strong correlation with the number of tubers in the tuber size fraction.

Marketable tuber yield of potato was significantly and positively associated with marketable tuber number (r =0.34*). This could be explained by production of more marketable tuber number at wider spacing resulted in higher marketable tuber yield per hectare.

The Leaf area index was significantly and positively associated with plant height (r =0.45*) and unmarketable tuber number (r =0.51**). According to Hay and Walker (1989), higher crop yield may not be associated with a higher photosynthetic capacity (LAI), because overshadowing of canopy affects carbon assimilation and favored for more respiration at the lower side leaves.

Days to maturity was significantly and positively correlated with days to emergence (r = 0.74**) and days to flowering (r =0.47*). This showed that early emergence and flowering contributed for early maturity of the tuber and vice versa because when tubers emerge earlier they start their growth earlier than late emerged tubers and finish their growth cycle faster.

Table 7. Correlation coefficients among parameters in potato varieties

Variable	PH	SN	MTN	UMTN	TNTU	DEM	DF	MD	LAI	MYT	UMYT
PH	1										
SN	0.39*	1									
MTN	0.01	0.44*	1								
UMTN	0.05	-0.44*	-0.38*	1							
TNTU	0.05	0.18	0.81**	0.22	1						
DEM	-0.83**	-0.40*	-0.07	-0.03	-0.09	1					
DF	-0.74**	-0.13	-0.10	0.04	-0.08	0.58**	1				
MD	-0.87**	-0.57**	-0.02	0.04	0.00	0.74**	0.47*	1			
LAI	0.45*	-0.35*	-0.45*	0.51**	-0.15	-0.40*	-0.17	-0.33*	1		
MYT	0.34*	0.71**	0.34*	-0.42*	0.09	-0.33*	-0.33*	-0.40*	-0.46*	1	
UMYT	-0.33*	-0.41*	-0.35*	0.25	-0.21	0.34*	0.44*	0.25	0.29	-0.63**	1
TOT	0.31*	0.71**	0.31*	-0.42*	0.06	-0.31*	-0.29	-0.40*	-0.46*	0.99**	-0.52**

**, * = indicate significant correlation at 0.01 and 0.05 probability level, respectively

Where PH=plant height, SN=stem number, MTN=marketable tuber number, UMTN=unmarketable tuber number, TNTU=total number of tuber, DEM=date of emergency, DF=date of flowering, MD=maturity date, LAI=leaf area index, MYT=marketable tuber yield, UMYT=unmarketable tuber yield, TOT=total tuber yield.

5. SUMMARY AND CONCLUSION

Ethiopia has the greatest potential for potato production and 70 percent of the arable land mainly in highland areas above 1500 m which is believed suitable for potato production. Since the highlands are also home for about 90 percent of Ethiopia's population, the potato could play a key role in ensuring national food security.

The study area is suited in the central high land and the most densely populated with very small land holding per household. Potato is the main staple and food security crop next to enset in the study area. Even though the study area is characterized as the potential potato producing area, using the low yielding local cultivars with out standardized spacing led the growers to be ineffective in properly using their scanty land holding which consequently resulted in inferior productivity.

Potato is main food for about three to four months in a year, May to August. Therefore, to utilize the small land intensively and to exploit the potential of the crop there was a need to develop proper agronomic packages such as optimum plant spacing and introduction of better performing varieties to the study area.

Optimum plant spacing and selection of high yielding variety are important economic considerations in potato production. These factors influence tuber yield and quality especially in terms of marketability, which may negatively affect the final income of the growers due to consumer rejection. The selection of best performing variety with suitable intra-row spacing helps to utilize the small land efficiently and intensively not only for higher ware tuber yield but also for quality tuber seed.

Since there is shortage of land and absence of improved varieties at the study area (Geta Woreda, Gurage Zone), an experiment was conducted to determine the optimum intra-row spacing for selected potato varieties (Gudenne, Jalenne, Gera and Guassa) at Geta Woreda, Gurage Zone in 2009/10 with irrigation.

The experiment consisted of two factors; four intra-row spacings (20, 25, 30, and 35 cm) and four varieties (Gudenne, Jalenne, Gera, and Guassa) arranged in a Randomized Complete Block Design replicated three times. Data for growth parameters were recorded before harvest and data for tuber number, marketable and unmarketable tuber number, and days to maturity were recorded at harvest. Whereas, yield, specific gravity, and tuber dry matter content were recorded after harvest.

From the results of this study, it was observed that variety had substantial influences on emergency date, days to flowering, plant height and maturity date. Accordingly, for Jalenne and Gudenne took shorter days to reach 50% emergence and Guassa took shorter days to reach 50% flowering. Gera took longer days for 50% emergence, 50% flowering and maturity dates. The highest plant height was recorded for Gudenne and Jalenne.

