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Response of Potato (Solanum tuberosum L.) to the Application of Mineral Nitrogen and Phosphorus Fertilizers under Irrigation in Dire Dawa, Eastern Ethiopia

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Abstract

Potato is an important cash and food security crop in eastern Ethiopia. However, nutrient requirement of the crop under warmer dry conditions has not been studied in the region. Therefore, an experiment was conducted at Dire Dawa, eastern Ethiopia to investigate the response of potato to the application of mineral nitrogen and phosphorus fertilizers under irrigated condition. Four rates of nitrogen (0, 56, 112 and 168 Kg N ha^{-1}) and four rates of phosphorus (0, 46, 92 and 138 Kg P_2O_5 ha^{-1}) were combined in 4 x 4 factorial arrangement and laid out in randomized complete block design with three replications. Improved potato variety "Bubu" was used as a test crop. Growth, yield and yield components data were collected and analyzed. Results of the study revealed that both the main and interaction effects of nitrogen and phosphorus affected most of the studied growth and yield parameters of the crop. Growth, yield, and yield components of the crop were obtained in response to the application of 56 kg N ha^{-1} and 138 kg P_2O_5 ha^{-1}, with reductions in most of parameters studied as the rate of nitrogen was increased beyond this level. However, the cost-benefit analysis indicated that application of nil kg N ha^{-1}and 138 kg P_2O_5 ha^{-1} would lead to significant economic benefits for farmers.

Keywords: Nitrogen, Phosphorus, Interaction, Potato.

1. Introduction

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and genus Solanum. It is native to South America it has been introduced to Ethiopia in 1859 by a German Botanist called Schimper (Berga et al., 1994). Nowadays, potato is one of the major world's agricultural crops with annual production of 330 million metric tons with area coverage of 18,651,838 ha. In Africa total production of potato is about 17,625,680 tons with total area coverage of 1,765,617ha. Potato is one of the major world food crops in its ability to produce high food per unit area per unit time Ethiopia is endowed with suitable climatic and edaphic conditions for potato production. However, land acreage under potato production is estimated to be only about 69,784 ha with total production around 572,333 tons and the national average yield is about 8.2t ha^{-1}, which is very low as compared to the world's average production of 17.67t ha^{-1}(FAOSTAT, 2010).

Potato is a major part of the diet of half a billion consumers in the developing countries. It is an important food and cash crop in Eastern and Central Africa, playing a major role in national food security and nutrition, poverty alleviation, income generation, and provides employment in the production, processing and marketing sub-sectors (Lung'aho et al., 2007). Low soil fertility status is among the bottle–necks that contribute to lower yields of crops including potato. Inorganic nitrogen sources (fertilizers) have been used as means to increase crop yield per unit area of land for decades to cope with food demands of the ever-increasing population. Depending on conditions, the potato crop is a heavy feeder of the major soil nutrients, removing estimated amounts of 90 to 120 kg N ha^{-1}, 13.8 to 25.8 kg P ha^{-1}, and 150 to 250 kg K ha^{-1}from the soil (Sikka, 1982).

In Ethiopia, low soil fertility is one of the factors limiting the productivity of crops, including potato (Berga et al., 1994).This might be caused because of the removal of surface soil by erosion, crop removal of nutrients from the soil, total removal of plant residues from farmland and lack of proper crop rotation program (Timm, and Flockner, 1966).Traditionally, farmers maintain or improve the fertility of farmland soils by practicing fallowing, use of farmyard manure, intercropping and/or crop rotation. Available statistical data indicate that the average national household land holding per average household size of 5 members in the country is about 0.68 ha and 0.22 ha for "Meher" and "Belg" season, respectively (EASE, 2003).

In the tropics and subtropics where Ethiopia is located, the major limiting factors for potato production are heat and water stresses. These factors have significant effects on physiology, yield and grade of potato crop. The meteorological elements governing growth, development, production, and quality of potato tubers at a given site are basically air and soil temperatures, solar radiation, photoperiod, soil moisture, and crop water use or evapotranspiration (Midmore, 1992). Potatoes grow best under temperate conditions (Hijmans, 2003). Tuber growth and yield can be severely reduced by temperature fluctuations outside 5-30°C. Temperatures above 30°C can have a range of negative effects on potato including slowing tuber growth and initiation, less partitioning of starch to the tubers, physiological damage to tubers; shortened or non-existent tuber dormancy and making tubers sprout too early (Levy et al., 2001).

These effects temperature can reduce crop yield, number and weight of tubers. Due to this in areas where current temperatures are near the limits of potatoes temperature range, for instance much of Sub-Saharan Africa, will likely suffer large reductions in potato crop yields (Hijmans, 2003). Likewise at low temperatures potatoes are at risk of frost damage, which can reduce growth and badly damage tubers (Haverkort et al., 2012). At high altitudes and high latitude countries such as Russia and Canada, potato growth is currently limited or impossible due torisks of frost damage. It may be possible to produce potato in such areas with the existing rising temperatures in the world by extending both the growing season and production area (Haverkort et al., 2012,).

Adaptation of potato farming practices and potato varieties to changing conditions caused by climate variability's could help to maintain crop yields and allow potato to be grown in areas with predicted conditions unsuited to current commercial potato cultivars. Methods to adapt potatoes to climate change include shifting production areas, improving water use efficiency and breeding new tolerant potato varieties. Specific cultivars can be possibly bred that are specifically adapted to hot climates and there are reports indicating the existence of genetic variability for heat tolerance in potato genotypes. Several wild potato species have been found to be more heat tolerant than *Solanum tuberosum* and crossing of these species with cultivated potato helps to produce heat tolerant polyploidy hybrid (Mendoza and Estroda, 1979; Levy et al., 2001; Hijmans 2003;).Though, international potato research program recently developed heat tolerant genotypes furthermore, heat tolerant and early maturing potato cultivars are developed in some countries like India (Mendoza and Estroda, 1979), though these cultivars are not currently available in

Ethiopia. However, Haramaya University has been started screening of potato genotypes for heat tolerance a couple of years ago from limited number of introduced heat tolerant genotypes and many early maturing potato genotypes maintained at the University since the introduction of potato for research in the country. Mendoza and Estroda, 1979)

Haramaya University has been given the responsibility to develop potato varieties that are tolerant to heat for the country as well as to determine fertilizer requirement of the crop. It is screening potato genotypes that produce high yield in lowland areas such as Dire Dawa. Determination of fertilizer requirement of the crop at lowland is as equally important as developing varieties tolerant to heat. This is because information is scanty on the requirement of nitrogen and phosphorus fertilizers for enhancing tuber yields of potato in lowland areas of the country. Thus, conducting systematic investigation in this line is very important to come up with relevant recommendations that will help to increase the yield of the crop in such areas. Therefore, this experiment was carried out with the objective to understanding the response of potato to different rates of mineral nitrogen and phosphorous fertilizers in terms of growth, yield and yield components as well as tuber quality attributes in the a lowland area where high temperature prevails throughout the growing period.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at Dire Dawa (Tony farm) Research site of the Haramaya University, 40 kilometers away from Haramaya University 66 kilometers away from Harere and 518 kilometers away from Addis Ababa. The climatic condition of Dire Dawa seems to be greatly influenced by its topography, which lies between 950 –1250 meter above sea level, latitude 9°36′N, 41°52′E9. and longitude 600°N, 41.867°E and which is characterized by warm and dry climate with a relatively low level of precipitation. The mean annual temperature of Dire Dawa is about 25.4^{0}C. The average maximum temperature of Dire Dawa is 31.40C, while its average minimum temperature is about 18.2^{0}C. The region has two rain seasons; that is, a small rain season from March to April, and a big rain season that extends from August to September. The aggregate average annual rainfall that the region gets from these two seasons is about 604 mm. On the other hand, the region is believed to have an abundant underground water resource (Levoyageur, 2012).

2.2. Experimental Material

A potato variety named "Bubu" was used as a test crop. This variety was released by the Potato Improvement Programme of Haramaya University in 2010. The variety was released by the University for mid to high altitude areas of eastern Ethiopia. The variety has been earlier evaluated at Dire Dawa against other potato genotypes for heat tolerance and it produced reasonable yield (14t ha^{-1}) which is above the national average yield of the crop (HUPIP, 2013 unpublished report).

