EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF POTATO (*Solanum tuberosum* L.) AT OFLA WOREDA, NORTHERN ETHIOPIA

M.Sc. Thesis

HARNET ABRHA

October, 2011

Jimma University

EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF POTATO (*Solanum tuberosum* L.) AT OFLA WOREDA, NORTHERN ETHIOPIA

A Thesis Submitted

to the College of Agriculture and Veterinary Medicine Department of Horticulture and Plant Sciences, School of Graduate Studies JIMMA UNIVERSITY

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

By

Harnet Abrha

October, 2011

Jimma University

APPROVAL SHEET

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

As thesis research advisors, we here by certify that we have read and evaluated this thesis prepared, under our guidance, by Harnet Abrha entitled "Effect of Inter and Intra Row Spacing on Yield and Yield Components of Potato (*Solanum tuberosum* L.) at Ofla Woreda, Northern Ethiopia." We recommend that it be accepted as fulfilling the thesis requirement.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

As members of the Board of examiners of the final M.Sc. Thesis Open Defense Examination, we certify that we have read and evaluated the thesis prepared by Harnet Abrha entitled "Effect of Inter and Intra Row Spacing on Yield and Yield Components of Potato (S*olanum tuberosum* L.*)* at Ofla Woreda, Northern Ethiopia" and recommend that it be accepted as fulfilling the Thesis requirements for the Degree of Master of Science in Horticulture (Vegetable Science).

Chairperson	Signature	Date
External Examiner	Signature	Date
Internal Examiner	Signature	Date

DEDICATION

I dedicate this thesis manuscript to **MY MOTHER MANA ABRHA** for her dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

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

Brief quotations from this thesis are allowable without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the Head of the Department of Horticulture or the Dean of the School of Graduate Studies when the proposed use of material is for scholarly interest. In all other instances, however, permission must be obtained from the Author.

Name: Harnet Abrha   Signature: ______________

Place: Jimma University, Jimma

Date of submission: ______________________

BIOGRAPHICAL SKETCH

The author, Harnet Abrha, was born on March 21, 1985 at Wukro, Eastern Tigray, Ethiopia. She attended her primary and junior secondary school from 1993 to 2003 at Haykimeshal Elementary School and Agazi Comprehensive Secondary School (Wukro), respectively.

She joined Jimma University in December, 2003 and completed her undergraduate study with B.Sc. degree in Horticulture on July, 2006. Up on her graduation, she was recruited as junior researcher at Alamata Agricultural Research Center (AARC) of the Tigray Agricultural research Institute (TARI) in December 2008 after two year service at the research center; she joined Jimma University in September 2009 to pursue her post-graduate study leading to M.Sc. Degree in Horticulture (Vegetable Science).

ACKNOWLEDGEMENTS

First of all, I would like to express my heartfelt appreciation and special gratitude to my major advisor Dr. Derbew Belew for his guidance, inspiration, encouragement and support throughout the study period which made the completion of this study smooth and successful.

I wish to take this opportunity to extend special gratitude to my research co-advisor Mr. G/medihin Woldegiorgis for his inspiration, thoughtful guidance and suggestions from the very beginning in executing the research work and in the write-up of the thesis.

I would like to thank the Tigray Agricultural Research Institute (TARI) and Ethiopian Institute of Agricultural Research (EIAR) for offering me the opportunity of this study. I am also thankful to Rural Capacity Building Project for sponsoring the M.Sc thesis study.

I also highly appreciate and thank Mr. Muez Mehari and Miss Mizan Tesfay for their comprehensive support, kind-hearted treatment, assistance, collaboration, organizing and mobilizing all the necessary facilities during the study period. I would like also to express my sincere gratitude to my best friends Miss Serkalem Getahun and Mr. Besufekad Enideg for their moral support and unreserved all rounded help that contributed directly or indirectly towards the completion of this work.

I would like to express my special thanks to Mr. Tesfay Hagos coordinator of Alamata Agricultural Research Center for mobilizing some of the facilities necessary for the experiment. I would like to thank Mrs. Luchiya Tekle and Mr. Kebede Manjur for their comprehensive support, special treatment and friendly advice during the time of study.

My thanks go to Mr. Berhanu Amare, for his valuable help in site selection and co-operation in data collection. I would like to thank the Holeta Agricultural Research Center for providing me potato-seed-tubers used for the study. Special thanks and appreciations is also extended to all, who are too many to mention, who have in one way or another contributed to the successful completion of the study.

I would like to express my heartfelt gratitude to my father Haftu G/slasse and my mother Mana Abrha for their dedication in bringing me up and strong support throughout my life. I would like to acknowledge my lovely sisters Mulu Abrha, Selamawit Haftu and Rahel Haftu for their endless encouragement and moral support during the study period.

Last, but not least, I would like to thank my grandmother Emahoy Kahsa Reda for her encouragement, affection and prayer served me as a source of strength, inspiration, impetus and she nurtured and inspired me with strong belief in God throughout my life.

Above all, I would like to thank the Almighty God for He made all things possible to finish the study.

ABBREVIATIONS AND ACRONYMS

AARC	Alamata Agricultural Researcher Center
BoANRM	Bureau of Agriculture and Natural Resources Management
BoARD	Bureau of Agriculture and Rural Development
CIP	International Potato Center
CV	Coefficient of variance
DPI	Department of Primary Industries
EARO	Ethiopia Agriculture Research Organization
FAO	Food and Agriculture Organization of United Nations
FAOSTAT	Food and Agricultural Organization of the United Nation Statistics
LA	Leaf Area
LAI	Leaf area index
LSD	Least significant difference
MoARD	Ministry of Agricultural and Rural Development of Ethiopia
RCBP	Rural Capacity Building Project
TARI	Tigray Agricultural Research Institute

TABLE OF CONTENTS

Contents Page

LIST OF TABLES

Tables **Page**

LIST OF FIGURES

Figures **Page**

LIST OF APPENDICES

Appendix Tables **Page**

EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF POTATO *(Solanum tuberosum* L.) AT OFLA WOREDA, NORTHERN ETHIOPIA

ABSTRACT

A 4x4 factorial experiment arranged in Randomized Complete Block Design (RCBD) with three replications was conducted at Ofla Woreda, Southern Zone of Tigray from December 2010 to April 2011 to assess the effect of inter-row and intra-row spacing on yield and yield components of potato (Solanum tuberosum L.). *Four different intra-row (20, 25, 30 and 35 cm) and inter-row (65, 70, 75 and 80 cm) spacing were used in the experiment. The result revealed that inter and intra-row spacing significantly ($p<0.001$) affected total tuber number ha^{-1}, the maximum total tuber number (532,865 and 558,174) was recorded at 65 and 20 cm inter and intra-row spacing, respectively. While the lowest (447,586 and 430,311) at 80 and 35 cm inter and intra row spacing, respectively. Inter and intra-row spacing significantly affected total tuber yield ha^{-1}, the maximum tuber yield (36.89 and 37.54 ton ha^{-1}) was recorded at 65 and 20 cm inter and intra-row spacing, respectively, while the lowest (31.87 and 29.38 ton ha^{-1}) was recorded at the widest (80 and 35cm) inter and intra-row spacing, respectively. Significantly maximum marketable tuber number (485,144 and 501,651 ha^{-1}) was obtained at 65 and 20 cm inter and intra-row spacing, respectively. Inter and intra-row spacing also showed significant effect on marketable yield ha^{-1}, the maximum marketable yield (35.89 and 35.09 ton ha^{-1}) was recorded at 20 and 65 cm intra-row and inter row spacing, respectively. Interaction of inter and intra-row spacing significantly affected unmarketable yield ha^{-1}. The maximum unmarketable yield (2.403 ton ha^{-1}) was recorded by combination of 65 and 20 cm between row and within-row plant spacing. While the lowest unmarketable yield (0.24 ton ha^{-1}) was recorded by the combination of 80 and 35 inter and intra-row spacing. Total yield per hectare was highly and positively correlated with marketable yield per hectare ($r=0.99$***), total tuber number per hectare ($r=0.64$**) and number of marketable tuber ha^{-1} ($r=0.55$**). Significantly ($p<0.01$) the highest leaf area index (3.21) was recorded at 20 cm intra-row spacing, while the lowest (2.32) was obtained at 35 cm spacing. Similarly leaf area index was highly and positively correlated with tuber yield ha^{-1} ($r=0.71$**), total tuber number ha^{-1} ($r=0.61$**), marketable yield ha^{-1}(r=0. 0.69**), number of marketable tuber ha^{-1} ($r=0.55$**). The result of this study verified that yield and yield components of potato are influenced by different inter-and intra-row spacings. From this study, it can be concluded that the narrow spacing (20 and 65 cm intra and inter-row spacing) produced higher yield and marketable yield per hectare than other spacings. Thus, potato (Jalenie variety) growers in the study area (southern zone of Tigray) can be benefited if they use this narrow spacing (20 and 65 cm intra and inter-row spacing).*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is originated in the high Andes of South America and was first cultivated in the vicinity of Lake Titicaca near the present border of Peru and Bolivia (Horton, 1987). In the term of quantity produced and consumed worldwide, potato is the most important vegetable crop. It is one of the most important food crops in the world, in volume of world crops production it ranks fourth following by wheat, rice and maize (FAO, 2008). Among the root and tuber crops, it ranks first followed by cassava, sweet potatoes and yams (Hawkes, 1990; FAO, 2008).

Potato produces more energy and protein per unit area and unit of time than most other major food crops; it is fat-free and contains substantial amounts of minerals (Lutaladio and Castaldi, 2009). The balance of protein to calories, the balance among the more important amino acids in protein, and the composition of minerals make potato second only to eggs in nutritional value as a single source (Swaminatha and Sawyer, 1983). Potato ranks first in the expansion of production in the developing countries (FAO, 2010).

The crop is 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 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). Based on those facts currently government and non-government organization give a great attention 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.

The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist (Pankhurst, 1964). Among African countries, Ethiopia has possibly the greatest potential for potato production; 70 percent of its arable land mainly in highland areas above 1500 m is believed suitable for potato. 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 (FAO, 2008).

However, the current area cropped with potato about 0.16 million hectares and the national average yield is about 7.2 t/ha, which is very low as compared to the world's average production of 16.8 t/ha (Adane *et al*., 2010). The crop yield in Ethiopia is lower than that of most potato producing countries in Africa like South Africa and Egypt, which produce 34.0 and 24.8 t/ha, respectively (FAO, 2008). At present, potatoes are still 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 production has increased from 280 000 tones in 1993 to around 525 000 tones in 2007 and 280 million tons in 1993 to around 329,556,000 tons in 2009 in Ethiopia and World respectively (FAOSTAT, 2010).

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).

Many diverse and complex biotic, abiotic, and human factors have contributed to the existing low productivity of potato. Some of the production constraints which have contributed to the limited production or expansion of potato in Ethiopia include shortages of good quality seed tubers of improved cultivars, disease and pests, and lack of appropriate agronomic practices including optimum plant density, planting date, soil moisture, row planting, depth of planting, ridging and fertility status (Berga *et al*., 1994).

The optimizing of plant density is one of the most important subjects of potato production management, because it affects 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). Therefore, many studies have been conducted to establish the optimal combination of seed size and planting distance for a certain environment (Barry *et al*., 1990; Strange and Blackmore, 1990; Kleinhenz and Bennett, 1992; Negi *et al*., 1995; Creamer *et al*., 1999; Bussan *et al*., 2007). In general, total yields increased as increasing plant density while percentage of large tubers decreased. However, the optimal planting density differed depending on the environmental conditions and cultivars. 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).

A study at Alemaya evaluated the effect of three row width (60, 70 and 80 cm) in combination with four in-row distance (10, 20, 30 and 40 cm) the wider row width by wider in-row distance (80 x 40 cm) gave the highest (34 t/ha) yield and the 60 x 20 treatment gave the lowest yield (22.2 t/ha) (Berga *et al.,* 1994). In contrary the number of tuber set by plants is 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 during the maturity (O'Brien and Allen, 2009).

The optimum intra-row spacing in potato production plays a great role on yield and yield components. Ahmed (1989) found that closer spacing (20 cm) gave higher yields than wider spacing (30 cm). Rahemi *et al.* (2005) also reported that 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. Intra-row distance of 20 cm increased total tuber number and weight, and tuber weight per plant and the marginal return rate increased by 13% when intra-row distance decreased from 35 to 25 cm. EARO (2004) also determined that there is a little difference in yield between intra-row spacing of 25 and 30 cm for all varieties released so far in Ethiopia and the 30 cm intra-row spacing accepted as standard. Besides to the above varying trends of optimum spacings, 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.

Farmers in the study area (Sothern zone of Tigray) are using different spacing below or above the national recommendation depending on the purpose of planting either for consumption or seed tuber due to lack of recommended inter and intra- row spacing. Hence, it is important to maintain appropriate plant population per unit area to have high yield, marketable size and good quality of seed tuber. Even though different research is done in different parts of the country about potato plant density, the condition is not studied in Ofla Woreda, Southern Zone of Tigray. This study was therefore conducted with the objective:

- To determine the best inter and intra-row spacing for optimum yield and quality of potato tuber at Ofla Wereda, Northern Ethiopia.

2. LITERATURE REVIEW

2.1 The Potato Plant

The potato (*Solonaum tuberosum L.*) is a member of the *Solanaceae* family with chromosome number of 2n= 48 (Decoteou, 2005). As a popular belief the potato is not a storage root, but rather a specialized underground stem. If a whole tuber or piece of tuber containing one or more eyes is planted, the buds sprout and a plant develops above the ground. Well before plant emergence the developing sprout grows adventitious roots, which constitute the root system. Also developing from the underground portion of the stem are stolons (rhizomes), which may bear new tubers at their tips (Ewing, 1997).

The main stem of the potato plant terminates in a flower cluster. Flower bud abortion may occur at a very early stage of development; but in any case apical growth of the main stem ceases with formation of the flower buds. The cessation of growth of the main shoot axis may not be obvious because sympodial growth of one or more axillary branches just below the apex permits further extension above the flower cluster. After developing up to six or more leaves, the new axillary branch (es) will terminate in a flower cluster in the same manner; but new sympodial growth may again occur. In this manner the main axis may be extended by three or more levels of branching (Alemkinders and Struik, 1994).

Branching may occur at any node, but branching is most common at the base of the plant. Some branches arise from underground nodes on the main stem. Without disturbing the soil it is difficult to distinguish these from stems that have arisen from separate eyes of the seed tuber. Other axillary branches arise from nodes just above the soil level. End of the growth of the main axis associated with flower bud formation encourages basal axillary branching. The extent of axillary branching, both sympodial and basal, is of crucial importance in determining yield potential.