Stem number, marketable, unmarketable and total tuber yield (t/ha) were significantly affected by variety and intra row spacing. Explicitly, stem number and marketable tuber yield (t/ha) were increased with the increment of intra row spacing from 20 cm to 35 cm though the unmarketable tuber yield (t/ha) was decreased. Tuber production per plant are directly correlated with number of main stems per plant and significantly affected by intra-plant competition

This result revealed that Jalenne and Gudenne varieties planted at 30 cm intra-row spacing gave higher yield 31.69 and 29.72 t/ha respectively where as Gera recorded the lowest 26.15 t/ha. Thus it is advisable to the users using Jalenne and Gudenne for getting higher tuber yield. At closer plant spacing, unmarketable yield was also increased leading to lower marketable yield. It is, therefore, possible to increase marketable tuber yield by improved varieties and spacing manipulation.

Marketable and unmarketable tuber numbers per plant were influenced by intra-row spacing. In addition, the interaction effect of variety and intra-row spacing were significant for leaf area index. Accordingly, Jalenne planted at 20 cm intra-row spacing resulted in higher LAI than all other combinations.

In general, from the conducted experiment, it can be concluded that planting density and variety difference have valid effects on tuber yield and quality. Gudenne variety planted at 30 cm intra-row spacing were positively influenced the majority of yield and quality parameters evaluated. Thus, it is advisable to use variety Gudenne planted at 30 cm intra-row spacing for marketable tuber yield.

As this experiment was conducted only for one season at one location, further investigations are suggested to be conducted in line with irrigation methods and frequency, fertilizer types and rate, and at both major growing seasons **(***belg* and *meher*) to come up with complete recommendation and to ascertain the findings of this work.

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7. APPENDICES

Appendix Table 1. Mean square values of plant height, stem number, days to emergence, and days to flowering at Geta Woreda (2009/10)

Sources of variation	DF	Mean square values			
		plant height	stem number	days to emergence	days to flowering
Block	2	0.727	0.050	2.645	7.937
Variety	3	403.00***	7.93***	55.96***	374.38***
Spacing	3	2.07*	8.68***	1.243	6.05
Variety * spacing	9	0.816	0.238	1.631	5.70
Error	30	72.003	0.110	1.179	2.515

*, **, *** = indicates significant at (P < 0.05), (P <0.01) and (P <0.001) level respectively.

Appendix Table 2. Mean square values of, Leaf area index and days to maturity at Geta Woreda (2009/10)

Sources of variation	Degree of freedom	Mean square values	
		Leaf area index	Days to maturity
Block	2	0.21	2.437
Variety	3	12.16***	249.74***
Spacing	3	51.74***	0.74
Variety * spacing	9	1.84**	1.24
Error	30	0.55	1.86

*, **, *** = indicates significant at (P < 0.05), (P <0.01) and (P <0.001) level respectively.

Appendix Table 3. Mean square values of number of marketable, unmarketable, total number of and marketable tuber yield at Geta Woreda (2009/10)

Sources of variation	Degree of freedom	Mean square values			
		Number of marketable tubers	Number of unmarketable tubers	Total number of tubers	Marketable tuber yield
Block	2	4.84**	0.02ns	4.73*	0.97ns
Variety	3	0.08^{ns}	0.30ns	0.35ns	63.78***
Spacing	3	7.53***	2.95***	1.36ns	151.06***
Variety * spacing	9	0.08ns	0.26ns	0.29ns	6.95ns
Error	30	0.560	0.190	0.927	5.958

*, **, *** =indicates significant at (P < 0.05), (P <0.01) and (P <0.001) level respectively.

Appendix Table 4. Mean square values of Unmarketable tuber yield tone/ha and Total tuber yield tone/ha at Geta Woreda (2009/10)

Sources of variation	degree of freedom	Mean square values	
		Unmarketable tuber yield	total tuber yield t
Block	2	0.35	0.44
Variety	3	1.87**	47.07**
Spacing	3	2.35***	118.25***
Variety * spacing	9	0.15	6.07
Error	30	0.21	6.13

*, **, *** =indicates significant at (P < 0.05), (P <0.01) and (P <0.001) level respectively

Appendix Table 5. Some physical and chemical properties of soil at experimental site

Character	Sampling depth	pH 1:2.5	Ava. P (ppm)	OC %	Texture % fraction				Class
					EC (dS/m)	Sand	Silt	Clay	
values	20 cm	5.2	1.8	2.77	0.01	40	21	39	loam

OC = Organic carbon, p = available phosphorus (ppm), EC = electric conductivity, PH = Soil reaction.

Parameters & method used for the chemical and physical analysis were;

pH (H_2O)…………… …….1:2.5soil/Water paste using PH Electrode

Texture…………………….Hydrometer method

Organic Carbon……………Walkely & Black Method

Available Phosphorus …….Olsen Method