2.3 Treatments and experimental design

The treatments consisted of four levels of nitrogen (0, 56, 112 and 168 kg N ha^{-1}) and four levels of phosphorus (0, 46, 92, and 138 kg P2O5ha^{-1}). Urea (46% N), and Triple Super Phosphate, TSP (46% P_2O_5), were used as fertilizer sources for nitrogen and phosphorus, respectively.

The experimental plots were arranged in a randomized complete block design in a factorial arrangement with three replications per treatment. Treatments were assigned to each plot randomly. The sizes of the plots were 4.5 m long and 3.60 m wide (16.2 m2). Each plot had six rows with 12 plants each.

2.4. Experimental Procedures

i) Land preparation

The selected experimental land was ploughed to a fine tilthtoadepthof25-30cm, harrowed using a tractor and levelled and pulverised manually. A total of 48 experimental plots were laid out and the required numbers of ridges were marked and ridges were formed manually in each plot with the spacing of 75cm between ridges.

ii) Planting

Well sprouted medium-sized potato tubers with approximate weight of 30 to 75g (Jaleta, 1997) with sprout length of 1.5 to 2.5cm (Lung'aho et al., 2007) were planted on the ridges at the spacing of 75cm between ridges and 30cm between tubers at the depth of about 10cm and covered with soil. The space between adjacent plots was 1 metre whereas the space between adjacent blocks was 1.5 metres.

iii) Methods and time of fertilizer application

All phosphorus fertilizer at the specified rates was applied by banding the granules of TSP (Triple superphosphate) at the depth of 10 cm below and around the seed tuber at planting. Nitrogen at the specified rates was applied in three splits in the form of urea (1/4th at plant emergence, 2/4th at mid-stage of vegetative growth (about 30 days after planting), and 1/4th at the initiation of tubers. Urea was applied by slightly opening the soil at each hill, and covering the fertilizer with soil to prevent loss by volatilization.

iv) Other cultural practices

Weeds were controlled by hoeing. Earthling-up was done as required to prevent exposure of tubers to direct sunlight and for promoting tuber bulking and for ease of harvesting. Application of irrigation water was done every three days at field capacity.

v) Harvesting

The haulms were mowed two weeks before harvesting to thicken tuber periderm when the plants reached physiological maturity and senesced. This was done to toughen the periderm in order to reduce bruising and skinning during harvesting and post-harvest handling. For yield estimation, tubers were harvested from plants grown in the four middle rows, leaving the plants growing in the two border rows as well as those growing at both ends of each row to avoid edge effects.

2.5. Soil Sampling and Analysis

2.5.1. Soil analysis

Surface soil (0-30 cm depth) samples were collected by using an auger from 10 spots of the experimental field as in zigzag pattern before planting. These samples were composited to three samples. These samples were composited to yield one representative sample per replication. The samples were subjected to air drying and ground to allow them to pass through 2.0 mm sieve before laboratory analysis. The soil samples were analyzed for some parameters at Haramaya University's Soil Laboratory. The soil pH was determined in 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Page, 1982). Texture of the soil was determined by the sedimentation method (Day, 1965). Organic matter content of the soil was determined by the volumetric method based on the oxidation of organic carbon with acid potassium di-Chromate (KCO) medium using the Walkley and Black method (1934). Total Nitrogen was determined according to Micro-Kjeldahl method with sulpheric acid (Dewis and Freitas, 1984).Exchangeable potassium was extracted using 1N neutral ammonium acetate at pH 7 (Hesse, 1975) and determined by atomic absorption spectrophotometer. Available phosphorus was determined by the Olsen method (Olsen *et al.,* 1954).

2.6. Data Collection and Measurements

Data on crop phenology, growth, yield, and yield components were collected following the standard procedure established by the International and National research institutes from randomly selected plants for growth parameters, on plot basis for phenological data and from each net plot for yield and yield components. The data recording and measurements for each character were carried out as follows.

2.6.1. Crop phenology and growth parameters

Days to 50% emergence: recorded when 50% of the plants in each plot sprouted and emerged.

Days to 50% maturity: The number of days from planting to 50% of plants in each plot showed yellowish haulms.

Plant height (cm): The height of 10 randomly selected plants from the central rows was measured at physiological maturity stage from ground surface to the tip of the main stem in centimetre and averaged to get the mean plant height in centimetre.

Total leaf area per hill (cm^2): It was estimated using a portable leaf area meter (Model CI-202 Area meter) and expressed as cm^2 at a week after the plants started flowering assuming that the produced leaves attained maximum leaf area. This was determined by counting the leaves of 5 randomly sampled plants and taking the average.

Number of main stem per hill: The total numbers of stems that arose from the ground were counted in 10 randomly selected plants from the central rows in each plot to get the mean number of stem per hill. The actual number of stems per hill was recorded at the plants reached flowering stage.

2.6.2. Yield and yield component parameters

Average tuber number per hill: This was recorded as the number of tubers collected from matured plant in each net plot at harvest.

Average tuber mass per hill (kg): This refers to the average weight of tubers per hill, which was obtained by weighing the total mass of tubers from randomly sampled five plants from the central rows of each plot and divided by five.

Average tuber weight (g/tuber): This refers to the average weight of a tuber. It was determined by dividing the total fresh tuber yield of randomly sampled five plants to the respective total tubers number.

Marketable tuber number (per hill): The number of tubers which were free from diseases, insect pests, with the mean weights of above 25g was determined by counting the total tubers harvested from five plants in the middle row and divided by five at harvest.

Unmarketable tuber number (per hill):The number of tubers which were unhealthy, injured by insect pests, and less than 25g in weight was determined by counting from plants the middle five rows and divided by five at harvest.

Total tuber number (per hill): total tuber number was obtained by adding up the number of marketable and unmarketable tubers.

Marketable tuber yield (t ha^{-1}): The average mass of tubers which were free from diseases, insect pests and with the mean weights of above 25g were recorded from five randomly taken plants and calculated to t ha^{-1}.

Unmarketable tuber yield (t ha^{-1}): The average mass of tubers which were unhealthy, injured by insect pests, and less than 25g size category tubers were recorded and calculated to t ha^{-1}.

Total tuber yield (t ha^{-1}): The total tuber yield per hectare was recorded by adding up the weights of marketable and unmarketable tubers.

2.6.3 Tuber Quality parameters

Tuber size distribution in number: This refers to the proportional number of tubers size categories. All tubers from five randomly taken plants was categorized into very small (<30 g), medium (30-75 g), and large (>75 g) according to Lung'aho *et al.* (2007). The proportion of the number of each tuber category was expressed in percentage. The data were taken from plants harvested in the four middle rows at harvest.

To determine, tuber dry matter percent, five tubers representing all size categorise of the varieties, were chopped into small 1-2 cm cubes, mixed thoroughly, and two sub-samples each weighing 200 g was weighed. The exact weight of each sub-sample was determined and recorded as fresh weight. Each sub-sample was placed in a paper bag and put in an oven until constant dry weight was attained after checking the weight at intervals. Each sub-sample was immediately weighed and recorded as dry weight. Then per cent dry matter content for each sub-sample was calculated [(International Potato Centre (CIP)], 2006).

Dry matter: the dry matter percentage was calculated according to Williams (1968).

$$\text{Dry matter}\ (\%) = \frac{\text{weight of sample after drying (g)}}{\text{initial weight of sample (g)}}\ \text{x}100$$

Specific gravity of tubers: was determined using the weight in air/weight in water method. A Five kg tuber of all shapes and size categories were randomly taken from each plot and washed with water. The tubers were then weighted first in air then in water. The specific gravity was then calculated using the following formula (Kleinkopf *et al*, 1987).

$$\text{Specific Gravity} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

Harvest index: It was calculated as the ratio of dry mass of tubers to the dry mass of total biomass and express in ratio.

2.7. *Data Analysis*

The data were subjected to analysis of variance using Gen Stat, 13th Edition (VSN Ltd, Oxford UK) statistical software package LSD test at 5% probability was used to separate means when the analysis of variance indicated the presence of significant differences among treatments. Correlation analysis was performed to determine associations of yield and yield components as affected by the phosphorus and nitrogen rates.