Propagation from tubers is vegetative, not sexual. All plants obtained from the offspring of a single tuber are genetically identical, unless chance mutations have occurred. This means that all tubers of a given cultivar should be highly uniform unless they have become infected with a disease organism (Ewing, 1997).

2.2 Importance of Potato

Potato is the most important food crop, after cereals, in human diet. It surpasses wheat, rice and corn in the production of dry matter and protein per unit of area (Romero-Lima *et al*., 2000). It is one of the world's major staple crops producing high yields of nutritionally valuable food in the form of tubers, which is an excellent source of carbohydrates, proteins, vitamins and minerals. It is also an important crop towards food security, although it is a minor crop in the world trade (Sadowska *et al*., 2004; Miller *et al*., 2006).

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 requirement of vitamin C, which other staples such as rice and wheat have none. Potato is very low in its fat content, just 5 percent of the fat content in wheat, and one- fourth of the calories of bread. Boiled potato has more protein, and nearly twice the calcium than maize. It has the highest protein content (around 2.1 percent on a fresh weight basis) of a fairly high quality as compared to other root and tuber crops, especially its amino acid pattern is reported to match well to human requirements (FAO, 2008). Recent data indicate that potatoes produce 54 percent more protein per unit of land area than wheat and 78 percent more than rice. No other foods, not even soybean, can match the potato for production of food energy and food value per unit of land area (Stevenson *et al*., 2001).

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 FAOSTAT (1998), potato consumption in developing countries had increased from 9 kg/capita in 1961-1963 to 14 kg/capita in 1995-97. These averages are still a fraction of per capita consumption levels of 86 and 63 kg/year in Europe and in North America respectively, suggesting the possibilities of future increment in per capita consumption (Otroshy, 2006).

2.3 Cultural Requirements of Potato

The potato is considered a cool season vegetable crop, although it possesses only moderate frost tolerance. Optimum temperature for foliage growth and net photosynthesis are 15- 25^{o}C and 20^{o}C for tuberization. When the temperature is above 29^{o}C tuberization is inhabit, foliage growth is promoted and net photosynthesis and assimilate partitioning to the tubers are reduced (Thornton *et al*., 1996).

The root system of the potato plant is not extensive and ample soil water is necessary whether from rain or supplemental irrigation. Potato plants require a well drained soil. The most attractive tuber shape and skin appearance are achieved with light, sandy soils or with muck soils. It should be grown at soil reaction between pH of 4.8 to 5.4. This is mainly to control the scab disease of potato. Better tuber yields have been obtained from potatoes grown at soil reaction ranging from pH 5.0 to 7.0 (AGRISNET, 2010).

Seed tubers that are planted too deep will be slow to emerge and may be more subject to attack by various diseases. 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. Many growers like to plant seed tubers relatively deep but then cover them with only a shallow layer of soil, more soil covering will then be added as the plant develops (Alexander *et al*., 2001). A good rule of thumb is never to have more than 10 cm 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. 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. Secondary benefits of ridging up the soil are that it facilitates harvest and provides weed control (Gebremedihin *et al.*, 2008; Suman, 2010).

The rate of nitrogen fertilization is a key consideration in managing fertility, because excessive applications delay maturity and reduce the partitioning of dry matter to the tubers, not to mention possible adverse effects on processing quality and on the environment (Ewing, 1997).

2.4 Effect of Inter and Intra-Row Spacing on Yield and Yield Component of Potato

It is well known that 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 elements reduction, increase in interspecies competition and large number of tubers produced by high number of stems.

Georgakis *et al*. (1997) concluded that by increasing plant density, the tuber yield was increased. Karafyllidis *et al*. (1997) also reported 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 densities. Alvin *et al*. (2007) reported that with increasing plant density, yield of potato increased. On the other hand, increase in plant density, probably is the reason of the lack of nutrient elements for each plant or production of more tubers per unit area and reduction of their mean size. Zabihi *et al*. (2011) also reported 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.

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 (Mauromicale *et al*., 2003). Planting of large seed tubers can be advantageous under certain circumstances such as soil and weather conditions at planting are unfavorable, if the growing season is short and if there is a risk (frost, hail or drought) during the first part of the growing season (Beukema and Vander Zaag, 1990). Hammes (1985) had studied the effects of competition on potato crop and reported that, potato possesses self regulating mechanism and there for, could adapt to new competitive situations, which allow reaching a state of tuber yield equilibrium at higher densities.

At Alemaya evaluation was done on the effect of three inter-row spacing (60, 70 and 80 cm) in combination with four intra-row spacing (10, 20, 30 and 40 cm), the wider inter-row by wider intra-row spacing (80 x 40 cm) was obtained highest yield (34 t/ha) and at narrow spacing (60 x 20 cm) the lowest yield (22.2 t/ha) was obtained (Berga *et al.,* 1994). In related study Holetta evaluated the effect of intra-row spacing on tuber size and yield of different varieties. In all varieties the highest total yield was obtained from the 20 cm intra-row and 75 cm inter-row spacing. In a situation where the number of tuber is of greater importance, as in seed production, the narrow intra-row spacing (20 cm) is preferred (Gebremedhin *et al*., 2001).

According to Leyla and Halis (2009) closer spacing reduced tuber number per hill, average tuber weight, tuber yield per hill and percentages of large and medium size tubers and total yields increased as increasing planting density up to 20 cm spacing.

Very little or no benefit is gained from increasing row width above 75 cm. Yield was consistently and significantly improved for in-row spacing of 10, 20 and 30 cm as row width increased from 45 to 75 cm (Allen *et al*., 1992). 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. Bohl *et al.* (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).

2.5 Leaf Area Index

Tuber yield in potato is closely related to the plants ability to intercept solar radiation and its efficiency in dry matter accumulation. Intercepted radiation levels may be determined using leaf area and ground cover measurements (Boyd *et al*., 2002).

Midmore (1992) 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*., 1995). 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, 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 *et al*., 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).

2.6 Yield Components of Potato

Yield development in potato is known to be the result of three physiological processes leading to the formation of yield components (De la Morena *et al*., 1994). These 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. The sequential system of yield development of the potato involves interactions among individual yield components, in which later developing components are found to be dependent upon earlier developing ones (De la Morena *et al*., 1994).

2.6.1 Main stems number per plant

The potato plant commonly consists of various stems, each stem forming roots, stolen and tuber behaving like an independent plant. It is usually propagated by using underground storage organs known as tubers. Potato tubers show a wide range of variation and possess 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 stem that bears the leaves and flowers, and the underground one whose terminal portion swells to form the tubers as it accumulates starch and sugars from photosynthesis in leaves.

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 on the number of eyes on tuber surface, there seems to be only one eye on a tuber that develops into stems and also no difference exists between eye types (apical or lateral) in their yield potential (Rajadurai, 1994).

The increases 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. Similar results were also reported by Burhan (2007) where yield total and marketable tuber yield exposed close relationship with number of main stems or above ground stems. He indicated that high number of stem per plant to favor tuber production, influencing the growth of haulm and the number of tuber per plant. In contrast to these reports, Iritani *et al*. (1983) reported higher number of stem per plant to bring about yield reduction, as these results in the increase of small tuber size. Hammes (1985) also reported that no relationship between yield and main stems, for at the same above ground stem density, seed tuber with many main stems and seed tubers with single well branched main stems give similar yield.

The number of stems per plant is reported to be under the influence of variety, seed (tuber) size, physiological age of the seed, storage condition, and number of viable sprouts at planting, sprout damage at the time of planting and growing conditions (De la Morena *et al*., 1994).

Many investigators reported the absence of close relationship between mineral nutrition and the number of stems per plant (De la Morena *et al*., 1994; Lynch and Rowberry, 1997). Lynch and Rowberry (1997) from their studies on yield development of potato as influenced by nitrogen fertilizer observed that the yield difference due to nitrogen treatment was not attributed to its effect on stem density as the number of stems was not significantly influenced by nitrogen nutrition.

According to Wiersema (1987), the main stem grows directly from the seed tuber and more productive unlike secondary stem that are generally less productive. The latter is not considered in determining stem density or stand population of potato, except when they branch below the soil surface near the seed tuber and produce roots. Therefore, main stems together with lateral stems branching from the main stem below the soil surface from the above ground stems. According to Leyla and Halis (2009) number of main stems per plant was not significantly affected by in-row spacing, number of main stems per unit area significantly decreased with wider in-row spacing.

2.6.2 Tuber number

The number of tubers formed per plant is called the tuber set. The plant may initially produce 20 to 30 small tubers, but only 5 to 15 tubers typically reach maturity. The growing plant absorbs some of the tubers in the original set. The number of tubers that achieve maturity is related to available moisture and nutrition. Optimum moisture and nutrient levels early in the growing season are critical to the maintenance and development of tubers. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas a higher temperature favors development of large tubers (Western Potato Council, 2003).

The number of tuber set by plants is determined by stem density, spatial arrangement, cultivar and season (Wurr *et al*., 2001). Number of tubers set per potato plant largely governs the total tuber yield as well as the size categories of potato tubers. Number of tubers set by plants was determined by stem density, spatial arrangement, variety, season and crop management. Increase in the stem density over the economical range (which varies with the soil type, climate, management etc.) resulted in a reduction in the number of tubers set per stem. 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 that increasing stem density over a wide range either by planting larger seed tubers or more seed tubers for most varieties resulted in increased number of tubers per unit area. The number of tuber set by plants also affected by cultivar and the growing season. Spatial arrangement affected the number of tubers in a similar manner to that of density, since increasing rectangularity reduced number of tubers set per stem, while increasing tuber number per plant.

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. 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 spacings of 30 cm to 40 cm are better for ware potatoes.

2.6.3 Average tuber weight

Average tuber weight has been reported to be the third most important yield component contributing to the total tuber yield (Lynch and Tai, 1989; De la Morena *et al*., 1994). The growth of tuber tissue is reported to occur both by cell division as well as expansion. Tuber weight is affected by variety and growth conditions. Environmental factors that favor cell division and cell expansion such as optimum water supply, mineral nutrition, etc were reported to enhance tuber size (Reeve *et al*., 1973).

Saluzzo *et al*. (1999) suggested 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. 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. Ali (1997) also reported that increase in density probably causes the increase in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight.

2.7 Yield

2.7.1 Total tuber yield

According to Tisdale *et al*. (1995), factors limiting crop yield both in quantity as well as quality can be categorized into four major headings: the management practices, the soil upon which the crop grows, the genetic make-up of the crop and the climatic conditions during the growth of the crop.

The optimum growth condition could increases 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 is turn improve early tuber growth, but it may be counterbalanced by increase in leaf senescence that reduces photosynthesis and slow tuber growth (Ronald, 2005).

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 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).

2.7.2 Marketable tuber yield

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

It has been reported by many authors (Stoffela and Bryan, 1988; Khalafalla, 2001) regarding plant density effect on marketability of the crop. Close spacing of 15-25 cm was reported to give better proportion of marketable yield than wider spacing of 35 cm; both plant spacing and seed size are reported to have considerable effect 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 (Stoffella and Bryan, 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 practice like plant density is the factor for determining marketable yield and reducing or decreasing unmarketable yield (Geremew *et al*., 2010). According to this report, the highest marketable yield of tomato 607.9 q/ha was obtained at closer spacing of (40 x 30 cm) whereas, the lowest marketable yield (475.85 q/ha) was recorded from the widest spacing (100 × 30 cm).

2.8 Quality Traits of Potato

2.8.1 Potato tuber size categories

Tuber size is 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. The market demand for shapes and sizes of tubers varies. The size of tubers required by consumers depends upon the ease of handling for household purposes and also upon the acceptable level of peeling loss (Mulubrhan, 2004).

Seed tuber size generally influenced performance of the potato crop such as emergence, seedling vigor, subsequent plant growth and final yield. 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 computation reduced the average tuber size. Further they indicated that varieties that set many tubers per stem require significantly lower stem densities for graded yield than for total yield. Such varieties were inappropriate for the production of the larger tuber size grades.

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 saleable 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 is influenced by the planting density and the number of sprouts that form from each seed tuber.

2.8.2 Dry matter content (DMC)

It is often necessary to know the dry matter content of potato tubers since this largely governs the weight of processed products, which can be obtained from a given weight of raw tubers. It is also one of the determinants of tuber quality, both for processing as well as cooking (DPI, 2010). Tuber dry matter content can also modified by production system and climate factors like, (solar radiation, air temperature and soil moisture). Therefore, the use of pre-sprouted potato seed tubers or higher seedling density exerts a strong positive effect on dry matter content, while late planting reduces dry matter content of tubes (Storey and Davies, 1992; DPI, 2010).

Nelson and Jenkins (1989) reported that, tuber dry matter percentage was largely a function of yield. They showed a liner relationship between tuber dry matter percentage and the mean fresh tuber weight during the main period of tuber bulking.

Increasing plant density resulted in higher tuber yield, number of stolon, dry weight of tuber and total dry matter yield and decreased harvest index (Shahzad *et al*., 2010).

2.8.3 Tuber Specific Gravity (TSG)

Specific gravity of raw potatoes is widely accepted by the potato processing industry as a measure of total solids, starch content and other qualities (Storey and Davies, 1992). High, uniform specific gravity in potato tubers is important to the grower and the processor because they affect the quality and yield of the 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), which is an expression of density, is 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 wide range within one variety of potato due to other environmental and field management factors (DPI, 2010).

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).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted in 2010/2011 under irrigation condition in Southern Zone of Tigray, Ofla Woreda at Hashenge Kebele, on farmer field. The experimental site is located at 12^{0}31’ N latitude and 39^{0}33’ E longitude at an elevation of 2500 meter above sea level. It is located about 620 km away from Addis Ababa to the north part of the country and about 126 km to the south of Mekelle town. Maximum and minimum temperature ranges from 22.57^{0}C and 6.8^{0}C, respectively. The mean annual rainfall of the area is 806.5 mm with a pH of 6.8 (BoARD, 2009).

The Woreda is classified into three agro-ecological zones, namely, highland, midland, and lowland. The midland covers the largest part which accounts about 42% of the total 133, 296 ha while both the highland and lowland covers 29%. The average land holding in the Woreda is about 0.5 ha per household and estimated total population of 132,491 (BoANRM, 2007).

The study area has a bimodal rainy season namely; “Kiremt” the main wet season is from June to September and “Belg”, the short wet season which extends from March to May. The rainfall distribution of the area is characterized by heavy and erratic rainfall, in 2010; the annual rainfall of 918mm was recorded.

Different local and improved potato varieties are being growing in the area. Among the improved variety, Jalenie is growing widely and has got acceptance by farmers due to its high yielding ability and acceptability by consumers.

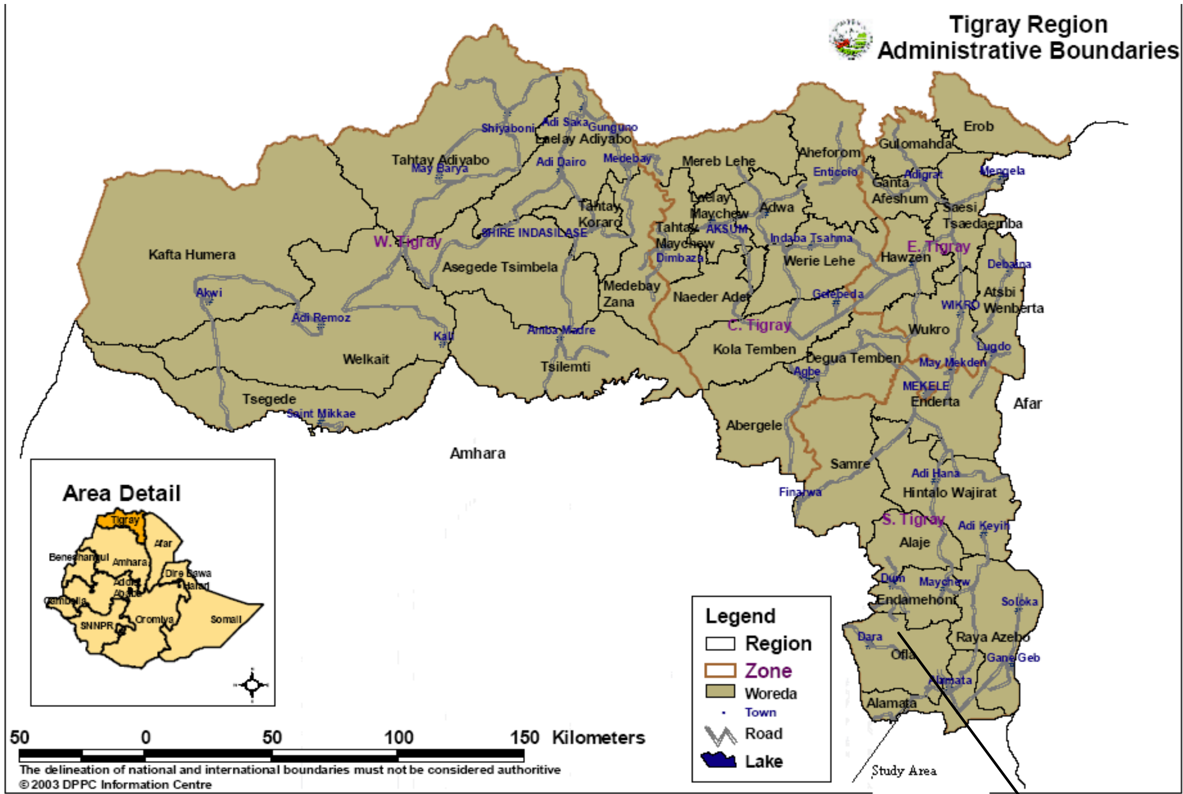

Figure 1. Map of Tigray Regional State showing the experimental location

Ofla (the study area)

3.2 Field Experiment

3.2.1 Experimental material and the treatments

Jalenie variety was obtained from Holleta Agriculture Research Center and used as planting materials. There were 16 treatment combinations, consisting of four inter-row spacings (65, 70, 75 and 80 cm) and four intra-row spacings (20, 25, 30 and 35 cm). 75 cm inter-row spacing and 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 inter and intra-row spacings.

Table 1. Details of the treatment combinations

Inter-row spacing (cm)	Intra-row spacing (cm)
65	20
	25
	30
	35
70	20
	25
	30
	35
75	20
	25
	30
	35
80	20
	25
	30
	35

Table 2. Average yield and other characteristics of Jalenie variety released by EARO that was used for the study

Variety	Year of release	Area of adaptation		Maturity days	Yield (t/ha)		Releasing research center
		Altitude (m a.s.l)	Rain fall (mm)		Researc h field	Farmer' s field	
Jalenie	2002	1600-2800	700-1000	90-120	44.80	29.13	Holleta

Source: Extracted from EARO (2008)

3.3 Experimental Design

The experiment was laid out in 4 x 4 factorial arrangement using a Randomized Complete Block Design (RCBD) with three replications. The length of each experimental plot was 3.15 meters and the width was adjusted according to the inter-row spacing's capacity to hold the specified number of rows per plot; 2.60, 2.80, 3.00 and 3.20 meter plot width for 65, 70, 75 and 80 cm inter-row spacings, respectively. Each plot contain four rows with different number of plants per row 15, 12, 10 and 9 plants for 20, 25, 30 and 35 cm intra-row spacing, respectively. A foot path of 0.5 and one meter was left between plots and blocks, respectively.

3.4 Experimental Procedures

Land preparation was done in late October, 2010. Medium sized and well-sprouted tubers were planted on December 10, 2010 at a different spacing as per the experimental design. Fertilizers were applied to the experimental plots at a rate of 195 kg/ha DAP and 165 kg/ha Urea. Half of the recommended urea was applied during planting and the remaining half of the urea rate was applied as two side dressing 45 days after planting. The whole rate of DAP was applied during planting. Other cultural practices were done as per the recommendation of the crop (EARO, 2004). No major diseases and pest's incidence were encountered.

3.5 Data Collected

Data were recorded from the two middle rows only, to avoid border effect. But, samples of five plants per plot for LAI and ten plants each for stem number and plant height measurement were taken. The following parameters were recorded for final analysis.

3.5.1 Data recorded on growth response variables

A. Days to 50% flowering: Data taken when 50% of the plant population in each plot produced flowers.

B. Total leaf area and leaf area index: Fully opened and a representative sample of physiologically active green leaves were taken from 5 randomly selected plants. From each plant only single stem was randomly taken and the average leaf area was measured using an automatic leaf area meter, and multiplied by total leaves on the stem. Leaf area index was calculated as the ratio of total leaf area to the ground area of the plant from the 5 randomly selected plants (Bleasdale, 1965).

C. Stem number per plant: was recorded as average stem count of ten hills per plot and expressed as number of stems per hill.

D. Plant height (cm): Height of 10 sample plants per plot was measured from the base of the stem to shoot apex at flowering.

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

3.5.2 Data recorded on yield response variables

A. Total tuber yield (t/ha): The sum of marketable and unmarketable tuber yields. The total yield (kg/plot) were weighed and converted in to t/ha.

B. Average tuber yield g/plant: Mean weight of marketable and unmarketable tubers produced from middle row. It was recorded after harvest and expressed in kilogram using a sensitive balance.

C. Marketable yield (t/ha): Mean weight of marketable tubers produced from middle row, it was recorded at harvest by weighting tubers which are healthy and greater than 20 mm diameter and weighed in kg/plot and converted into t/ha.

D. Marketable tuber yield g/plant: Mean weight of marketable tubers produced from middle row. It was recorded at harvest by weighting tubers which are healthy and greater than 20 mm diameter, and expressed as marketable tuber yield per plant.

E. Unmarketable Yield (t/ha): Mean weight of unmarketable tubers produced from middle rows. It was recorded at harvest by weighting tubers which are rotten, greened and less than 20 mm diameter, and expressed as unmarketable tuber yield per hectare.

F. Total number of tuber per hectare: To determine total tuber number, harvested tubers were counted per experimental plot and converted to tuber number per hectare (000's ha^{-1}).

G. Average tuber number per plant: Mean tuber numbers produced from middle rows. It was measured at harvest and expressed as number of tubers per plant.

H. Marketable tuber number per hectare: Mean number of marketable tuber produced from middle row. It was recorded at harvest by counting tubers which are healthy and greater than 20 mm in diameter and converted to marketable tuber number per hectare (000's ha^{-1}).

I. Marketable tuber number per plant: Mean number of marketable tubers produced from middle row. 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.

J. Average fresh tuber weight (g): It was determined by dividing the total fresh tuber yield to the respective total number of tubers.

3.5.3 Data recorded on quality response variables

A. Dray matter content (%): Five fresh tubers were selected from each plot and weighed, then sliced, and dried in oven at 65 ^{o}C for 72 hours to a constant weight. Their dry weight was recorded. Dry matter percentage was calculated by

$$\text{Percent dry matter content (DMC)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

B. Tuber specific gravity (g/cm^3): Specific gravity of tubers was determined by harvesting the middle rows and the harvested tubers were washed and then a representative five kg of clean tubers from each plot were taken. These sample units were weighing in air and reweighed under water method (Kleinkopf *et al.*, 1987). The average was taken as TSG and it was calculated based on the following formula.

Specific gravity = (weight of tuber in the air) ÷ [(Weight in air) - (weight in water)]

C. Tuber Size categories: The harvested tubers were cleaned and graded into 5 categories by using caliper (lass than 20, 20-30, 30-40, 40-50 and grater than 50 millimeter diameter) based on their size. Tubers below 20 mm were considered as unmarketable.

3.6 Data Analysis

The data collected on different growth, yield and quality parameters (total tuber yield obtained in t ha^{-1}, marketable and unmarketable yield in t ha^{-1}, total and marketable tuber number ha^{-1}, leaf area index, dry matter content and specific gravity, were checked for normality and meeting all ANOVA assumptions. Then the data was subjected to Analysis of Variance (ANOVA) and correlation by using SAS Computer software version 9.0 (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. All the graphs and tables were generated by using excel computer program.

4 RESULTS AND DISCUSSION

The results recorded on yield and yield components of potato affected by different levels of inter-row and intra-row spacing are presented and discussed here under.

4.1 Growth Parameters

4.1.1 Days to 50% flowering

A very highly significant ($P<0.001$) interaction effect of inter-row spacing with intra-row spacing was observed for days to 50 % flowering (Table 3 and Appendix Table 3). The present result revealed that plants in the treatment combination of 65, 70 and 75 cm inter- row with all intra-row spacings (20, 25, 30 and 35 cm) flowered earlier (58 days) except 75 cm inter-row spacing with combination of 35 cm intra-row spacing for the value of 60.67 days. Whereas plants in the treatment combination of 80 cm inter- row with all intra-row spacings (20, 25, 30 and 35 cm) took longer (62 days) for flowering.

The result of this experiment indicated that the shortest days to reach 50 % flowering were recorded at closer inter and intra-row spacings. This finding agrees with that of El-Naim (2003) who confirmed that closer spacing could reduce vegetative growth and enhance flower formation. Van Deynze *et al*. (1992) also reported that increased row spacing delayed flowering in rape. Nevertheless, the present result disagrees with that of Abubaker *et al.* *(*2007) who reported that no significant effects of plant population on time of flowering.

4.1.2 Plant height (cm)

Interaction effect of inter-row spacing with intra-row spacing showed highly significant ($P<0.01$) effect on plant height of potato (Table 3 and Appendix Table 3). The highest and significantly different plant height (81.47 cm) was recorded in the treatment combination of

80 cm inter-row and 35 cm intra-row spacing. The results of this experiment indicated that the combinations of wider inter and intra-row spacing resulted maximum plant height. On the contrary, the lowest plant height (57.07 cm) was recorded in the treatment combination of 65 cm between row and 20 cm between plant spacing and it was significantly different from the other treatment combinations. This might be due to the fact that plants at wider spacing practiced less competition for growth resources such as water, light and nutrients and grow more vegetatively whereas, plants that exhibit intense competition decreased in height. The result of this investigation agrees with the finding of Zamil, *et al*. (2010) who reported that the widest spacing gave the tallest plant which was significantly different from the closest spacing.

Endale and Gebremedhin (2001) also reported that significant effect of spacing (spatial arrangement) on plant height. This might have resulted due to the availability of growth factors in the wider inter and intra-row spacing. In contrary Ahmed *et al.* (2010) reported that intra-row spacing had no significant effect on plant height.

4.1.3 Days to maturity

The result of this experiment indicated that the interaction effect of inter-row and intra-row spacing showed a very highly significant ($P<0.001$) effect on days to maturity (Table 3 and Appendix Table 3). Plants at the treatment combination of 65 cm inter-row spacing with 20, 25 and 30 cm intra-row spacings matured earlier (118 days), whereas, the treatment combination of 80 cm between rows with 35 cm intra-row spacing matured late (125.3 days) and statistically similar with the treatment combination 80 cm inter-row with 30 cm intra-row spacing.

This study clearly indicated that wider plant spacing not only delayed maturity but also caused total yield reduction. It is obvious that when inter and intra-row spacing increases, the number of plants per unit area become less; thus more mineral nutrients, light, moisture and space become available for each plant. Thus, the plant may tend to grow more vegetatively and bear more branches at the expense of reproductive parts.

These results were inline with the findings of Tesfu and Charles (2010) who revealed that increasing planting density appeared to shorten days to maturity, plants at high density were observed to mature few days earlier than plants at low planting density. In contrast to this study, Oad *et al*. (2002) reported wider inter and intra-row spacing hastened maturity. 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.

Table 3. Means for interaction effect of inter and intra-row spacing on days to 50 % flowering, plant height and days to maturity of potato

Inter-row spacing (cm)	Intra-row spacing (cm)	Days to 50% flowering	Plant height (cm)	Days to maturity
65	20	58.00^{c}	57.07^{i}	118.0^{f}
65	25	58.00^{c}	59.30^{h}	118.0^{f}
65	30	58.00^{c}	60.10^{gh}	118.0^{f}
65	35	58.00^{c}	63.93^{f}	119.0^{e}
70	20	58.00^{c}	60.33^{gh}	119.0^{e}
70	25	58.00^{c}	61.23^{g}	121.0^{d}
70	30	58.00^{c}	65.90^{e}	121.0^{d}
70	35	58.00^{c}	66.77^{e}	121.0^{d}
75	20	58.00^{c}	59.87^{gh}	121.0^{d}
75	25	58.00^{c}	63.97^{f}	122.0^{c}
75	30	58.00^{c}	67.33^{e}	124.0^{b}
75	35	60.67^{b}	71.13^{c}	124.3^{b}
80	20	62.00^{a}	64.27^{f}	124.3^{b}
80	25	62.00^{a}	69.43^{d}	124.0^{b}
80	30	62.00^{a}	73.00^{b}	125.0^{a}
80	35	62.00^{a}	81.47^{a}	125.3^{a}
LSD (5%)		0.48	1.52	0.42
CV (%)		3.03	9.42	2.15

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.1.4 Leaf Area Index

Intra-row spacing showed a very highly significant ($P<0.001$) effect on leaf area index. However, the effect of inter-row spacing and interaction showed no significant difference in leaf area index (Fig 2 and Appendix Table 3). The result revealed that significantly the highest leaf area index (3.21) was recorded at 20 cm intra-row spacing, and this could be due to high number of haulms per unit area. Whereas the lowest (2.32) leaf area index was recorded from 35 cm intra-row spacing and it is statistically difference from the other three (30, 25 and 20 cm) intra-row spacings.