3. Results and Discussion

3.1 Soil physicochemical Properties of the Experimental Site

The physic-chemical properties of the soil of the experimental site are shown in Table 1. The texture of soil of the experimental site is sandy loam of alluvial deposition, which contains high amount of sand and medium amounts of silt and clay. The soil is alkaline in reaction. According to the classification of Landon (1991), the soil could be classified as containing very low amount total nitrogen, a medium amount of available phosphorus, and low amounts of organic carbon. However, the pH of the soil is higher than the optimum required for potato, which are ranges between 5.2 to 6.5 (Mclean et al, 1967) as cited by Fageria et al. (2011). Under this pH condition, phosphorus availability is likely to be a construing factor to potato production since phosphate precipitates as calcium and magnesium carbonates under such conditions as suggested by Mengel et al (2001). Therefore, the relatively medium amount of available Olsen phosphate may not be indicative of good availability of the nutrient to the potato crop in the study area.

Table 1: Selected physicochemical properties of the experimental site soil

Soil physicochemical property	Content
pH	7.79
Texture %	Alluvial soil
Sand %	57
Silt %	22
Clay %	21
Total nitrogen %	0.044
Available phosphorus (ppm)	14
Exchangeable potassium (mol/kg soil)	1.21
Organic carbon %	0.515

Sources from: Haramaya University Soil Laboratory

3.2. Effect of Nitrogen and Phosphorus Rates on Crop Phenology and Growth parameters

3.2.1. Days to 50 % emergence

The analysis of variance revealed that the main effect of nitrogen and phosphorus as well as their interaction significantly ($P < 0.01$) influenced days to 50% emergence. Increasing nitrogen application from 0 to 168 kg N ha^{-1} significantly reduced the time required to attain 50% emergence of potato plants which ranged from 25 to 14.83 days. The lowest and the highest number of days to reach 50% emergence were recorded for the application of 168 and 0 kg N ha^{-1}, respectively. Similarly, increased phosphorus application from 0 to 138 kg P_2O_5 ha^{-1} reduced the days to 50% emergence from 25 to 16.17 (Table 2). On the other hand, the lowest (12.43) and the highest (25) number of days to reach 50% emergence were recorded for the combined application of 168 N with 138 kg P_2O_5 ha^{-1} and 0 N with 0 P_2O_5 ha^{-1}, respectively (Table 2).These could be due to the interaction of the mineral fertilizer and temperature.

According to Wang and Altman , 2003, for non-dormant seeds, it appears to be a general rule that germination rate is zero below a base temperature and increases linearly with temperature up to the optimum at which the rate is maximal and beyond which it declines again almost linearly to zero. Temperature was categorized as a rate modifier because so many physiological processes depend on biochemical reactions that respond to the temperature of cell in which they occur.

According to Struik et al., (1999), higher temperatures increased gibberellic acid production (GA), in additional mineral fertilizer, particularly nitrogen which also promotes gibberellic acid and thus increase the rate of emergence.

Table 2: Interaction effect of Nitrogen and Phosphorus rate on days to 50% emergence of potato

	Phosphorous rate (kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	25^{a}	17.33^{cde}	16.79^{cde}	16.17^{def}
56	18.33^{bck}	14.27^{fgh}	13.8^{ghijk}	13.17^{ghijk}
112	15.83^{ef}	13.67^{ghijk}	13.38^{ghijk}	12.99^{hijk}
168	14.83^{fg}	13.03^{ghijk}	12.85^{hijk}	12.43^{hijk}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance.

3.2.2. Days to 50% physiological maturity

The main effect of nitrogen and phosphorus significantly ($P < 0.01$) influenced days to 50% maturity. But, the interaction of nitrogen and phosphorus did not significantly affect days to 50 % physiological maturity.

The main effects of nitrogen and phosphorus on days to 50% physiological maturity are given in Table 3. Application of nitrogen had highly significant influence on maturity of the crop which prolonged the time required to reach 50 % physiological maturity. The prolonged physiological maturity of the crop may be due to the application of nitrogen fertilizer prolonged the canopy life of the plant, which enabled the potato plant to maintain physiological activity for an extended period, thereby continuing photosynthesis. The increased application rate of nitrogen from 0 to 168 kg N ha^{-1} delayed days to 50% maturity from 87.2 to 115.1. Therefore, a crop with more nitrogen will mature later in the season than a crop with less nitrogen because extended vegetative growth is related to excessive haulm development whereas early tuber growth to less abundant haulm growth (Israel et al., 2012, Barbara,. 2007),

On the other handed increased application of phosphorus from 0 to 138 kg $P_2O_5ha^{-1}$ significantly reduced days to 50% physiological maturity from 112.8 to 98.3 with significant difference of 14.5 days (Table 3).This might be due to the role of phosphorus in accelerating the physiological maturity of potato. The result of the present study investigation was supported by the earlier studies where phosphorus was reported to be related with shortening maturity of potato (Kleinkopf et al. 1987; Mulubrhan, 2004, Israel et al., 2012).

Table 3: Effect of Nitrogen and Phosphorus rates on day to 50 % physiological maturity

Nitrogen rate (kg ha^{-1})	Day to 50 % maturity
0	87.2^{d}
56	103.2^{bc}
112	109.8^{ab}
168	115.1^{a}
LSD (5%)	9.76
significance	**
Phosphorus rate (kg P_2O_5 ha^{-1})	
0	112.8^{a}
46	103.1^{ab}
92	101.2^{bc}
138	98.3^{c}
LSD (5%)	9.76
significance	*
CV (%)	11.3

*&** Significant at $P<0.5$ and $P<0.01$ respectively.

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.2.3 Plant height

The main effects of nitrogen and phosphorus as well as the interaction effect significantly ($P < 0.01$) influenced the height of potato plant.

Increasing nitrogen application from 0 to 168 kg ha^{-1} increased the height of potato plants which ranged from 34.00 to 88.67cm (Table 4). The highest and the lowest height of potato plants were recorded for the application of 0 and 168 kg N ha^{-1}, respectively. Similarly, increasing the rate of phosphorus application from 0 to 138 kg P_2O_5 ha^{-1} increased the height of potato plants from 34.00 to 64.00 cm (Table 4).The lowest (34.00 cm) and the highest (113.33 cm) height of potato plant were recorded for the combined application of 0 N ha^{-1} with 0 P_2O_5 $ha^{-1}$and 168 kg N ha^{-1} with 138 P_2O_5 kg ha^{-1}, respectively. This could be due to the interaction of the mineral fertilizers and temperature. Temperature was categorized as a rate modifier because so many physiological processes depend on biochemical reactions that respond to the temperature of cell in which they occur.

According to Struik et al., (1999), higher temperatures increased gibberellic acid (GA), which gibberellic acid is a functional endogenous hormone for cell elongation and cell division that results the fast growth of potato plant in high temperature region. Boral and Milthorpe (1962) found that haulm growth was more rapid at higher temperatures (27^{0}C), while the ratio of the weight of leaves to stems decreased because the optimum temperature for leaf development was 12 to 14^{0}C.

The result of the present study is in agreement with that of Zelalem et al., (2009) who have reported that the application of N and P had highly significant effect on height of potato which increased the plant height. Similarly Iseal et al., (2012) have found that increasing application of nitrogen and phosphorus significantly increased plant height.

Table 4: Interaction effect of nitrogen and phosphorus on plant height of potato

	Phosphorous rate (kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	34^{m}	55^{l}	60.67^{k}	64^{jk}
56	68.67^{ij}	70.67^{hi}	72.33^{hi}	75^{jh}
112	77.67^{g}	79^{fg}	82.67^{ef}	86.33^{de}
168	88.67^{cd}	92.67^{c}	101^{b}	113.33^{a}

Means with followed by same letter(s) in rows and columns are not significantly different at 5% level of significance

3.2.4. Total leaf area per hill

Nitrogen had significant ($P < 0.01$) influence on total leaf area per hill but neither phosphorus nor the interaction between the nitrogen and phosphorus did not significantly affect on leaf area of potato plants.

In this study, it was observed that as the rate of nitrogen increased the total leaf area per hill also significantly increased. However, with increased application of phosphorus did not increase total leaf area significantly. The highest total leaf area per hill was obtained from the rate of 168 kg N ha^{-1} as compared to control treatment. Increasing nitrogen application from 0 to168 kg N ha^{-1}increased the total leaf area per hill of potato plants from 17.76 to 23.26 cm^2 (Table 5).These could be due to the development of more above ground biomass with the expanded leaves produced in response to nitrogen.