This result is in agreement with the findings of Ronald (2005) and Tamiru (2005) who reported that the highest density increased leaf area index, possibly indicating potential partitioning of assimilates for vegetative growth. Burstall and Harris (1983) also reported that 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.

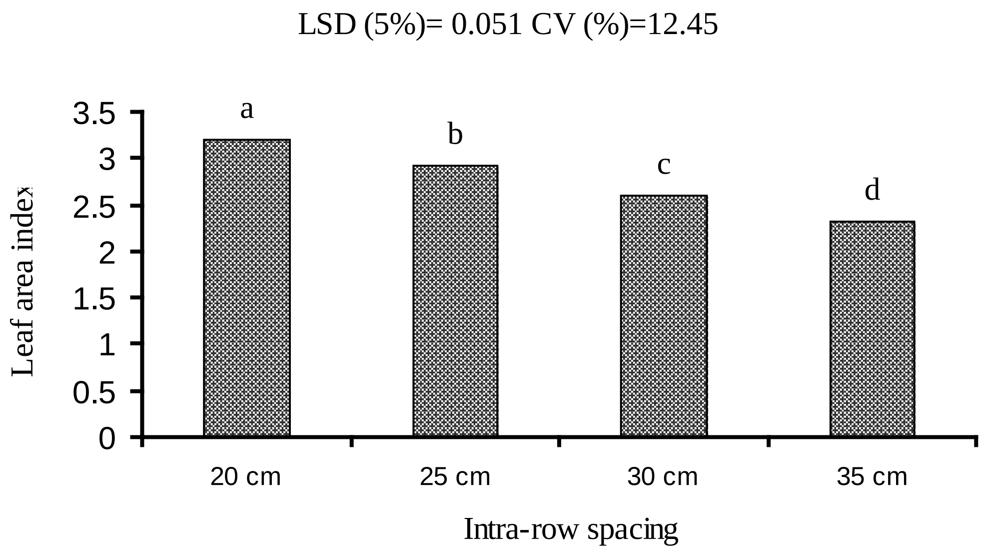

Figure 2. Means for the effect of intra-row spacing on leaf area index

4.1.5 Number of main stems per plant

Although main stem number is one of the most important yield components in potato, the result of the present study showed that inter and intra-row spacing as well as their interaction showed no significant differences with regard to the number of main stem per plant (Appendix Table 3).

This result is consistent with the findings of Vander Zaag *et al*. (1990) who reported that numbers of main stems per plant were not influenced by plant spacing. Main stems number was not significantly influenced much by planting density, possibly stem number may be influenced by other factors such as physiological age of the seed tuber, pre-plant storage temperatures or green sprouting and variety (Sturz *et al*., 2007).

Planting distance determines the number of plant (hill) per unit area. Several stems develop from individual seed tubers depending on size and physiological age of seed tubers. Each stem behaves as separate potato plant since each has own root and shoot system (Struik, 2007). Therefore, number of main stems per unit area (stem density) is generally considered as more realistic indicator of plant density than number of planted tubers in potato field (Bussan *et al*., 2007; Firman and Allen, 2007).

4.2 Yield Parameters

4.2.1 Total tuber yield (t/ha)

The effect of inter-row and intra-row spacing showed a very highly significant (P<0.001) differences on total tuber yield ha^{-1} (Table 4 and Appendix Table 4). However, the interaction effect was non-significant (P>0.05). The highest yield (36.89 t/ha) was obtained from 65 cm inter-row spacing, whereas the lowest (31.87 t/ha) yield was recorded at 80 cm inter- row spacing.

Regarding the intra-row spacing, the higher total yield per hectare (37.54 t/ha) was obtained from 20 cm intra-row spacing. As intra-row spacing increased from 20 cm to 35 cm, total tuber yield decreased from 37.54 to 29.38 t/ha. Intra-row spacing of 35 cm showed lower total tuber yield (29.38 t/ha) and it was significantly different from the three levels. It was clearly evident from the results that the yield of tuber per hectare was increased with decreasing plant spacing.

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. At closer spacing there is high number of plants per unit area which brings about an increased ground cover that enables more light interception, consequently influencing photosynthesis. It is therefore, very likely that substantial increases in rate of land coverage and thereby tuber yield could be achieved by dramatically increasing the stem density per unit area.

The present result agrees with the findings of Zabihi *et al*. (2011) who reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and tuber quality. Increase in plant density led to decrease in mean tuber weight but number of tubers and yield per unit area were increased. Karafyllidis *et al*. (1997) also reported 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 densities. Lemma *et al.* (2003) also reported the highest total pepper pod yield of 20.09 q/ha at Bako and 15.57 q/ha at Didesa planted at closer spacing of 20 cm between plants. In contrary Berga *et al. (*1994) reported wider row width by wider in-row distance (80 x 40 cm) gave the highest yield (34 t/ha) and the 60 x20 treatment gave the lowest yield (22.2 t/ha).

The yield of potatoes, as in many crops, is dependent on many factors like the amount of minerals in the soil, plant spacing, cultivars etc. Plant spacing had a marked effect on yield. Increasing the density can increase the yield in three ways. First, the green leaves will cover the soil earlier and will absorb more sunlight and lead to more assimilation. Second, few lateral shoots will grow and the third is that the growth of tubers will start earlier (Beukema and Vander Zaag, 1990).

4.2.2 Average tuber yield (g) per plant

The effect of inter-row and intra-row spacing showed highly significant ($P<0.01$) differences on average tuber yield per plant (Table 4 and Appendix Table 4). However, the interaction effects was statistically non-significant ($P>0.05$).

Accordingly, the maximum yield per plant, 770.2 and 694.8 g/plant were obtained from 30 and 75 cm intra and inter-row spacing respectively. Wider spacing decreased the yield per hectare but increased the yield per plant. While the lowest yield, 542.4 and 650.1 g/plant, was recorded at 20 and 65 cm intra and inter-row spacings, respectively. The present result is in agreement with the finding of Sultana and Siddique (1991) who reported that the yield of tubers per hill increased significantly with increase in plant spacing but the yield of tuber per hectare did not follow the same trend.

Table 4. Means for the effect of inter and intra-row spacing on total tuber yield per ha^{-1} and average tuber yield per plant

Treatments	Total tuber yield (t/ ha)	Average tuber yield (g/plant)
Intra-row spacing(cm)		
20	37.54 ^{a}	542.4^{c}
25	35.75 ^{b}	646.1^{b}
30	35.61 ^{b}	770.2^{a}
35	29.38 ^{c}	742.3^{a}
Inter-row spacing (cm)		
65	36.89 ^{a}	650.1^{b}
70	35.33^{b}	669.0^{ab}
75	34.18^{b}	694.8^{a}
80	31.87 ^{c}	687.2^{a}
LSD (5%)	1.18	28.24
CV (%)	11.25	14.47

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.2.3 Marketable yield (t/ha)

The data concerning marketable yield as influenced by planting density is presented in (Table 5). Inter and intra-row spacing showed a very highly significant ($P<0.001$) effect on marketable yield (Appendix Table 5). Significantly maximum marketable yield (35.89 and 35.09 t/ha) was obtained at a 20 and 65 cm intra-row and inter-row spacing respectively. While the lowest marketable yield (28.65 and 31.42 t/ha) was obtained at the wider spacing (35 cm intra-row and 80 cm inter-row spacing, respectively). However the interaction effect did not show significant difference on marketable yield per hectare.

The highest marketable yield recorded at closer spacing which is attributed to more tubers produced at the higher plant population per hectare. The present result agreed with the findings of many authors (Stoffela and Bryan, 1988; Khalafalla, 2001) regarding plant density effect on marketability of the crop. Close spacing of 15-25 cm was reported to give better proportion of marketable yield than wider spacing of 35 cm. Kantona *et al*. (2003) also observed a greater increase in marketable yield of onion as plant density increased.

Table 5. Means for the effect of inter and intra-row spacing on marketable yield per hectare

Treatments	Marketable tuber yield (t/ ha)
Intra-row spacings (cm)	
20	35.89[a]
25	34.49[b]
30	34.66[b]
35	28.65[c]
Inter-row spacings (cm)	
65	35.09[a]
70	33.86[b]
75	33.32[b]
80	31.42[c]
LSD (5%)	1.18
CV (%)	10.31

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.2.4 Marketable yield g/plant

Inter-row and intra-row spacing showed significant ($P<0.05$) and highly significant ($P<0.01$) effect on marketable yield per plant (Table 6 and Appendix Table 4). Higher marketable yield (750.3 and 678.5 g/plant) was obtained at 30 and 75 cm intra-row and inter-row spacing respectively. The lowest marketable yield (519.2 and 619.4 g/plant) was recorded from the 20 and 65 cm intra-row and inter row spacing respectively. However, the interaction effect was not significant.

The increasing of marketable yield per plant at wider spacing can be explained by the reduction of intra-specific competition, resulting in increased biomass accumulation of a few large tubers rather than producing many small tubers. Under commercial conditions, this situation would be desirable, but in potato seed programs it is important to obtain as many tubers as possible per surface unit. This result is in agreement with Vander Zaag *et al.* (1990) who reported that average tuber weight per plant 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 the effect of inter and intra-row spacing on marketable yield per plant

Treatments	Marketable yield g/plant
Intra-row spacing(cm)	
20	519.2[c]
25	624.1[b]
30	750.3[a]
35	724.5[a]
Inter-row spacing (cm)	
65	619.4[b]
70	642.2[b]
75	678.5[a]
80	678.0[a]
LSD (5%)	28.01
CV (%)	15.44

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.2.5 Unmarketable yield (t/ha)

A highly significant (P<0.01) interaction effect of inter-row spacing with intra-row spacing was observed for unmarketable yield per hectare (Fig 3 and Appendix Table 4). Significantly the highest unmarketable tuber yield (2.4 t/ha) was recorded in treatment combination of 65 and 20 cm between row and between plants spacing. While the lowest unmarketable yield per hectare (0.25 t/ha) was recorded in the treatment combination of 80 cm between row and 35 cm between plants spacing and significant difference from the other treatment combinations.

This result is in agreement with the findings of Beukema and Vander zaag (1990) who pointed out that planting density 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 decreased because of increased inter-plant competition with closer spacing and resulted in high unmarketable yield per hectare.

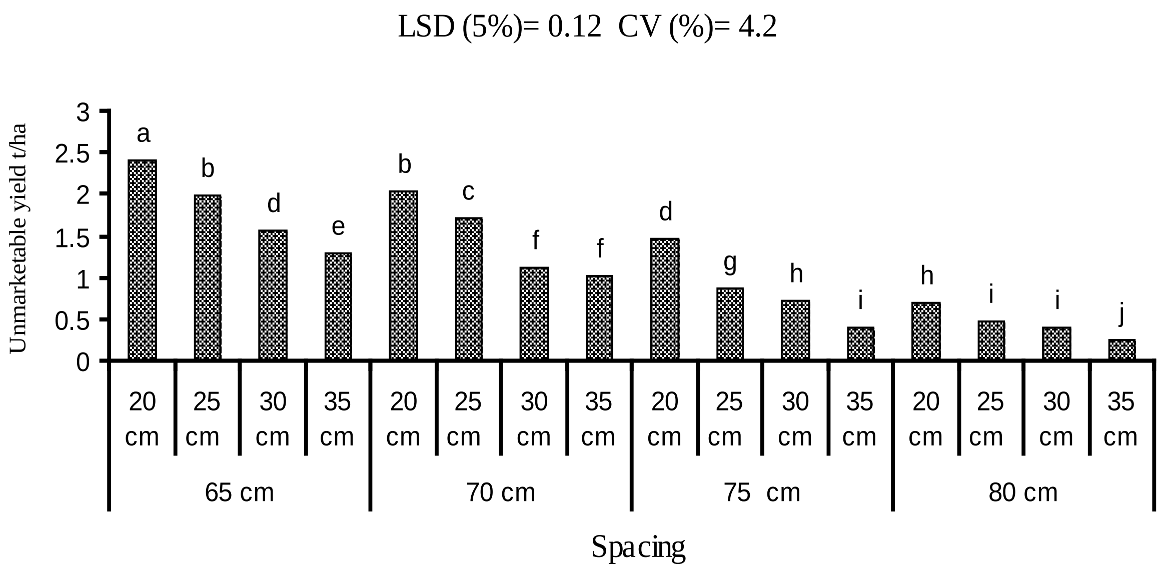

Figure 3. Means for interaction effect of inter and intra-row spacing on unmarketable yield per hectare

4.2.6 Total number of tubers per hectare

The results of total number of tuber (ha^{-1}) as influenced by inter and intra-row spacing is presented in (Table 7). Inter and intra-row spacing had very highly significantly ($P<0.001$) affected total number of tuber per ha (Appendix Table 5). Significantly maximum total number of tuber per hectare (532,865) was recorded at 65 cm inter-row spacing. While the lowest number of tuber per hectare (447,586) was obtained at wider spacing (80 cm) inter-row spacing.

As far as the intra-row spacing is concerned, significantly maximum total number of tuber per hectare (558,174) was obtained from 20 cm spacing. Whereas the lowest total number of tuber per hectare (430,311) was obtained at 35 cm spacing. Total tuber number per hectare was increased with closer spacing. The highest number of tuber at closer spacing is due to high number of plants per unit area. Rahemi *et al*. (2005) reported that intra-row distance of 20 cm increased total tuber number and weight per unit area. The interaction between inter and intra-row spacing didn't significantly (P>0.05) affect total number of tuber per hectare.

4.2.7 Marketable tuber number per hectare

Marketable tuber number (000's ha^{-1}) as influenced by inter-row and intra-row spacing is presented in (Table 7). Inter and Intra-row spacing had very highly significant (P<0.001) effect on marketable tuber number per hectare (Appendix Table 5). However, the interaction effect had no significant (P>0.05) effect on marketable tuber number per hectare.

Maximum marketable tuber number (485,144 and 501,651) was obtained at 65 cm and 20 cm inter-row and intra-row spacing respectively, while the result recorded at 20 cm intra-row spacing was significantly different from the other intra-row spacings. The lowest number of marketable tuber per hectare (411,315 and 395,106) was obtained at 80 cm inter-row and 35 cm intra-row spacing, respectively. Among the inter-row spacings, statistically the same results were obtained from 65 cm and 70 cm, which scored the highest marketable tuber number per hectare, 485,144 and 455,026, respectively.

Related study was reported by Kantona, *et al*. (2003) where number of marketable yield increased significantly as plant density increased. Burton (1989) also reported 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 saleable yield.

Table 7. Means for the effect of inter and intra-row spacing on total and marketable number of tuber ha^{-1}

Treatments	Total number of tuber Per hectare	Number of marketable tuber per hectare
Intra-row spacing(cm)		
20	558174^{a}	501651^{a}
25	486858^{b}	445568^{b}
30	455014^{bc}	423513^{bc}
35	430311^{c}	395106^{c}
Inter-row spacing (cm)		
65	532865^{a}	485144^{a}
70	496599^{a}	455026^{a}
75	453307^{b}	411315^{b}
80	447586^{b}	414352^{b}
LSD (5%)	37587.6	37667.7
CV (%)	15.57	15.61

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.2.8 Average tuber number per plant

Intra-row spacing showed very highly significant ($P<0.001$) effect on average tuber number per plant (Fig 4 and Appendix Table 5). Significantly maximum average tuber number per plant (17.02) was recorded at wider intra-row spacing (35 cm) and it was significantly different with 30, 25 and 20 cm intra-row spacings. While the lowest number of tuber per plant (13.40) was obtained from 20 cm intra-row spacing. However, the main effects of inter-row spacing and its interaction with intra-row spacing didn't show any significant difference on average tuber number plant.

The effects of intra-row spacing on total number of tuber per plant and per hectare were opposite. Wider intra-row spacing resulted in significantly higher number of tuber per plant, whereas the widest intra-row spacing produced the lowest number of tuber per hectare. This may be because wider spacing resulted in less competition because of less number of plants per unit area, and thus, highest number of tubers per plant was obtained.

Inline with this result, Leyla and Halis (2009) reported that closer spacing reduced tuber number per hill, average tuber weight, tuber yield per hill and percentages of large and medium size tubers.

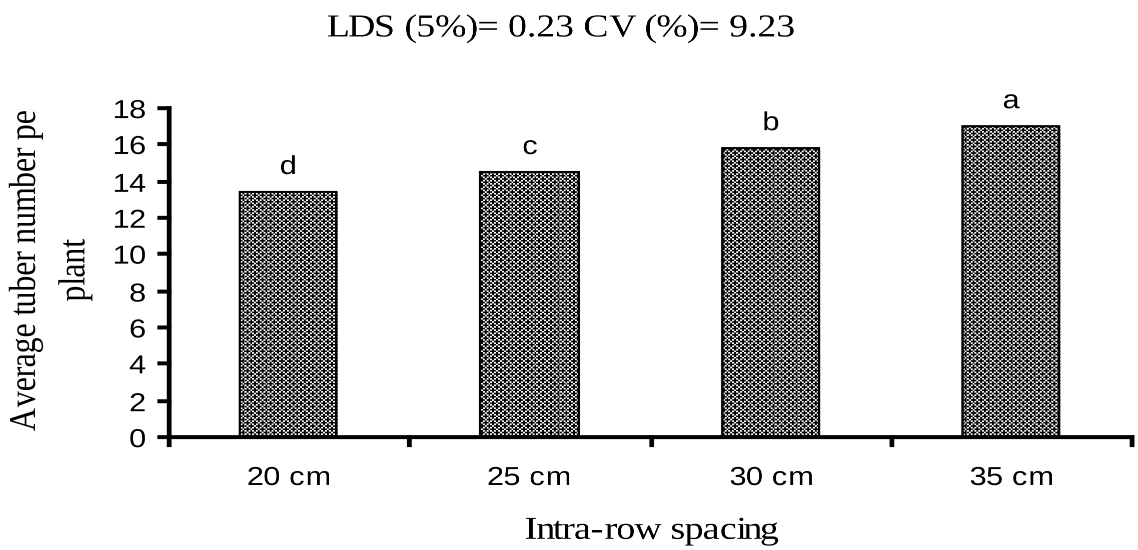

Figure 4. Means for the effect of intra-row spacing on average tuber number per plant

4.2.9 Marketable tuber number per plant

Intra-row spacing showed highly significant (P<0.01) effect on number of marketable tubers per plant (Fig 5). However, effects of inter-row spacing and its interaction with intra-row spacing was not significant (P>0.05) for marketable tuber number per plant (Appendix Table 5). Significantly maximum marketable tuber number (11.55) was obtained at 35 cm intra-row spacing, tubers produced at this planting density mostly have bigger sized tubers and the marketable yield per hill increased. Whereas the lowest marketable tuber number (6.76) 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 *et al*., 2007) whereas, plants that exhibit intense competition showed a decreased in tuber size. Midmore (1992) also reported that at closer spacing absence of air circulation resulted in development of disease and associated diseased plants which contribute more for un-marketability.

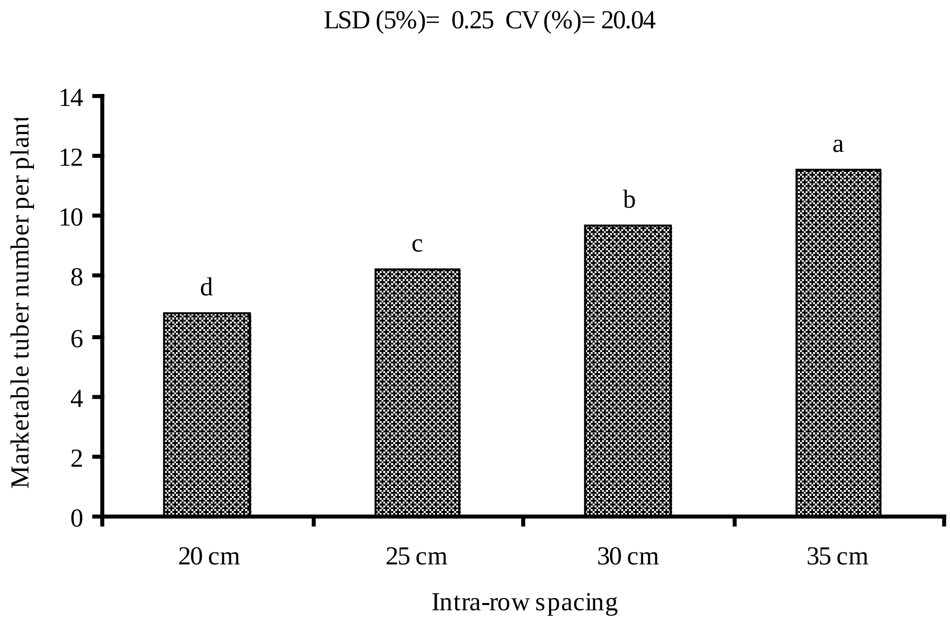

Figure 5. Means for the effect of intra-row spacing on marketable tuber number per plant

4.2.10 Number of unmarketable tuber per plant

A very highly significant (P<0.001) effect of intra-row spacing was observed on the number of unmarketable tubers per plant (Fig 6 and Appendix Table 5). Significantly maximum number of unmarketable tuber per plant (6.65) was recorded at 20 cm intra-row spacing. The least unmarketable tuber number (5.47) was obtained at wider within-row (35 cm) spacing. However, the main effect of inter-row spacing and its interaction with intra-row spacing didn’t show any significant difference on number of unmarketable tubers per plant.

The present result indicates that number of unmarketable tubers per plant 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 high unmarketable tuber per plant. This result is in agreement with Khalafalla (2001) who reported unmarketable tuber number per hill increased with decreased intra-row spacing.

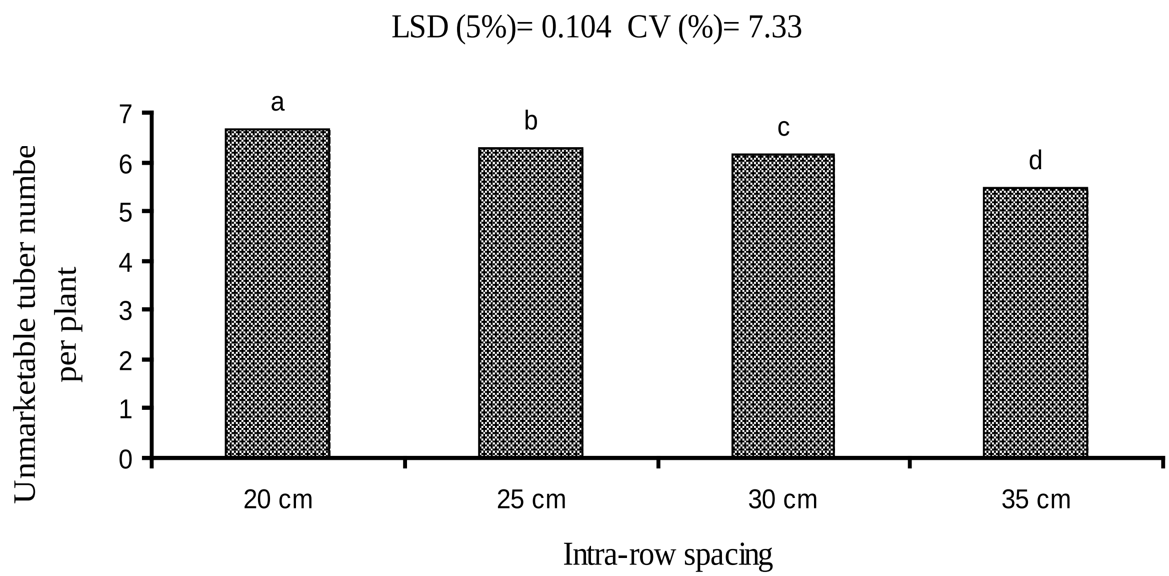

Figure 6. Means for the effect of intra-row spacing on number of unmarketable tuber per plant

4.2.11 Average fresh tuber weight (g)

Intra-row spacing showed highly significant ($P<0.01$) difference on average fresh tuber weight per plant (Fig 7). However, the main effects of inter-row spacing and its interaction with intra-row spacing had no significant ($P>0.05$) difference on average fresh tuber weight (Appendix Table 6). The maximum mean tuber weight (79.68 g) was recorded at 35 cm intra-row spacing but not statistically different with 25 cm intra-row spacing. The smallest average fresh tuber weight (67.3 g) was recorded at 20 cm intra-row spacing. However, it was not significantly different from 25 and 30 cm intra-row spacing for the values of (74.24 and 69.16 g, respectively).

Increase in density probably increased competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, resulted in decline of mean tuber weight. This result is inline with Ali (1997), who found higher average fruit weight at wider spacing as compared to closer spacing. 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.

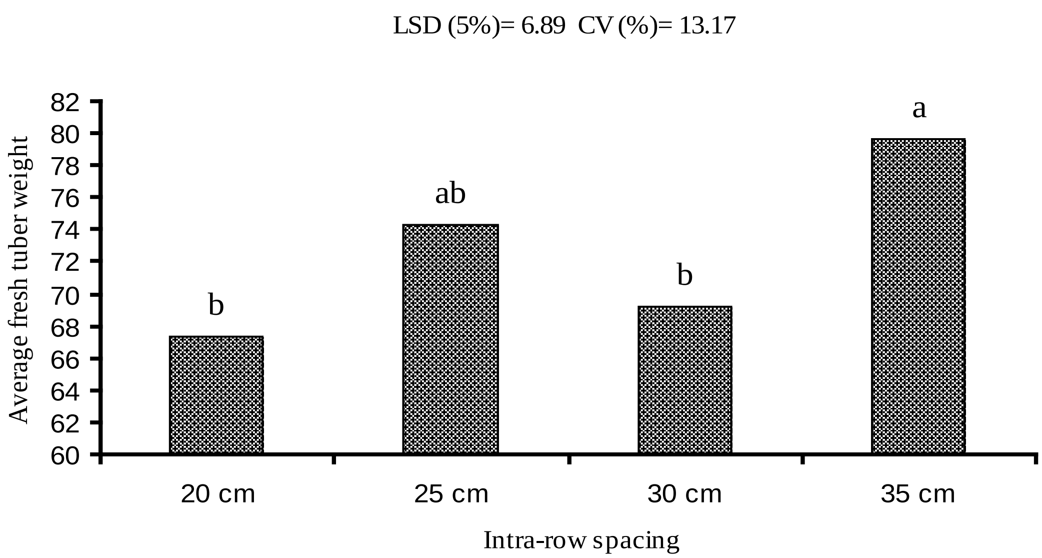

Figure 7. Means for the effect of intra-row spacing on average fresh tuber weight

4.3 Quality Traits

4.3.1 Tuber size category

Intra-row spacing had showed highly significant (P<0.01) effect on number of tubers graded less than 20 millimeter (Table 8 and Appendix Table 7). Maximum (9.96 percent) less than 20 millimeter number was recorded at intra-row spacing of 20 cm. However, it was not significantly different from 25 cm intra-row spacing. While, the lowest (6.629 percent) at 35 cm. Intra-row spacing also showed a very highly significant (P<0.001) effect on weight of tubers graded less than 20 millimeter. Significantly maximum (0.74 percent) less than 20 millimeter weight was recorded at intra-row spacing of 20 cm. it was significantly different from the other intra-row spacings. However, the effect of inter-row spacing and interaction effect had no significant (P>0.05) difference for number and weight of tubers graded less than 20 millimeter.

Intra-row spacing also showed very highly significant (P<0.001) effect on tubers graded greater than 50 millimeter in terms of number and weight. Significantly maximum (23.74 number and 52.91 weight percent) greater than 50 millimeter graded tuber was recorded at 35 cm intra-row spacing. While, the lowest (18.50 number and 42.30 weight percent) was recorded at 20 cm intra-row spacing. However, the main effect of intra-row, inter-row spacing and interaction effect showed no significant (P>0.05) difference on tubers graded (20-30 millimeter weight and number, 30-40 millimeter number and 40-50 millimeter number and weight). Inter-row spacing showed highly significant (P<0.01) effect on tuber graded 30-40 millimeter weight. The highest (17.14 percent) tubers graded 30 -40 millimeter weight was recorded at 65 cm inter-row spacing.