According to Israel et al. (2012) and Mulubrhan, (2004), application of nitrogen fertilizer resulted in excessive development of haulm. Similarly, Zelalem et al. (2009) have found that increased application of nitrogen rate significantly increased total leaf area of potato.

Table 5: Effect of Nitrogen and Phosphorus rates on total leaf area per hill

Nitrogen rate (kg ha^{-1})	Total leaf area per hill (cm^2)
0	17.76^c
56	18.77^{bc}
112	20.45^b
168	23.26^a
LSD (5%)	2.031
significance	**
Phosphorus rate (kg P_2O_5 ha^{-1})	
0	19.37
46	19.83
92	20.12
138	20.93
significance	ns
CV (%)	11.3

** Highly significant, ns Non-significant.

Means followed by same letters with in a column in a given fertilizer are not significantly at $P<0.05$.

3.2.5 Number of main stem per hill

The main effects of nitrogen and phosphorus as well as their interaction effect did not affect the number of main stem per hill.

Although stems density is one of the most important yield components in potato, the results of the present study showed that the influences of N and P on the number of main stem per hill were non-significant (Table 6). This could be due to the fact that the number of main stem per hill is determined very early in the ontogeny of yield (Lynch and Tai, 1989) and thus may be affect by other factors such as condition of seed tubers (Allen, 1978), physiological age of the seed tuber (Iritmti et al, 1984), variety (Lynch and Tai, 1989) and tuber size (Harris, 1978).

As a result, in this study, the fertilizers effect may not have occurred sufficiently early to influence the number of main stem per hill. This result is similar with the findings of Zelalem et al. (2009), Israel et al. (2012) and Mulubrhan, (2004), who reported that mineral fertilizers like nitrogen and phosphorus did not affect the number of main stem of potato.

Table 6: Effect of Nitrogen and Phosphorus rates on number of main stem per hill

Nitrogen rate (kg ha^{-1})	Number of main stem/ hill
0	6.58
56	6.33
112	6.5
168	6.41
significance	ns
Phosphorus rate (kg P_2O_5ha^{-1})	
0	6.66
46	6.41
92	6.33
138	6.42
significance	ns
CV (%)	15.9

ns; Non-significant.

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.3. Effect of Nitrogen and Phosphorus Rates on Potato Yield and Yield Components parameters

3.3.1. Average tuber number per hill

Both the main effects of nitrogen and phosphorus significantly ($P < 0.01$) influenced average tuber number hill^{-1}. The analysis of variance also revealed that the interaction between the two had significant ($P<0.05$) effect on average tuber number hill^{-1}.

Average tuber number per hill increased significantly in response to increasing rate of phosphorus overall rate of nitrogen. Increasing the rates of nitrogen increased average tuber number per hill over all rates of phosphorus only up to 56 kg ha^{-1}.Therefore, increasing the rate of nitrogen beyond 56 kg N ha^{-1}significantly decreased tuber number per hill over all rates of phosphorus application. The highest tuber number per hill was recorded for 56 kg N ha^{-1}and 138 kg P_2O_5ha^{-1} whereas the lowest was recorded at nil rates of phosphorus and 168kg N ha^{-1}. Thus, the number of tubers per hill produced in response to applying 56 kg N ha^{-1}and 138 kg P_2O_5ha^{-1} exceeded the one obtained from applying nil kg P_2O_5ha^{-1}and 168 kg N ha^{-1} without P by 194% (Table 7). This may indicate that the increased N rate might have an inhibitory effect on tuber initiation process that may be coupled with high temperature of the area which increased haulm development but reduced tuber initiation.

This result is in accord of the suggestion of Gregory (1956) who has described that low temperatures, especially low night temperatures increase the number of tubers per plant while at higher temperatures fewer tubers per plant are formed, but larger tubers are obtained. Although, increases in either day or night temperatures above optimal levels reduce tuber yields, high night temperatures seem to be more deleterious. Similarly, Ewing et al. (2004) have found that high nitrogen concentration in the plant and temperatures restrict tuber formation. Growth substances are involved in plant response to environmental factors. Among the growth hormones, gibberellic acid (GA) endogenously increased under high temperatures, which generally inhibits tuber initiation.

The present study is in agreement with the finding of Israel et al. (2012), who have reported that the interaction effect of nitrogen and phosphorus affected average tuber number hill-1of potato plants. Zelalem et al. (2009) have also found that increased rates of nitrogen and phosphorus significantly increased average tuber number hill^{-1} of potato due to differences in the growth conditions.

Table 7: Interaction effect of Nitrogen and Phosphorus on Average tuber number per hill of potato

	Phosphorous rate (P_2O_5 kg ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	6.48^{g}	7.86^{e}	8.9^{c}	10.2^{b}
56	7.2^{f}	8.4^{d}	9.2^{c}	10.8^{a}
112	3.93^{mn}	5.13^{ij}	5.3^{hi}	5.66^{h}
168	3.67^{n}	4.13^{lm}	4.46^{kl}	4.8^{jk}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

3.3.2. Average tuber mass per hill

Analysis of variance result revealed that the main effects of nitrogen and phosphorus and their interaction significantly ($P < 0.01$) influenced average tuber mass hill^{-1}.

Increasing the rate of nitrogen up to 56 kg ha^{-1}increased average tuber mass hill^{-1}by about 18%, but application of nitrogen at 168 kg ha^{-1} highly significantly decreased average tuber mass hill^{-1}by about 64% for all the rates of the phosphate fertilizer. The highest average tuber mass hill^{-1}was recorded in response to applying 56 kg N ha^{-1}and 138 kg P_2O_5ha^{-1}. However, the lowest was obtained in response to applying of nil kg P_2O_5ha^{-1}and 168 kg N ha^{-1} (Table 8). This may show that the increasing the rate of nitrogen beyond 56 kg ha^{-1} had inhibitory effect on tuber initiation process and consequently accumulation of tuber mass. Additionally, in the area where there is high temperature, there will be fast growth of aboveground biomass which leads to higher respiration than photosynthesis, hence, utilization of stored food from the tubers for cooling and counteracting the negative effect of high temperature on the plant (Ewing et al. 2004). In accord with this suggestion, Johnstan et al, (1986) have observed that, at low temperature, in the winter season, maximum tuber mass was obtained at 12 to 14^{0}C. In the summer season, when light intensity is higher, maximum tuber mass was obtained at 18 to 20^{0}C.

The present study is, however, in contrast to the finding of Israel et al. (2012) who reported that N and P interaction significantly increased average tuber mass hill^{-1}of potato plants. Similarly, Zelalem et al. (2009) have found that increasing the rate of nitrogen and phosphorus significantly increased average tuber mass hill^{-1}of potato.

Table 8. Interaction effect of Nitrogen and Phosphorus on average tuber mass per hill of potato

	Phosphorous rate (P$_2$O$_5$ kg ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	0.33^{g}	0.4^{e}	0.49^{c}	0.55^{b}
56	0.39^{f}	0.46^{d}	0.51^{c}	0.59^{a}
112	0.15^{l}	0.21^{i}	0.22^{hi}	0.24^{h}
168	0.14^{l}	0.17^{kl}	0.18^{jk}	0.19^{ij}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

3.3.3. Average tuber weight

The main effect of nitrogen and phosphorus was highly significant ($P < 0.01$) but the interaction between nitrogen and phosphorus did not show significant difference for average tuber weight.

Increasing the rate of applied nitrogen from nil to 56 kg ha^{-1} increased the average tuber weight. However, in response to increasing the rate of nitrogen from 56 to 112 and 168 kg N ha^{-1}(Table 9) average tuber weight decreased significantly. This shows that increasing the rate of nitrogen application beyond 56 kg N ha^{-1}was detrimental to the production of liter tubers. This could be attributed to possible re-absorption of the stored food from the tubers because the high temperature in the experimental site as suggested by (Ewing et al., 2004). have suggestion is consistent also with the postulation of Westermann et al. (1994b) that the aboveground biomass leads to reuse or re-sorption of stored food in tubers, which negatively impacts on the tuber weights of the crop plant.