The results of this investigation clearly indicated that the level of intra-row spacing largely affected potato tuber size distribution. Thus, based on market and consumers' demand, it is possible to produce either seed potato or ware potato of required size through the selection of appropriate planting density (intra-row spacing).

The present result is in agreement with the finding of Wiersema (1987) who reported that at higher stem density, the tuber produced will remain smaller than at lower stem densities. Khajehpour (2006) also reported that increase in plant density decreases mean tuber size probably because of plant nutrient elements reduction, increase in interspecies competition and large number of tubers produced by high numbers of stems. Generally the result of this study indicates that tuber size category is influenced mainly by intra-row spacing rather than inter-row spacing.

Table 8. Means for the effect of intra-row spacing on tuber size category

Intra-row spacing (cm)	%Weight of tubers graded less than 20 millimeter	% Number of tubers graded less than 20 millimeter	% Weight of tubers graded greater than 50 millimeter	% Number of tubers graded greater than 50 millimeter
20	0.7335[a]	9.961[a]	42.30[c]	18.50[b]
25	0.7066[b]	8.121[ab]	44.21[c]	19.02[b]
30	0.6808[c]	7.485[b]	49.06[b]	22.00[a]
35	0.5005[d]	6.629[b]	52.91[a]	23.74[a]
LSD (5%)	0.005	1.904	3.401	2.419
CV (%)	14.10	25.2	12.12	17.55

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

4.3.2 Tuber dry matter content (Percent)

The result obtained in this study indicates that, inter-row, intra-row spacing and the interaction of inter and intra-row spacing showed very highly significant (P<0.001) effect on tuber dry matter content (Fig 8 and Appendix Table 6). The highest dry matter content (31.62 percent) was recorded in the treatment combination of 80 cm inter-row with 35 cm intra-row spacing. The lowest dry matter content (22.25 percent) was recorded in the treatment combination of 65 cm between rows with 20 cm between plants spacing, but not statistically different with treatment combination of 70 cm between row and 20 cm between plant spacing.

The present results showed that increasing plant density could result in decreasing dry matter content, which indicates existence of competition between plants for water and nutrient uptake. The percent tuber dry matter content, which consisted both soluble and insoluble carbohydrates, was significantly influenced by plant spacing. Agele *et al.* (1999) also reported that dry matter and TSS contents are indicators of mineral nutrient concentration these values generally increase with decrease in plant population and decrease with increase in plant density.

The present result agrees with the finding of Burton (1989) and Tamiru (2005) who observed a significant increase in tuber dry matter content with decrease in population density. Saluzzo *et al*. (1999) also reported that 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.

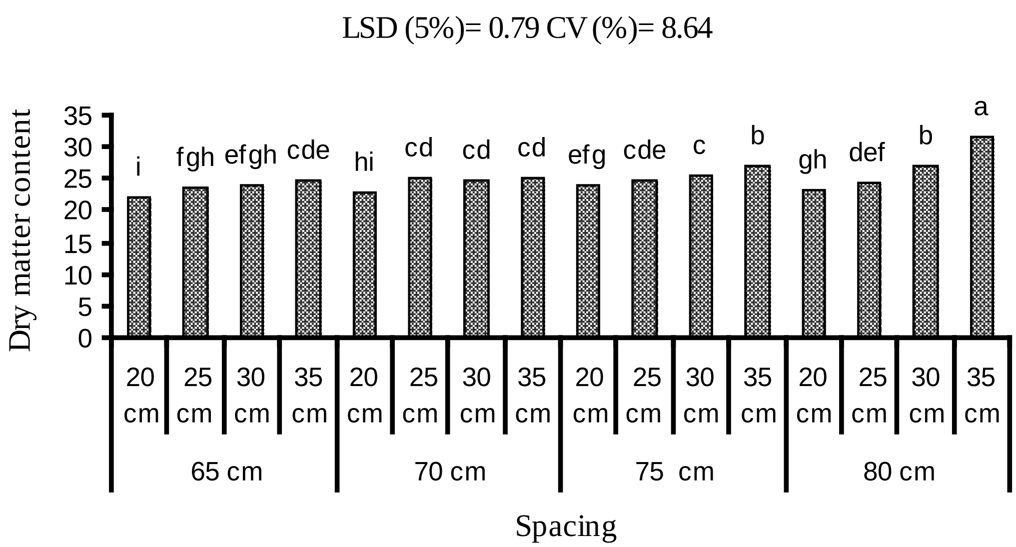

Figure 8. Means for interaction effect of inter and intra-row spacing on dry matter content

4.3.3 Tuber specific gravity

The effect of inter-row spacing, intra-row spacing as well as their interaction showed no significant (P>0.05) effect on tuber specific gravity (Appendix Table 6).

5 SUMMARY AND CONCLUSION

Ethiopia has suitable edaphic and climatic factors for the production of high quality ware and seed potatoes. About 70 percent of the available agricultural land is located at an altitude of 1800-2500 m.a.s.l with an annual rainfall of about 600 mm which is 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.

Farmers around the study area are using different spacings below or above the national recommendation depending on the purpose of planting either for consumption or seed tuber. Around the study area, one of the major causes for low productivity is improper agronomic practices including plant spacing. 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. The selections of best inter and intra-row spacings help to utilize the small land efficiently and intensively not only for higher ware tuber yield but also for quality tuber seed.

With these backgrounds, a study was conducted to investigate the effect of inter-row and intra-row spacing on the yield and yield components of potato (*Solanum tuberosum* L.). The study was carried out at Ofla Woreda, North Ethiopia, which lies at an elevation of 2500 meters above sea level. A Randomized Complete Block Design (RCBD) was employed with three replications, which constituted four levels of inter-row (65, 70, 75 and 80cm) and four levels of intra-row (20, 25, 30 and 35 cm) spacing. Different parameters were recorded before harvest, at harvesting and after harvesting.

From the results of this study, it was observed that leaf area index, total tuber number per hectare, total tuber yield per hectare , marketable tuber yield per hectare, marketable tuber number per hectare and unmarketable yield per hectare increased significantly with increasing plant population (narrow inter and intra-row spacing).

Significantly highest leaf area index (3.21) was recorded at 20 cm intra-row spacing, while the lowest (2.32) was obtained at intra-row spacing of 35 cm. Leaf area index was highly positively correlated with tuber yield (r=0.71**), marketable tuber yield (r=0.69**) and marketable tuber number (r=0.55**) (Table Appendix 9). Tuber yield was highly positively correlated with total number of tuber per hectare (r=0.64**), marketable number of tuber per hectare (r=0.60**) and marketable yield per hectare (r=0.99***). The interaction of inter-row and intra-row spacing significantly affected tuber dry matter content. Maximum dry matter content (31.62 per cent) was recorded in the treatment combination of 80 and 35 cm inter and intra-row spacing. In the present study, neither the main factors nor their interaction, had affected main stem number per plant, tuber specific gravity, tubers graded 20-30 millimeter weight and number, tubers graded 30-40 millimeter number and tubers graded 40-50 millimeter weight and number. Generally, increasing plant population per unit area (narrow spacing) increased total tuber yield, total number of tuber per hectare, marketable yield per hectare and number of marketable tuber per hectare but it decreased total number of tuber per plant. The highest total yield per plant was obtained from 30 and 75 cm intra-row and inter-row spacing.

The result of this study demonstrated that yield per unit area is influenced by the different level of inter and intra-row spacing. From this study, it can be concluded that the narrow spacing (20 and 65 cm intra and inter-row spacing) produced higher yield and marketable yield per hectare than other spacings. Thus, potato (Jalenie variety) growers in the study area (southern zone of Tigray) can be benefited if they use this narrow spacing (20 and 65 cm intra and inter-row spacing).The results obtained in this research are based on one season data and at one location. To come up with conclusive results, further study may consider assessing the effect inter-row and intra-row spacing on yield and yield component of potato in different location and with irrigation methods.

6 REFERENCES

Abubaker S., M. Kasrawi and A. Aburayyan, 2007. Effect of conventional, organic and GAP on nitrate content of plastic house beans. *Acta Horticulture*, **741**: 35-40.

Adane Hirpa, Miranda P. M. Meuwissen, Agajie Tesfaye, Willemien J. M. Lommen, Alfons Oude Lansink, Admasu Tsegaye & Paul C. Struik, 2010. Analysis of Seed Potato Systems in Ethiopia. *American Journal of Potato Research.*

Agele, S.O., G.O. Iremiren, and S.O. Ojeniyi, 1999. Effects of plant density and mulching on the performance of late-season tomato (*Lycopersicon esculentum*) in southern Nigeria. *J. Agr. Sci. Cambridge*, **133**: 397–402.

AGRISNET (Agriculture Information System Network), 2010. Department of Agriculture Government of Sikkim. India.
http://www.sikkimagrisnet.org/General/en/Agriculture/Potato_Soil_Requirement.aspx

Ahmed, M. E. N., M. Amgad, H. S. Muatasim and A. E. Abdalla, 2010. Effect of Intra-row Spacing on Growth and Yield of Three Cowpea (*Vigna unguiculata* L. Walp.) Varieties under Rainfed. *Res. J. Agric. & Biol. Sci*., **6**(**5**): 623-629, 2010.

Ahmed, M.K., 1989. Effects of inter-row spacing and size of seed tuber on potato production in the Gezira. In: Potato Development in the Sudan. Proceedings of a symposium held at Khartoum 15 – 17, February 1989.

Alemkinders, C.J.M. and P.C. Struik, 1994. Photothermal response of sympodium development and flowering in potato (*Solanum tuberosum* L.*)* under controlled conditions. *Netherlands Journal of Agricultural Science* **42**: 311-329.

Alexander, S.A., Caldwell, J.S., Hohlt, H.E., Nault, B.A., O'Dell, C.R., Sterrett, S.B., and Wilson, H.P., 2001. Commercial Vegetable Production Recommendations (No. 456-420) Virginia Cooperative Extension, (pg. 173-178).

Ali, N., 1997. Sesamum Research in Pakistan. In: sesame and safflower status and potentials. Althertoni, J. and J.Rudich, 1986. The Tomato Crop. Chapman and Hall, London, U.K. *Journal of Food Science* **15**: 842-859p.

Allen E.J. and D.C.E. Wurr, 1992. Plant density. In PM Harris (ed) The Potato Crop, The scientific basis for improvement, Chapman & Hall, UK, pp.293-333.

Allen, E.J., D.C.E. Wurr and J.R. Fellows, 1992. Determination of optimum tuber planting density in the potato varieties Pentland Squire, Cara, Estima, Maris Piper and King Edward. *J Agric Sci Camb* **119**:35-44.

Alvin, J.B., P.D. Mitchell, M.E. Copas and M.J. Drilias, 2007. Evaluation of the Effect of Density on Potato Yield and Tuber Size Distribution. *Crop science society of America* **47**: 2462-2472.

Barry, P., T.S. Storey and R. Hogan, 1990. Effect of plant population and set size on the seed yield of the main crop potato variety Cara. *Irish J. Agric. Res*. **29**: 49-60.

Berga Lemaga, Gebremedhin G.Giorgis, W.Teressa jeleta and Bereke Tuku, 1994. Potato agronomic research in Ethiopia in: Horticulture research and development in Ethiopia. Proceeding of the 2nd national Horticulture workshop. 1-3 December 1992, Addis Ababa, Ethiopia. Herath, E, and Lemma Dessalgne (Eds.), pp 101-119. IAR/FAO. Addis Ababa.

Berga, L. and K. Caesar, 1990. Relationships between the number of main stems and yield components of potato (*Solanum tuberosum* L.) as influenced by different day- lengths .*Potato Res*. **33**: 257-267.

Beukema, H.P. and D.E. Van der Zaag, 1990. Introduction to potato production. Center for agricultural publishing and documentation, pudoc. Wageningen, the Netherlands. 208p.

Bleasdale, J.K.A., 1965. Relationships between set characters and yield in maincrop potatoes. *J. Agric. Sci*. **64**: 361–366.

BoANRM (Bureau of Agriculture and Natural Resources Management), 2007. Description of the Study Area. Ofla, Tigray, Ethiopia. Unpublished Document.

BoARD (Bureau of Agriculture and Rural Development), 2009. Annual report, Bureau of Agriculture and Rural Development. Ofla, Tigray, Ethiopia. Unpublished document.

Bohi, W.H., P. Nolte, G.E. Kleinkopf, and M.K. Thornton, 2000. Potato seed management, seed size and age. Cooperative extension system bulletin.

Bohl, W.H., S. Love and A.L. Thompson, 2010. Effect of seed piece removal on yield and agronomic characteristics of Russet Burbank potatoes. *Am. J. Potato Res*. **78**: 397-402.

Boyd, N., R. Gordon, S.K. Asiedu and R.C. Martin, 2001. The effects of living mulches on tuber yield of potato (*Solanum tuberosum* L.). *Biol. Agric. Hortic.* **18**: 203–220.

Boyd, N.S., R. Gordon and R.C. Martin, 2002. Relationship between leaf area index and ground cover in potato under different management conditions. *Potato Res*. **45**: 117–129.

Burhan Arslan, 2007. Relationships among Yield and Some Yield Characters in Potato (*S. tuberosum* L.). *Journal of Biological Sciences.* **7**: 973-976.

Burstall, L. and P.M. Harris, 1983 .The estimation of percentage of light interception from leaf area in exand percentage ground covering potatoes. *J. Agri. Sci*., Vol.**100**: 241-244.

Burton, W.G., 1989. The Potato. 3rd ed. Longman Publisher Ltd.,African crop scince conference proceedings volume 8 pp.1207-1210, Tanzania.

Bussan, A.J., P.D. Mitchell, M.E. Copas, and M.J. Drilias, 2007. Evaluation of the effect of density on potato yield and tuber size distribution. *Crop Sci*. **47**: 2462–2472.

Creamer, N.G., C.R. Crozier and M.A. Cubeta, 1999. Influence of seed piece spacing and population on yield, internal quality, and economic performance of Atlantic, Superior, and Snowden potato varieties in Eastern North Carolina. *Am. J. Potato Res.* **76**: 257-261.

Decoteau, R.D., 2005. Principles of plant science .Educational factors and technology in growing plants. Pearson education .inc. New Jersey. p 412.

De la Morena, I.A. Guillen, and L.F. Garcia del Morel, 1994. Yield development in potatoes as influenced by cultivar and the timing and level of nitrogen fertilizer. *American Potato Journal*. **71**:165-173.

DPI (Department of Primary industries), 2010 Potatoes: Measurement of Specific Gravity**.** Victoria, Australia. http://new.dpi.vic.gov.au/agriculture/horticulture/vegetables/potatoes/potatoes-measurement-specific-gravity

DPI (Department of Primary Industries), 2010 Potatoes: Factors Affecting Dry Matter. Victoria, Australia http://new.dpi.vic.gov.au/agriculture/horticulture/vegetables/potatoes/potatoes-factors-affecting-dry-matter

EARO (Ethiopia Agriculture Research Organization), 2004. Directory of released crop varieties and their recommended cultural practices: Ethiopian Agricultural Research Organization, Addis Ababa.

Eremeev, V., A. Lohmus and J. Joudu, 2007. Effect of thermal shock and pre-sprouting on field performance of potato in Estonia. *Agronomy Research*, **5** (**1**): 21-30.

El-Naim, A.M., 2003. Effect of different irrigation water quantities and cultivars on growth and yield of sesame (*Sesamum indicum* L.). Ph.D.Thesis, faculty of Agricultural. University of Khartoum. 75p.

Endale Gebre and Gebremedhin Woldegiorgis, 2001. Effects of Spatial Arrangement on Tuber Yields of Some Potato Cultivars Ethiopian Agriculture Research Organisation, Holetta Research Centre, P. O. Box 2003/6282, Addis Ababa, Ethiopia, *African Crop Science Journal*, **9(1**): 67-76.

Ewing, E.E., 1997. Potato. In the physiology of vegetable crops (Ed. H.C. Wien). Pp 295-344.
Hailemichael, K.M. 1977. Ethiopia potato improvement program Alemaya College of Agriculture.

FAO, 2010. Production year book. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, 2008. Production year book. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAOSTAT, 1998. Statistics Database (online). June. Available HTTP:http://apps.fao.org

FAOSTAT, 2008. World Food and Agricultural organization Data of statistics. http://faostat.fao.org/site/567/default.aspx#ancor

Firman, D.M. and E.J. Allen, 2007. Agronomic practices. In Vreugdenhill *et al*. (eds) Potato Biology and Biotechnology, Advances and Perspectives, Elsevier, Netherlands pp. 719-738.

Gebremedhin W/Giorgis, Endale Gebere, Kiflu Bedane and Bekele Kassa, 2001. Country profile on potato production and utilization: Ethiopia. PP. 24-39.

Gebremedhin, W., G. Endale, and B. Lemaga, 2008. Potato variety development. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 15–32. Addis Abeba: Ethiopian Institute of Agricultural Research.

Georgakis, D.N., D.I. Karafyllidis, N.I. Stavropoulos, E.X. Nianiou, and I.A. Vezyroglou, 1997. Effect of planting density and size of potato seed-minitubers on the size of the produced potato seed tubers. *Acta Hort*. **462**: 935-942.

Geremew Awas, Teshome Abdisa, kasaye Tolosa and Amanti Chali, 2010. Effect of inter-row spacing with double row arrangement on yield and yield component of tomato (*Lycopersicon esculuntum* Mill.). *African Journal of Agricultural Research*, **6**(**13**): 2978-2981.

Haase, T., C. Schuler and J. Heb, 2007. The effect of different N and K sources on tuber nutrient uptake, total and graded yield of potatoes (*Solanum tuberosum* L.) for processing. *Euro. J. Agron*., **26**: 187-197.

Hammes, P.S., 1985. The effect of stem population on tuber yield in a trial with single stem seed pieces. *Potato Research Journal*, **28**:119-121.

Hawkes, J.C., 1990. The Potato: Evolution, Biodiversity, and Genetic Resources. Belhaven Press, London. pp. 259.

Hogy, P. and A. Fangmeier, 2009. Atmospheric CO2 enrichment affects potatoes: Tuber quality traits. *Eur. J. Agron*., **30**: 85-94.

Horton, D., 1987. Potatoes: production, marketing and for developing countries. West view press (Boulder), IT Publications (London), p.243.

Iritani, W.M., L.D. Weller and N.R. Knowles, 1983. Relationship between stem numbers, tuber set and yields of Russet Burbank potatoes. *American potato Journal*, **60**:423-431.

Kantona, R. A. L., L. Abbeyb, R. G. Hillac, M. A. Tabil and N. D. Jane, 2003. Density Affects Plant Development and Yield of Bulb Onion (*Allium* cepa L.) in Northern Ghana. *Journal of Vegetable Crop Production*, Volume 8, pages 15 – 25.

Karafyllidis, D.I., D.N. Georgakis, N.I. Stavropoulos, E.X. Nianiou, and I.A. Vezyroglou, 1997. Effect of planting density and size of potato seed-minitubers on their yielding capacity. *Acta Hort*., **462**: 943-950.

Khajehpour, M., 2006. Production of industrial plants. Jehad-e-Daneshgahi Isfahan press. Isfahan. Iran. 580: ISBN 961-6122-63-9.

Khalafalla, A. M., 2001. Effect of Plant Density and Seed Size on Growth and Yield of Solanum Potato in Khartoum State, Sudan *African Crop Science Journal*, **9**(**1**): 77-82.

Kleinhenz, M.G. and M.A. Bennett, 1992. Growth and yield of potato (*Solanum tuberosum* L.) cultivars Atlantic and Monona as influenced by seed type and size. *Am. Potato J*., **69**: 117-129.

Kleinkopf, G.E., D.T. Westermann, M.J. Wille and G.D. Kleinscmidt, 1987. Specific Gravity of Russet Burbank Potatoes. *American Potato Journal*. **64**: 579-587.

Lemma, D., Z. Yayeh and E. Helath, 2003. Agronomic studies on Tomato and Capsicum. Pp.153.In: Helath E. and Lemma D, (Eds). Horticultural Research and Development in Ethiopia. Proceedings of the second Horticultural work shop of Ethiopia, 1-3 December, 1992. Addis Abeba, Ethiopia.

Leyla Güllüoglu1 and Halis Arıoglu, 2009. Effects of seed size and in-row spacing on growth and yield of early potato in a mediterranean-type environment in Turkey. *African Journal of Agricultural Research Vol*. **4(**5): 535-541.

Lister, C.E. and J. Munro, 2000. Nutritional and health qualities of potatoes- a future focus. Crop & Food Research, Confidential Report No. 143.

Lutaladio, N.B. and L. Castaldi, 2009. Potato: The hidden treasure. *J. Food Comp. Anal*., **22**: 491-493.

Lynch, D.R. and R.G. Rowberry, 1997. Population density studies with Russet Burbank potatoes. II. The effect of fertilization and plant density on growth, development, and yield. *American Potato Journal*. **54**: 57-71.

Lynch, D.R., and G.C. Tai, 1989. Yield and yield component response of eight potato genotypes to water stress. *Crop Science*. **29**: 1207-1211.

Margaret, J.M., M.K. Anton and E.R. Vincent, 2007. Hartmann's plant science, growth, development, and utilization of cultivated plants 4th ed. Pearson's Prentice Hall. pp 156-166.

Marschner, H., 1995. Mineral nutrition for higher plants. Second edition, Academic Press, London. San Diego, CA, 889p.

Mauromicale, G., P. Signorelli, A. Ierna and S. Foti, 2003. Effects of intraspecific competition on yield of early potato grown in Mediterranean environment. *Am. J. Potato Res.*, **80**: 282-288.

Midmore, D.J., 1992. Potato production in tropics. In the potato crop. Ed.Paul harris. 2nd ed. Pp. 728-780. Reference to the efficient use of nitrogen and potassium, PhD. Thesis, Univ. Reading.

Miller, J., N. Olsen, L. Woodell, L. Porter and S. Clayson, 2006. Post harvest applications of Zoxamide and phosphate for control of potato tuber rots caused by Oomycetes. *American Journal of potato research*, **83**:269-278.

MoARD, 2006. Discussion on root and tuber crops as sustainable food security. Ministry of Agricultural and rural development of Ethiopia.

Mulatu, E., E.I. Osman and B. Etenesh, 2005. Improving potato seed tuber quality and producers' livelihoods in Hararghe, Eastern Ethiopia. *Journal of New Seeds*, 7(**3**): 31–56.

Mulubrhan Haile, 2004. The Effect of N, P, K Fertilization on Yield and Yield Components of Potato (*Solanum tuberosum* L.) Grown on Vertisols of Mekelle Area, Ethiopia. M.Sc. Thesis, the University of Haremaya, p.15.

Negi, S.C., J. Shekhar and J.P. Saini, 1995. Effects of seed size and spacing on potato production. *Indian J. Agri. Sci.*, **65**: 286–287.

Nelson, D.G. and P.D. Jenkins, 1989. Effect of physiological age and floating plastic film on tuber dry matter percentage of potato, cv. record. *Potato Research*, **33** (2): 159-169.

Ngungi, D.N., 1982. Agronomic concept of potato with reference to increasing the potential yield under Tropical condition. In: Potato seed production for Tropical Africa, (eds.) Nganga, S. and F. Shielder, CIP, Lima, and Peru. pp.13-16.

Oad, F.C., M. A. Samo, S. M. Qayyum and N. L. Oad, 2002. Inter and intra row spacing effect on the growth, seed yield and oil content of safflower (*Carthamus tinctorius* L.). *Asian J. Plant Sci*. **1**: 18-19.

O'Brien, P.J and E. J. Allen, 2009. Effects of date of planting, date of harvesting and seed rate on yield of seed potato crops. *The Journal of Agricultural Science*, Cambridge University Farm, Huntingdon Road, Girton, Cambridge, UK, **118**: 289-300.

Otroshy, M., 2006. Utilization of tissue culture techniques in a seed potato tuber production scheme. PhD Thesis, Wageningen University. P. 264.

Pankhurst, R. 1964. Notes for a history of Ethiopian agriculture. Ethiopian Observer. **7**:210-240.

Rahemi, A., A. Hasanpour, B. Mansoori, A. Zakerin and T. S. Taghavi, 2005. The effects of intra-row spacing and n fertilizer on the yield of two foreign potato cultivars in Iran. *International Journal of Agriculture & Biology*, **7**(**5**): 705–707.

Rajadurai, S., 1994. Effect of seed tuber size and planting space on growth, yield and tuber size distribution of potato in irrigated red-yellow latosols of the dry zone. *J. National Sci. Council Sri Lanka*., **22:** 115–23.

Reeve, H.M., H. Timm, and M.L. Weaver. 1973. Parenchyma Cell Growth in Potato Tubers. I. Different tuber regions. *American Potato Journal*. **50**: 50-58.

Reich, P.B., T. Koike, S.T. Gower and A.W. Schoettle, 1995. Causes and consequences of variation in conifer leaf life-span. In Ecophysiology of Conifers (W. K. Smith and T M. Hinckley, Eds.), Academic, San Diego, CA, pp. 225–254.

Rex, L.B., A.W. Russell and R.H. Wolfe, 1987. The effect of spacing of seed pieces on yield, quality and economic value for processing of Shepody potatoes in Manitoba. *American Potato Journal*, **64**:177-189.

Roghayyeh Zabihi-e-Mahmoodabad,Shahzad Jamaati-e-Somarin, Majid Khayatnezhad and Roza Gholamin. 2011. Correlation of Tuber Yield Whit Yield Components of Potato Affected by Nitrogen Application Rate in Different Plant Density. Advances in Environmental Biology, 5(1) Islamic Azad University, Ardabil, Iran. Pp.131-135.

Romero-Lima, M.R.A., T. Santos, R. Garcia-Espinosa and R. Ferrera-Cerrato, 2000. Yield of Potato and soil microbial biomass with organic and mineral fertilizers. *Pbcado Com ARTICULO Agrociencia* **34**: 261-269.

Ronald, A., 2005. Effect of pre-harvest management on yield, process quality, and disease development in Russet Burbank potatoes. M.Sc. Thesis, the University of Manitoba Winnipeg, p.174.

Sadowskal, J., J. Fornall, J. Vacek, T. Jelins and B. Flis, 2004. Characteristic of physical properties of genetically modified potatoes. I: mass and geometric properties of tubers. *Int*. *Agrophysics*, **18**: 269-276.

Saluzzo, J.A., H.E. Echeverria, F.H. Andrade and M. Huarte, 1999. Nitrogen nutrition of potato cultivars differing in maturity. *Journal of Agronomy and Crop Science*, **183**:157-165.

SAS Institute Inc. 2008. *SAS/STAT. 9.2 User's Guide*. Cary, NC: SAS Institute Inc. USA.

Stevenson,W.R., L. Rosemary, G.D. Franc and D.P. Weingartnur, 2001. Compendium of potato diseases. The American Phyto Pathological society. Second edition,USA.

Stoffella, P.J. and H.H. Bryan, 1988. Plant population influences growth and yield of bell pepper. *Journal of American Society Horticultural Science*, **113**: 835-839.

Storey, R.M.J. and H.V. Davies, 1992. Tuber quality. In: Harris PM (Ed.) The Potato Crop: The Scientific Basis for Improvement, Chapman Hall, London, pp 507–552.

Strange, P.C. and K.W. Blackmore, 1990. Effect of whole seed tubers, cut seed and within row spacing on potato (cv Sebago) tuber yield. *Aust. J. Exp. Agric*. **30**: 427-431.

Struik, P.C., 2007. Above-ground and below ground plant development In Vreugdenhill *et al*. (pls provide the complete names) (eds) Potato Biology and Biotechnology, Advances and Perspectives, Elsevier, Netherlands, pp. 219-236.

Sturz, A.V., W. Arsenault and B. Sanderson, 2007. Production of Processing Potatoes from Whole Seed. Department of Agriculture, Prince Edward Island, Canada.

Sultana, N. and M.A. Siddique, 1991. Effect of cut seed piece and plant spacing on the yield and profitability of potato. *Bangladesh Hort*., **19** (**1):**37-43.

Suman Rani, 2010. Best agricultural techniques for successful potato production in India. Saching.com. India

Swaminathan, M.S. and R.L. Sawyer, 1983. The potential of the potato at a world food. In research for the potato in the year 2000. Lima, Peru. International potato center. pp.1-10.

Tamiru Hirpa, 2005. Effect of plant population and harvesting time on tuber yield of potato (*Solanum tuberosum* L.*). Ethiopian Journal of Biological Sciences*, **4**(**1**): 1-9.