On the other hand, increasing the rate of phosphate from 0 to 46 kg k P$_2$O$_5$ ha^{-1} increased average tuber weight significantly. However, increasing the rate of phosphorus beyond 46 kg P$_2$O$_5$ha^{-1} did not further increase average tuber weight. This indicates the optimum rate of phosphorus for increased tuber weight was already attained at46kg P$_2$O$_5$ha^{-1}and it was not agronomical necessary and beneficial to increase the rate of the fertilizer further. The results of this study showed that the importance of nitrogen and phosphorus application to maximize tuber weight at lowlands but the application of both nutrients should be kept at a moderate rather than at high rates. However, in contrast to the present finding, Israel et al. (2012) and Zelalem et al. (2009) have reported significant increase in average tuber weight in response to increased rates of N application. Similarly, the results of the present study are in contrast to the same authors findings of significant increases in average tuber weight in response to increased rates of N application up to higher rates. The difference of may be due to environmental conduction where the potato plants were grown.

Table 9: Effect of Nitrogen and Phosphorus rates on average tuber weight

Nitrogen rate (kg ha^{-1})	Aver tuber weight (g)
0	62.13^{b}
56	62.97^{a}
112	45.8^{c}
168	44.17^{d}
LSD (5%)	0.27
significance	**
Phosphorus rate (kg P$_2$O$_5$ha^{-1})	
0	48.18^{d}
46	54.83^{c}
92	55.62^{b}
138	56.43^{a}
LSD (5%)	0.044
significance	**
CV (%)	3.1

*&** Significant at $P<0.5$ and $P<0.01$ respectively.

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.3.4. Marketable tuber numbers

Marketable tuber numbers hill^{-1} was highly significantly ($P < 0.01$) influenced by the main effects of nitrogen and phosphorus, but not by their interaction.

Increasing the rate of nitrogen from 0 to 56 kg ha^{-1} significantly increased marketable tuber number per hill. However, further increases in the rate of nitrogen from 56 to 112 and 168 kg N ha^{-1}it was linearly and significantly decreased (Table 10). The increase in the marketable tuber numbers hill^{-1}in response to increasing the rate of nitrogen at the lower signifies that the nutrient prompted production of larger numbers of tubers. However, the decrease in response to farther increase the nutrient supply indicates detrimental effects of too much nitrogen on number of tuber production. This shows that the optimum rate of nitrogen for enhanced number of tuber production was already reached at 56 kg ha^{-1}and increasing the rate of the nutrient beyond that rate negatively affected tuber production. This could be ascribed to the increase in vegetative growth due to higher nitrogen rates which results in the reuse of the stored food from tubers to support growth and survival of aboveground part and consequently the production of very small tubers that may have decreased marketable tuber number hill^{-1}.

However, unlike nitrogen, increasing the rate of phosphate application linearly and significantly increased increasing marketable tuber number. Thus, the highest value was produced observed for application of 138 kg P_2O_5ha^{-1}whereas the lowest was obtained from the control plot (Table 10).The increase in marketable tuber number from nil to138 kg P_2O_5ha^{-1}amounted to 68%. This increase may be due to the phenomenon that increased rate of phosphorus application might not increase the aboveground biomass as much as nitrogen rates. The increase in tuber numbers per hill in response to increased application of phosphorus is consistent with the results of Rosen et al. (2008).

According to Boral and Milthorpe (1962), the decrease in number of marketable tuber with increases in applied nitrogen is associated with the decrease in the number of large and medium size tubers due to metabolism and excessive growth of aboveground part of the plant. In the present study, the observed decreased number of marketable tuber may also be due to effect of increased rates of nitrogen application in reducing the number of large and medium size tubers coupled with the specific inhibitory effects of high temperature on the tuberization process, in addition to the reduced number of large and medium size tubers in response to increased rate of N applications.

3.3.5. Unmarketable tuber number

A highly significant ($P < 0.01$) influence of nitrogen and phosphorus was observed on unmarketable tuber numbers hill^{-1} as evident from the analysis of variance result. But, the interaction effect of nitrogen and phosphorus did not affect unmarketable tuber numbers hill^{-1}.

Increasing the rate of nitrogen from 0 to 56 kg N ha^{-1}did not affects unmarketable tuber number. However, increasing the rate of nitrogen from 56 to 120 and 168 kg N ha^{-1} linearly and significantly increased unmarketable tuber numbers of the plant significant. However, increasing the rate phosphate from 0 to 46, 92, and 138 kg P2O5ha-1significantly decreased the number of unmarketable tubers produced per hill (Table 10).

Highly-significantly increased unmarketable tubers number was observed in plants with applied nitrogen as compared to the control treatment. However, highly significant variation in unmarketable tuber number was observed as nitrogen application increased from 0 to 168 Kg N ha^{-1}.This could be due to nitrogen as well as temperature that accelerate the growth of aboveground part of plants and re-absorption in the tubers, which often leads reduced tuber size and weight so the tubers become unmarketable (stolon). On other hand, when the phosphorus level increased from 0 to138 kg P_2O_5ha^{-1}unmarketable tubers number hill^{-1}was reduced. This may be due to the phenomenon that phosphorus also increases aboveground biomass but not as much as nitrogen. This was important for photosynthesis and net assimilation processes and no re-absorption evidently took place from the tubers, leading to increased tuber size and weight so the tuber could be marketable (Boral and Milthorpe, 1962).

3.3.6. Total tube numbers

The results of analysis of variance revealed that the main effects of nitrogen and phosphorus significantly ($P < 0.01$) influenced total tuber numbers hill^{-1}.The analysis also revealed that the interaction effect of nitrogen and phosphorus did not affect total tuber numbers hill^{-1} significantly.

Increasing the rate of nitrogen from 0 to 56 kg N ha^{-1}did not increase total tuber numbers hill^{-1}. However, when the rate of the nutrient increased from 56 to 112 and 168 kg N ha^{-1}, total tuber number per hill decreased highly significantly. Thus, the lowest and the highest total tuber numbers hill^{-1}were recorded for the application of 168 and 56 kg N ha^{-1} respectively (Table 10). On the other hand, increasing the rate of phosphorus application increased linearly and significantly the total tuber numbers hill^{-1}from 6.392 to 7.942.The lowest (4.8) and the highest (10) total tuber numbers hill^{-1}were recorded for the combined application of 168 N with 0 P ha^{-1}and 56 N with 138 P_2O_5Kg ha^{-1}respectively.

In the present study, raising the rate of applied nitrogen from 0 to 56 kg ha^{-1}increased total tuber number by10.5%. On other hand, increasing the level of applied nitrogen from 56 to 168kg N ha^{-1}significantly reduced total tuber number hill^{-1}by 5.6%. Similarly, increasing the level of applied phosphorus from 0 to 138 Kg P_2O_5 ha^{-1}significantly increased total tuber number hill^{-1}from 6.392 to 7.942 which is about 12.4 %. Similar to the results of this study, Sommerfeld and Knutson (1965), Sparrow et al. (1992), Israel et al. (2012) and Zelalem et al. (2009) have reported that the increased rates of phosphorus has increased the number of potato tubers set per hill. Many researchers (Israel et al. 2012; Mahmoodabad et al. 2010; Zelalem et al. 2009; Hanley et al., 1965; Sommerfeld and Knutson, 1965) have reported that an increased rates of nitrogen application increased tuber number which is partially in agreement with the results of this study where the application of N increased tuber number only up to certain limit (56 kg N ha^{-1}) while the increased rates beyond that reduced total tuber number hill^{-1}. This difference may be due to the environmental conduction.

Table 10: Effect of nitrogen and phosphorus rates on total, marketable and unmarketable tuber number of potato

Treatments	Total tuber number per hill.	Marketable tuber number per hill.	Unmarketable tuber number per hill.
Nitrogen (kg ha^{-1})			
0	8.75^{a}	6.417^{ab}	2.333^{c}
56	9.192^{ba}	6.992^{a}	2.2^{c}
112	5.867^{c}	2.8^{c}	3.067^{ab}
168	5.172^{c}	1.797^{c}	3.375^{a}
LSD (5%)	2.02	2.58	0.57
Significance	**	**	**
Phosphorus (kg P_2O_5ha^{-1})			
0	6.392^{c}	3.292^{d}	3.1^{a}
46	7.108^{b}	4.275^{c}	2.833^{b}
92	7.538^{ab}	4.922^{b}	2.617^{bc}
138	7.942^{a}	5.517^{a}	2.425^{c}
LSD (5%)	0.5716	0.5449	0.2205
CV (%)	9.5	14.5	9.6
Significance	**	**	**

*&** Significant at $P<0.5$ and $P<0.01$ respectively.