Tekalign, T. and P.S. Hammes, 2005. Response of potato grown in a hot tropical lowland to applied paclobutrazol. II: Tuber attributes. *New Zealand J. Crop. Hort. Sci.* **33**:43-51.

Tesfu Mengistu and Charles Yamoah, 2010. *African Journal of Plant Science*. **4**(8): 270-279. http://www.academicjournals.org/AJPS ISSN 1996-0824 ©2010 Academic Journals (accessed on 15/02/2011).

Thornton, M.K., N.J. Malik and R.B. Dwelle, 1996. Relationship between leaf gas exchange characteristics and productivity of potato clones grown at different temperatures. *Amer Potato. J*, **73**: 63-77.

Tisdale, S.L., W.L. Nelson, J.D. Beaton and J.L. Halvin, 1995. Soil Fertility and Fertilizers (5th Ed.). Macmillan Publishing Co., Inc. New York. pp. 109-229.

Tooming, H.G., 1984. Ecological principles of maximum crops productivity. Leningrad: Gidrometeoizdat, 264 p. (in Russian with English abstract).

Van Delden, A., 2001. Yield and growth of potato and wheat under organic N-Management. *Agr. J.*, **93**: 1370–1385.

Van Deynze, A.E., P.B.E. McVetty, R. Scarth and S.R. Rimmer, 1992. Effect of varying seeding rates on hybrid and conventional summer rape performance in Manitoba. Can. J.

Vander Zaag, D.E. (Ed.).,1992. Pre-treatment of seed potatoes. In: Potatoes and their cultivations in the Netherlands. Wageningen, The Netherlands. pp. 44–49.

Vander Zaag, P., A.L. Demagante and E.E. Ewing, 1990. Influence of plant spacing on potato (*Solanum tuberosum* L.) morphology, growth and yield under two contrasting environments. *Potato Res*. **33**: 313-323.

Vreugdenhil, D., 2007. Potato biology and biotechnology advances and perspectives. Elsevier Ltd. 823p.

Western Potato Council, 2003. Botany of the potato plant. Adaptation from Guide to Commercial Potato Production on the Canadian Prairies.
http://www.agr.gov.sk.ca/docs/crops /horticulture/PotatoManual Botany.pdf.

Wiersema, S.G., 1987. Effect of stem density on potato production. Technical information bulletin 1. International Potato Center (CIP), Lima, Peru. (3rd revised ed.). pp 1-16.

Winch, T., 2006. Growing food: A guide to food production. Springer, Hereford, UK. 341p.

Wurr, D.C.E., J.R. Fellows, J.M. Akehurst, A.J. Hambidge and J.R. Lynn, 2001. The effect of cultural and environmental factors on potato seed tuber morphology and subsequent sprout and stem development. *J. Agric. Sci.*, **136**: 55–63.

Zamil M.F., M.M. Rahmani, M.G. Robbani and T. Khatun, 2010. Combined effect of Nitrogen and plant spacing on the growth and yield of Potato with economic performance. Bangladesh research publication journal.Bangladesh.pp.102.

7 APPENDICES

Appendix Table 1. Means for the effect of intra-row spacing on leaf area index, average tuber number per plant, marketable tuber number per plant, unmarketable tuber number per plant and average fresh tuber weight

Intra-row spacing (cm)	Leaf area index	Average tuber number per plant	Marketable tuber number per plant	Unmarketable tuber number per plant	Average fresh tuber weight
20	3.205^{a}	13.40^{d}	6.76^{a}	6.65^{a}	67.37^{b}
25	2.910^{b}	14.54^{c}	8.25^{b}	6.29^{b}	74.24^{ab}
30	2.587^{c}	15.86^{b}	9.72^{c}	6.14^{c}	69.16^{b}
35	2.316^{d}	17.02^{a}	11.55^{d}	5.47^{d}	79.68^{a}
LSD (5%)	0.051	0.23	0.25	0.104	6.89
CV (%)	12.45	9.23	20.04	7.33	13.17

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Appendix Table 2. Means for interaction effect of inter and intra-row spacing on unmarketable yield per hectare and dry matter content

Inter-row spacing (cm)	Intra-row spacing (cm)	Unmarketable yield (t/ha)	Dry matter content (%)
65	20	2.4^{a}	22.25^{i}
65	25	1.98^{b}	23.67^{fgh}
65	30	1.55^{d}	23.86^{efgh}
65	35	1.28^{e}	24.57^{cde}
70	20	2.04^{b}	23.01^{hi}
70	25	1.71^{c}	25.13^{cd}
70	30	1.13^{f}	24.88^{cd}
70	35	1.02^{f}	25.20^{cd}
75	20	1.46^{d}	23.90^{efg}
75	25	0.88^{g}	24.60^{cde}
75	30	0.72^{h}	25.44^{c}
75	35	0.40^{i}	26.83^{b}
80	20	0.68^{h}	23.20^{gh}
80	25	0.48i	24.51^{def}
80	30	0.39^{i}	26.89^{b}
80	35	0.25^{j}	31.62^{a}
LSD (5%)		0.12	0.79
CV (%)		4.2	8.64

Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Sources of variation	df	Mean square values				
		Days to 50 % flowering	Plant height	Days to maturity	Leaf area index	Main stem number
Block	2	0.08333	0.3681	0.06250	0.007014	1.3244
Intra-row spacing	3	1.33333***	238.5802**	7.68750***	1.790778***	0.3322ns
Inter-row spacing	3	44.00000***	302.3908**	93.40972***	0.003024ns	0.6206ns
Intra-row * inter-row spacing	9	1.33333***	14.5667**	1.61343***	0.002243ns	1.6172ns
Error	30	0.08333	0.8335	44.00000	0.003727	0.7693

** and *** = Highly significant and very highly significant difference at 1% and 0.1% probability levels, respectively. Ns = Non-significant

Appendix Table 3. Means squares for days to 50% flowering, plant height, days to maturity, leaf area index and main stem number

Sources of	df	Mean square values

Appendix Table 4. Means squares for total tuber yield ha^{-1}, average tuber yield per plant, marketable tuber yield ha^{-1}, marketable tuber yield per plant and unmarketable tuber yield ha^{-1}

Sources of variation	df	Total tuber yield t/ha	Average tuber yield g/plant	Marketable tuber yield t/ha	Marketable tuber yield g/plant	Unmarketable tuber yield t/ha
Block	2	2.912	1706	2.976	1699	0.004972
intra-row spacing	3	152.674***	128035**	126.177***	133214**	1.893984**
Inter-row spacing	3	53.557***	4786**	27.883***	10052**	4.415676**
Intra-row * inter-row spacing	9	2.908^{ns}	1353^{ns}	3.341^{ns}	1431^{ns}	0.079810
Error	30	2.016	1147	1.986	1128	0.004627

*, ** and *** = Significant, highly significant and very highly significant difference at 5%, 1% and 0.1% probability levels, respectively. NS = Non-significant.

Appendix Table 5. Means squares for Total tuber number ha^{-1}, average tuber number per plant, marketable tuber number ha^{-1}, marketable tuber number per plant and number of unmarketable tuber per plant.

Sources of variation	df	Mean square values				
		Total tuber number ha^{-1}	Average tuber number Per plant	Marketable tuber number ha^{-1}	Marketable tuber number per plant	Number of unmarketable tuber per plant
Block	2	2.726	0.00098	1.858	0.08235	0.07252
Intra-row spacing	3	3.690***	29.64356***	2.444***	50.39048**	2.90813***
Inter-row spacing	3	1.923***	0.17602^{ns}	1.494***	0.21916^{ns}	0.04763^{ns}
Intra-row * inter-row	9	3.394^{ns}	0.09172^{ns}	4.467^{ns}	0.06863^{ns}	0.01299^{ns}

spacing						
Error	30	2.032	0.07559	2.041	0.08856	0.01563

** and *** = Highly significant and very highly significant difference at1% and 0.1% probability levels, respectively. Ns = Non-Significant

Appendix Table 6. Means squares for Average fresh tuber weight, Tuber dry matter content and Tuber specific gravity

Appendix Table 7. Means squares for number and weight of tubers graded < 20 mm, number and weight of tubers graded 20-30 mm and number of tubers graded 30-40 mm.

Sources of variation	df	Mean square values		
		Average fresh tuber weight	Tuber dry matter content	Tuber specific gravity
Block	2	44.90	0.0281	0.00003333
Intra-row spacing	3	367.94**	32.8681***	0.00001319^{ns}
Inter-row spacing	3	105.32^{ns}	18.6072***	0.00001319^{ns}
Intra-row * Inter-row spacing	9	82.24^{ns}	6.3896***	0.00002801^{ns}
Error	30	68.28	0.2246	0.00001333

** and *** highly significant and very highly significant difference at 1% and 0.1% probability levels, respectively. Ns = Non-Significant

Sources of variation	df	Mean square values				
		Number of tubers graded < 20 mm	Weight of tubers graded <20 mm	Number of tubers graded 20-30 mm	Weight of tubers graded 20-30 mm	Number of tubers graded 30-40 mm
Block	2	7.686	0.00000272	8.62	14.520	1.73
Intra-row spacing	3	23.985**	0.13343823***	12.44^{ns}	6.115^{ns}	4.87^{ns}
Inter-row spacing	3	7.641^{ns}	0.00001705^{ns}	26.43^{ns}	6.172^{ns}	30.16^{ns}
Intra-row * inter-row spacing	9	8.338^{ns}	0.00001924^{ns}	6.56^{ns}	5.646^{ns}	7.05^{ns}
Error	30	5.217	0.00003511	11.77	5.600	16.68

** and *** = Highly significant and very highly significant difference at 1% and 0.1% probability levels, respectively. Ns = Non-significant

Appendix Table 8. Means squares for weight of tubers graded 30-40 mm, number and weight of tubers graded 40-50 mm and number and weight of tubers graded >50 mm

Sources of variation	df	Mean square values				
		Weight of tubers graded 30-40 mm	Number of tubers graded 40-50 mm	Weight of tubers graded 40-50 mm	Number of tubers graded >50 mm	Weight of tubers graded > 50 mm
Block	2	20.41	13.906	125.54	13.601	24.90
Intra-row spacing	3	6.50^{ns}	16.646^{ns}	30.40^{ns}	73.994***	275.74***
Inter-row spacing	3	59.13**	8.555^{ns}	42.00^{ns}	10.612^{ns}	11.31^{ns}
Intra-row * inter-row spacing	9	3.71^{ns}	15.324^{ns}	20.71^{ns}	10.444^{ns}	13.78^{ns}
Error	30	12.89	8.662	15.59	8.414	16.64

** and *** = Highly significant and very highly significant difference at 1% and 0.1% probability levels, respectively. Ns = Non-significant

Appendix Table 9. Simple correlation on growth, yield and quality traits

Variables	DF	DM	PH	LAI	MSN	TYH	TYP	MYH	MYP	UMYH	TNTH	MNTH	TNTP	MNTP	AFW	DMC	L20MN	L20MW	G50MN	G50MW
DF	1	0.51**	0.71**	-0.12	-0.03	-0.54**	0.15	-0.47**	0.22	-0.72**	-0.41**	-0.37*	0.12	0.14	0.03	0.50**	-0.26	-0.16	-0.08	0.04
DM		1	0.89**	-0.66**	-0.15	-0.77**	0.57**	-0.74**	0.60**	-0.67**	-0.69**	-0.66**	0.63**	0.64**	0.13	0.46**	-0.30*	-0.62**	0.32*	0.45**
PH			1	-0.63**	-0.09	-0.79**	0.61**	-0.74**	0.66**	-0.86**	-0.72**	-0.68**	0.61**	0.63**	0.17	0.89**	-0.37 *	-0.58**	0.26	0.42*
LAI				1	0.12	0.71**	-o.84**	0.69**	-o.83**	0.53**	0.61**	0.55**	-0.96**	-0.96**	-0.13	-0.66**	0.44*	0.86**	-0.57**	-0.72**
MSN					1	0.08	-0.06	0.09	-0.06	-0.03	0.13	0.25	-0.17	-0.18	-0.06	-0.15	-0.20	0.13	-0.26	-0.24
TYH						1	-0.41**	0.99***	-0.45**	0.73**	0.64**	0.60**	-0.69**	-0.72**	0.12	-0.77**	0.42**	0.80**	-0.36*	-0.49**
TYP							1	0.34*	0.99***	-0.61**	-0.63**	-0.55**	0.80**	0.79**	0.43**	0.57**	-0.42**	-0.56**	0.42**	0.56**
MYH								1	-0.38**	0.64**	0.60**	0.57**	-0.69**	-0.72**	0.17	-0.74**	0.39**	0.82**	-0.39**	-0.50**
MYP									1	-0.67**	-0.65**	-0.57**	0.79**	0.79**	0.03	0.60**	-0.43**	-0.56**	0.40**	0.55**
UMYH										1	0.68**	0.61**	-0.49**	-0.51**	-0.72**	-0.67**	0.46**	0.44**	-0.16	-0.30*
TNTH											1	0.96**	-0.58**	-0.59**	-0.41**	-0.69**	0.32*	0.50**	-0.27	-0.36*
MNTH												1	-0.53**	-0.54**	-0.37**	-0.66**	0.15	0.47**	-0.21	-0.29*
TNTP													1	0.99***	0.12	0.63**	-0.39**	-0.86**	0.57**	0.71**
MNTP														1	0.14	0.64**	-0.42**	-0.90**	0.57**	0.71**
AFW															1	0.13	0.01	0.11	-0.02	-0.01
DMC																1	-0.30*	-0.62**	0.31*	0.45**
L20MN																	1	0.38**	-0.28	-0.35*
L20MW																		1	-0.53**	-0.67**
G50MN																			1	0.95***
G50MW																				1

*, ** and *** = Indicates that correlation is significant, highly significance and very highly significant difference at $p \leq 0.05$, 0.01 and 0.001 level, respectively.

DF= days to 50% flowering, DM=days to maturity, PH= plant height, LAI= leaf area index, MSN= main stem number, TYH= total yield per hectare, TYP= total yield per plant, MYH= marketable yield per hectare, MYP=marketable yield per plant, UMYH= unmarketable yield per hectare, TNTH= total number of tuber per hectare, MNTH= marketable tuber number per hectare, TNTP= total number of tuber per plant, MNTP= marketable tuber number per plant, AFW= average fresh weight, DMC= dry matter content, L20MN= number of tubers graded less than 20 millimeter, L20MW= Weight of tubers graded less than 20 millimeter, G50MN= number of tubers graded greater than 50 millimeter and G50MW= weight of tubers graded greater than 50 millimeter.