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.3.7. Unmarketable tuber yield

The main effect of nitrogen was significant ($P < 0.01$) but the interaction of nitrogen and phosphorus as well as the main effect of phosphorus were not significant for unmarketable tuber yield ha^{-1}.

Increased N application from 0 to168 kg ha^{-1}significantly increased ($P<0.01$) the unmarketable tuber yield ha^{-1} ,which ranged from 2.231 to 2.780 t ha^{-1}.The lowest and the highest unmarketable tuber yield ha^{-1}of potato were recorded for the application of 0 and 168 N kg ha^{-1}, respectively (Table 11).This may be due to the increased nitrogen as well as the high temperature that might have accelerated the growth of aboveground biomass and promoted re absorption tubers, leading to reduced tuber size and weight and thereby high unmarketable tuber yields as suggested by Gebremedhin et al. (2008) in response to increased rate of nitrogen.

Table 11: Effect of Nitrogen and Phosphorus rates on unmarketable tuber yield

Nitrogen rate (kg ha^{-1})		Unmarketable tuber yield
	0	2.231^{b}
	56	2.175^{b}
	112	2.656^{a}
	168	2.78^{a}
LSD (5%)		0.2215
significance		**
Phosphorus rate (kg P_2O_5ha^{-1})		
	0	2.643
	46	2.455
	92	2.4
	138	2.343
significance		ns
CV (%)		10.8

** Highly significant; ns Non-significant

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.3.8. Marketable tuber yield

Marketable tuber yield ha^{-1} was highly significantly ($P < 0.01$) and significantly ($P < 0.05$) affected by the main effects of both nitrogen and phosphorus and their interaction, respectively.

Increasing the rate of nitrogen increased marketable tuber yield over all rates of P only up to 56 kg N ha^{-1}. However, beyond 56 kg N ha^{-1}, further increasing the rate of nitrogen significantly decreased marketable tuber yield over all rates of phosphorus. On the other hand, increasing the rate of phosphorus significantly increased marketable tuber yield of the crop over all rates of nitrogen. Thus, the marketable tuber yield produced in response to 56 kg N and 138 kg P_2O_5ha^{-1} exceeded the marketable tuber yield obtained at 56 kg ha^{-1}and without P_2O_5 by 713% (Table 12).

The increase in marketable tuber yield of potato in response to increasing the rate of nitrogen up to 56 kg N ha^{-1} may be attributed to the positive interaction and relation or complementary effect of nitrogen and phosphorus in affecting and increasing the marketable tuber yield of potato in the study area. This means positive interaction and complementary effect show the importance of nitrogen for haulm development and photosynthesis. The increase in marketable tuber yield in response to increasing the rate of phosphorus over all nitrogen rates indicates the absolute importance of phosphorus for growth and productivity of the crop. The reduced marketable tuber yield ha^{-1}at nitrogen rates higher than 56 kg ha^{-1}may indicate that increased rates of nutrient militates against the production of tubers together with the high temperature in the study area, which results in increasing haulm development but reducing tuber initiation as suggested by Burton (1981).

According to Ewing et al., (2004), high nitrogen concentration in the plant and the high temperatures restrict tuber formation. Similarly, Gregory (1956) showed that low temperatures, especially low night temperatures increase the number of tubers per plant but higher temperatures produced fewer tubers per plant. According to this author, although increases in either day or night temperatures above optimal levels reduce tuber yields, high night temperatures seem to be more deleterious. Growth substances are involved in the plant response to environmental factors. Gibberellic acid (GA) endogenously increased under high temperatures, which has generally an inhibiting effect on tuber formation Krauss and Marschner (1982).

The results of the present study are similar to the finding of Mahmoodabad et al., (2010) who have reported that the interaction of nitrogen and phosphorus had significant effect in increasing marketable tuber yield ha^{-1}of potato plants. Similarly, Mulubrhan, 2004 has found that increased application of N and P increased marketable tuber yield ha-1in potato, y which in turn increased marketable tuber yield ha^{-1}.

3.3.9. Total tuber yield

Total tuber yield ha^{-1} was highly significantly ($P < 0.01$) influenced by both main effects nitrogen and phosphorus as well as by their interaction effect.

Similar to marketable tuber yield, increasing the rate of N application from 0 to 56 kg ha^{-1} increased total tuber yield ha^{-1}of potato across all the phosphorus rates. However, increasing the rate of nitrogen beyond this level significantly reduced total tuber yields. On the other hand, increasing the rates of phosphorus from nil up to the highest level increased total tuber yield across most nitrogen rates. Thus, the highest total tuber yield was recorded for the combined application of 56 kg N ha^{-1}and 138 kg P_2O_5ha^{-1}. The lowest was obtained in response to the application of the highest rate of nitrogen across all rates of phosphorus (Table 12). The increased total marketable tuber yield up to 56 kg N ha^{-1}across all rates of phosphorus signify the importance of the two nutrients in having complementary positive physiological functions in the potato plan for growth, development, and productivity. Moreover, they are the major constituents of physiologically active organic compounds in the plant system, leading to a combined increase in total tuber yield. On other hand, the N and P interacted to reduce total tuber yield when Nitrogen was applied at rates beyond 56 kg ha^{-1}. This could be attributed to the promotion of increased growth of the aboveground biomass, leading to re-absorption (reused) tubers as suggested by Boral and Milthorpe (1962) under the high temperature condition.

Both high air temperature and high soil temperature causes yield reduction (Gregory 1965, Slater 1968). These authors have found that soil temperature influence tuber yield, with the optimum being 15 to 18^{0}C. Higher soil temperatures decreased tuber yields, especially when combined with high ambient air temperatures (30^{0}C day/23^{0}C night).

According to Ewing et al. (2004), high nitrogen concentration in the plant and temperatures restrict tuber intuition. High nitrogen concentration and high temperatures also promote growth substances like Gibberellic acid (GA), which generally inhibits tuber intuition.

The results of the present study are in agreement with the finding of Ewing et al. (2004) who have reported that high nitrogen concentration in the plant and low solar radiation restricts tuber intuition and with that of Burton (1981) has indicated that where temperatures are in excess of 30^{0}C, net assimilation for potato falls to zero and yield reduction may occur.

Table 12. Interaction effect of Nitrogen and Phosphorus on yield and yield components of potato

`Nitrogen rate (N kg ha^{-1})	Marketable tuber yield (t ha^{-1})				Total tuber yield (t ha^{-1})			
	Phosphorous rate (P_2O_5 kg ha^{-1})				Phosphorous rate (P_2O_5 kg ha^{-1})			
	0	46	92	138	0	46	92	138
0	11.56^g	16.02^e	18.78^c	21.94^b	14^g	18.23^e	20.93^c	24.06^b
56	14.08^f	17.39^d	19.55^c	23.82^a	16.38^f	19.57^d	21.69^c	25.9^a
112	3.5^{lm}	5.43^{ij}	6.01^{hi}	6.97^h	6.38^{kl}	8.05^{ij}	8.6^{hi}	9.5^h
168	2.93^m	3.88^{klm}	4.45^{jkl}	4.85^{jk}	5.89^l	6.68^{kl}	7.17^{jk}	7.49^{ijk}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

3.3.10. Harvest index

Analysis of variance results revealed that nitrogen and phosphorus as well as their interaction were highly significant ($P < 0.01$) effect on harvest index.

The lowest and the highest harvest index of potato were recorded for the application of 168 and 0 kg N ha^{-1}, respectively. The reduction in harvest index with increased nitrogen application ranged from 0.51 to 0.19.

However, the increased phosphorus application from 0 to 138 kg P_2O_5ha^{-1}increased harvest index of potato from 0.51 to 0.58 (Table 13). On the other hand, the lowest (0.19) were recorded for the combined application of 168 kg N ha^{-1}with 0 kg P_2O_5 ha^{-1}. This may be due to as nitrogen increased the vegetative part of the potato also increased and reduced the tuber yield of the potato while the highest (0.58) harvest index of potato in 0 kg N ha^{-1}with 138 P_2O_5 kg ha^{-1}. This may be due to the effect of phosphorus in increasing tuber production of the potato than the vegetative part of the potato plants.

According to Boral and Milthorpe (1962), have reported the slower tuberization at temperatures lower than 20^{0}C probably results from slowed metabolism and growth, whereas the delayed tuberization at 25^{0}C, when metabolism and growth are accelerated, is due to the specific inhibitory effects of the high temperature on the tuberization process. On other hand, Mares et al. (1981) showed that a high ratio of GA/ABA promotes haulm growth and inhibits tuber growth. This may be due to the inhibitory effect of high temperature on tuber initiation and growth that may result from an increase in GA content that promotes shoot elongation and enhances the partitioning of carbohydrates toward the elongating plant parts (shoot).

The present study was opposite to the finding of Zelalem et al. (2009) who have found that the N and P interaction had non- significant increased of harvest index of potato plants. Similarly, Israel et al. (2012) found that increasing application of N and P rate increased harvest index of potato but it was non-significantly. The findings of the present studies are deferent from these reports which may be due to temperature differences of the experiment sites.

Table 13. Interaction effect of Nitrogen and Phosphorus on harvest index (ratio) of potato

	Phosphorous rate (kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	0.51^c	0.5^{cd}	0.55^b	0.58^a
56	0.23^l	0.39^f	0.45^e	0.48^d
112	0.22^l	0.31^i	0.33^h	0.36^g
168	0.19^m	0.26^k	0.27^k	0.29^j

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

3.4. Effect of Nitrogen and Phosphorus rates on tuber quality of potato

3.4.1. Specific gravity

Specific gravity of potato tuber was highly significantly ($P < 0.01$) influenced by the main effect of nitrogen, and phosphorus but not by their interaction effect.

Increased nitrogen application from 0 to 56 kg ha^{-1}highly significantly increased specific gravity of potato tuber which ranged from 1.05 to 1.06. This could be associated with the influence of N and temperature on gibberellins biosynthesis and other phytohormonal activities which have direct influence on plant growth and dry matter accumulation (Bodlaender et al., 1964). Marinus and Bodlaender (1975) have found that high temperatures cause various tuber disorders, including irregular tuber shape, chain tuberization, secondary tuber formation (often associated with excessive stolon elongation and branching), sprouted tubers and reduced dry matter content.

The main effect of P significantly increased the specific gravity of potato tubers from 1.03 to1.066 when P level increased from 0 to138 Kg P_2O_5ha^{-1}. These could be due to phosphorus increased above-ground biomass that leads to increased photosynthesis and assimilation process (Table 14).

The results of present study are different from the findings of Habtamu (2012) where this variety registered 1.09specific gravity across three locations. This may be due to the growing environment differences where Habtamu was working at mid and high altitude whereas the present study was at lowland.

Potato chips processing requires tubers with dry matter content of greater or equal to 20% and specific gravity of greater or equal to 1.080. Eskin, 1989 reported that the specific gravity in potatoes is very variable and may range between 1.050-1.106. Potato tuber specific gravity and dry matter content are very important characteristics in determining suitability of the variety for crisps. Tubers with high specific gravity generally give higher yields of chips, have lower oil absorption and better texture and therefore, are more economical to process. Berga et al (1994) showed that potato should have a specific gravity value of more than 1.080 and potato tubers with specific gravity value less than 1.07 are generally unacceptable for processing. Therefore, all treatments did not produce potato tubers which are suitable for chips making. This may be due to the complementary effect of nitrogen and high temperature that affected the specific gravity of the variety.

Table 14: Effect of Nitrogen and Phosphorus rates on specific gravity

Nitrogen rate (kg ha^{-1})	specific gravity
0	1.053^a
56	1.055^a
112	1.037^b
168	1.024^c
LSD (5%)	0.011
significance	**
Phosphorus rate (P_2O_5kg ha^{-1})	
0	1.03^c
46	1.036^b
92	1.038^b
138	1.066^a
LSD (5%)	0.011
significance	**
CV (%)	1.3

** Highly significant

Means followed by same letters within a column in a given fertilizer are not significantly at P<0.05

3.4.2. Dry matter content of potato tubers

The analysis of variance result revealed that the main effect of nitrogen and phosphorus significantly ($P < 0.01$) influenced dry matter content of potato tubers, which was not significantly affected by the interaction of two factors.

Increased nitrogen application from 0 to 56 kg ha^{-1} increased dry matter content of potato tubers which ranged from 17.37 to 17.80 %, but the increasing level of Nitrogen beyond 56 up to 168 kg ha^{-1} highly significantly decreased dry matter content of potato tubers from 13.28 to 11.98 %. The lowest and the highest dry matter content of potato tubers were recorded for the application of 56 and 168 N kg ha^{-1}, respectively. On the other hand, increased phosphorus application from 0 to 138 kg $P_2O_5ha^{-1}$ increased dry matter content of potato tubers from 10.66 to 16.74 % (Table 15). Accordingly, the lowest (8.72) and the highest (20.83) dry matter content of potato tubers were recorded for the combined application of168 N kg $ha^{-1}$with 0 kg P_2O_5 ha^{-1} and 56 kg N $ha^{-1}$with 138 kgP_2O_5 ha^{-1} , respectively.

Increasing the application of N from 0 to 56 kg ha^{-1} increased the dry matter percent of tubers from 24.37 to 24.80%. These could be due to low concentration of nitrogen and high temperature increased tuber size (big tuber) was formed per plant of potato, but increase the level of nitrogen from 56 to 168 kg N ha^{-1}highly significantly decreased the dry matter percent of tubers from17.80 to 11.98 %. These may be due to high concentration of nitrogen and high temperature influence on gibberellins acid formation this lead to fast growth of aboveground biomass so reused of stored food from tuber was occurred as a result reduced dry matter percent of tubers.

On other hand, increasing the level of P from 0 to 138 kg $P_2O_5ha^{-1}$increased dry matter percentage of potato tubers from 10.66 to 16.66 % may be due to the fact that phosphorus is contributing to underground biomass formation as compared to aboveground biomass, However, the result of the present study was opposite to Sparrow et al. (1992) who have observed non significant reduction in percent dry matter of tubers due to increased P_2O_5 application and Zelalem et al. (2009) who have suggested that phosphorus fertilization did not significantly influence tuber specific gravity and dry matter content. According to Bodlaender et al. (1964) and Marinus and Bodlaender (1975) high temperatures may cause various tuber disorders, including irregular tuber shape, chain tuberization, secondary tuber formation (often associated with excessive stolon elongation and branching), sprouted tubers and reduced dry matter content.

The present study was in line with the finding of Israel et al. (2012) have reported that high nitrogen concentration as well as high phosphorus concentration in the plant significantly affects dry matter percentages. According to Westermann et al. (1994a), Kanzikwera et al. (2001) and Painter and Augustin (1976) have reported a significant reduction in percent dry matter content due to an increase in the application rate of N. This may be attributed to the fact that high rates of N stimulate top growth more than tuber growth thereby delaying tuber formation and maturity.

Hence, tubers tend to be harvested immature with low dry matter percentages. However, the present study was opposite to Sparrow et al. (1992) who have observed non- significant reduction in percent dry matter of tubers due to increased P application and Zelalem et al.(2009), have also, suggested that phosphorus fertilization did not significantly influence tuber specific gravity and dry matter content.

Potato chips processing requires tubers with dry matter content of greater or equal to 20% and specific gravity of greater or equal to 1.080 (Kabira and Lemaga, 2006). The dry matter is one of the important traits after yield, since the genotypes, which have more dry matter percentage have more importance for the industrial, economical purposes and also storage property. The dry matter content of potato tubers determines suitability for chip processing purposes by influencing the chip yield, texture flavor, final oil content and process efficiency (Kumlay et al., 2002; Kaaber et al., 2001).

Table 15: Effect of Nitrogen and Phosphorus rates on dry matter percentage

Nitrogen rate (kg ha^{-1})	Total Dry matter percentage
0	17.37^{a}
56	17.8^{a}
112	13.28^{b}
168	11.98^{c}
LSD (5%)	1.066
significance	**
Phosphorus rate (kg ha^{-1})	
0	10.66^{d}
46	13.13^{c}
92	14.6^{b}
138	16.74^{a}
LSD (5%)	1.066
significance	**
CV (%)	8.5

** Highly significant

Means followed by same letters within a column in a given fertilizer are not significantly at $P<0.05$

3.4.3. Potato tuber size categories in number

i) Large size tuber

The main effect of nitrogen and phosphorus as well as the interaction significantly ($P < 0.01$) influenced the production of large size tubers.

Increased nitrogen application from 0 to 56 kg N ha^{-1}increased the number of large size tubers which ranged from 1.75to 1.88 % (Table 16).Similarly, increased phosphorus application from 0 to138 kg P_2O_5ha^{-1}increased the number large size tuber from 1.75 to 3.63% (Table 16). On the other hand, the lowest (0) and the highest (3.63) large size tuber of potato were recorded for the combined application of 112 to 168 kg N ha^{-1} without $P_2O_5$and 0 N ha^{-1} with 138 P_2O_5kg ha^{-1}, respectively. These could be due to the interaction of the mineral fertilizer and temperature.

Nitrogen fertilizer had increased the vegetative part of the potato and affects the tuber initiation at high concentration and in area which received high temperature. Temperature also was categorized as a rate modifier because so many physiological processes depend on biochemical reactions that respond to the temperature of cell in which they occur. Levy (1986b).

Table 16. Interaction effect of Nitrogen and Phosphorus on large size tuber numbers of potato

	Phosphorous rate (kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	1.753^{h}	2.417^{e}	3.117^{c}	3.633^{a}
56	1.883^{g}	2.19^{f}	2.687^{d}	3.237^{b}
112	0^{i}	0^{i}	0^{i}	0^{i}
168	0^{i}	0^{i}	0^{i}	0^{i}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

ii) Medium size tuber

The main effects of nitrogen and phosphorus as well as the interactive effect significantly ($P < 0.01$) influenced the production of medium size tuber of potato.

Increased nitrogen application from 0 to 56 kg N ha^{-1} increased the medium size tuber of potato which ranged by 0.08 % (Table 17). The highest and the lowest medium size tuber of potato plant were recorded for the application of 56 and 168 N kg ha^{-1}, respectively. Similarly, increased phosphorus application from 0 to 138 kg P2O5ha^{-1} increased the medium size tuber of potato by0.33 % (Table 17). On the other hand, the lowest (0) and the highest (7.1%) medium size tuber of potato were recorded for the combined application of 168 N ha^{-1}with 0 P_2O_5ha^{-1}and 56 kg N ha^{-1} with 138 P_2O_5kg ha^{-1}, respectively. This could be due to the interaction of the mineral fertilizers and re-absorption of stored food from tubers because of fast growth of aboveground biomass due to nitrogen fertilizer.

The present results are in contrast to the findings of Sharma and Arora (1986), who found a significant increase in the yield of medium and large sized tubers due to N application.

Table 17. Interaction effect of Nitrogen and Phosphorus on medium size tuber numbers of potato

	Phosphorous rate (kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	6.127^{bc}	6.653^{ab}	6.827^{a}	6.983^{a}
56	6.733^{ab}	7.01^{a}	7.047^{a}	7.11^{a}
112	2.26^{g}	5.5^{cd}	4.997^{de}	4.59^{ef}
168	0^{h}	4.173^{f}	4.807^{ef}	4.51^{ef}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

iii) Small size tuber

The main effect of nitrogen and phosphorus as well as interaction effect of nitrogen and phosphorous significantly ($P < 0.01$) influenced small size tuber of potato.

Increased nitrogen application from 0 to 56 kg ha^{-1} decreased the small size tuber of potato which ranged from7.25 to 7.14 % but increased the level of nitrogen beyond 56 kg ha^{-1}increase small size tuber of potato (Table 18). The highest and the lowest number of small size tuber were recorded for the application of 168 and 56 kg ha^{-1}, respectively. Similarly, increased phosphorus application from 0 to 138 kg P ha^{-1} decreased the small size tuber of potato from 7.25 to 6.29 %. On the other hand, the lowest (6.2) and the highest (10%) small size tuber of potato were recorded for the combined application of 56 N ha^{-1}with138 $P_2O_5ha^{-1}$and 168 kg N ha^{-1} with 0 P_2O_5kg ha^{-1}, respectively (Table 18). These could be due to the interaction of the mineral fertilizer and re-absorption of stored food from tuber because of fast growth of aboveground biomass due to nitrogen fertilizer.

According to Sharma and Arora (1986) and Mulubrhan, (2004) the interaction effect of nitrogen and phosphorous increased medium and large size tuber but significantly decreased small size tuber of potato. The results of this study are in contrast to the findings of these authors, who found a significant decrease in the yield of small size due to N application.

The results of this investigation clearly indicated that the levels of N and P application largely affected potato tuber size distribution.

Table 18. Interaction effect of Nitrogen and Phosphorus on small size tuber numbers of potato

	Phosphorous rate(kg P_2O_5 ha^{-1})			
Nitrogen rate (kg ha^{-1})	0	46	92	138
0	7.253^{de}	6.89^{d}	6.543^{ef}	6.29^{f}
56	7.14^{def}	6.783^{def}	6.557^{ef}	6.237^{f}
112	9.743^{ab}	7.253^{de}	8.66^{c}	8.88^{bc}
168	10^{a}	8.983^{bc}	8.973^{bc}	8.917^{bc}

Means with followed by the same letter(s) in rows and columns are not significantly different at 5% level of significance

4. Summary and Conclusion

Information is scanty on the requirement of nitrogen and phosphorus fertilizers for enhancing tuber yields of potato in lowland areas of the country. Thus, conducting systematic investigation in this line is very important to come up with relevant information that would help to produce and increase yields of the crop in such areas. Therefore, this experiment was carried out with the objective of studying the effect of mineral N and P fertilizer on yield and yield components of potato. The experiment was conducted at Dire Dawa, eastern Ethiopia to study the response of potato to the application of mineral nitrogen and phosphorus fertilizers under irrigation condition. Four rates of nitrogen (0, 56, 112 and 168 kg N ha^{-1}) and four rates of phosphorus (0, 46, 92 and 138 kg $P_2O_5ha^{-1}$) were combined in 4 x 4 factorial arrangement laid out in randomized complete block design with three replications and the variety Bubu was used as experimental material.

The current study showed that both nitrogen and phosphorus rates had highly significant effect on phenology of the crop including days to 50% emergence. Nitrogen also highly significantly affect day to 50% physiological maturity. Both nitrogen and phosphorus rates showed highly significant effect on plant height, but significantly affected leaf area per hill. On other hand, both nitrogen and phosphorus rates did not significantly affect number of main stem per hill. While, both nutrients and their interaction highly significantly influenced yield and yield components of potato including shoot and root fresh and dry weight, average tuber mass per hill, average tuber number per hill, and marketable and total tuber yield. Number of large sized tubers was also highly significantly affected by nitrogen rates and significantly affected by rates of phosphorus. The tallest plants were obtained in response to application of 168 kg N and 138 kg $P_2O_5ha^{-1}$.

Similarly, a delay in days to 50% physiological maturity was observed with 168 kg N ha^{-1}while the delay in maturity of potato was observed in the absence of phosphorus application. The highest shoot and root dry weight of potato was obtained at 56 kg N ha^{-1} with138 kg $P_2O_5ha^{-1}$ interaction. Considering the yield of potato, the highest marketable tuber yield was obtained from the combined application of 56 kg N ha^{-1}with 138 kg P_2O_5ha^{-1}. In conclusion, the result of this study showed that different nitrogen and phosphorus rates and their interactions have significant impacts on growth and marketable tuber yield of potato.

Therefore, on the basis of the results of the present study, it is indicative that potato can be produce in Dire Dawa area and farmers can benefit more by using high rates of phosphorus and lower rate of nitrogen, which amounts to 56 kg N ha^{-1}. However, the cost benefits analysis indicated that application of no nitrogen but 138 kg P_2O_5ha^{-1} resulted in the highest returns, though; it is premature to draw a sound recommendation since the study was done for only one season and at one location. Therefore, experiments consisting of even higher rates of phosphorus than the highest rate applied in this study and the same rates of nitrogen should be conducted further to come up with a conclusive recommendation for the area.

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