Response of Potato (*Solanum tuberosum* L.) to Different Rates of Nitrogen and Phosphorus at Debark and Chilga Districts, Northwestern Ethiopia

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Abstract

Potato (Solanum tuberosum L.*) belongs to the family Solanaceae and genus Solanum. It is native to South America and introduced to Ethiopia in 1859 by a German Botanist called Schimper. In Ethiopia, about 70% of cultivated land is suitable for potato production. The Lowest soil fertility is the major constraints to potato production. Farmers should tackle this problem through the application of inorganic fertilizes, which amend the soil productivity. The application of appropriate amount of NP fertilizer is a major factor in potato production. A field experiment was conduct in 2018 and 2019 main cropping season to determine the optimum rate of NP on tuber yield of potato in Amhara Region, North Gondar at midland of Chilga and highland Debark districts on farmer's field respectively. The treatments were four levels of nitrogen (0, 46, 92, 138 kgha^{-1}) and three levels of phosphorus (0, 46, 69 kgha^{-1}) combined in factorial arrangements in randomized complete block design with three replications. The result of the study showed application of 92kg N ha^{-1} is recommend at Debark and similar agro ecology. Even if application of P has no effect on potato tuber yield 23 kg ha^{-1} phosphorus fertilizer should applied for soil fertility maintenance. For Chilga district and similar agro ecology application of NP at the rate of 138 kgha^{-1} and 46 kgha^{-1} respectively recommended.*

Keywords*: Chiliga, Debark, nitrogen, phosphorus , potato*

Introduction

Potato (*Solanum tuberosum* L.) is a herbaceous plant belongs to the family Solanaceae and genus *Solanum.* It is native to South America (Eskin and Michael, 1989). According to Berga *et al*., (1994b), potato was introduced to Ethiopia in 1859 by a German Botanist, Schimpera. The authors further indicated that potato production in Ethiopia was limited to homesteads for many years. Worldwide, potato *(Solanumtuberosum*L.) ranks next to wheat and rice in area production and consumption.

Its world annual production is about 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 1,765,617 ha. In Ethiopia, total production is around 572,333 tons on area coverage of 69784 ha. Ethiopia is suitable climatic and edaphic conditions for potato production. (FAOSTAT, 2010).

About 70% of cultivated agricultural land of Ethiopia is suitable for potato production (Yilma 1991). The annual potato production in Ethiopia was 1.62 million tons from an area coverage of 0.18 million hectares (CSA 2014). The national average yield is 9 tons ha^{-1} (CSA 2014) which is very low compared to the world mean of 17.7 tons/ha (FAOSTAT, 2010). One of the contributing factors was poor use of optimum plant nutrition.

Potato is very important for food security and as a source of income generation for a large proportion of the rural households of Ethiopia (FAO, 2008). Because, of its high yield per unit of land and time.

Potato requires a variety of plant nutrients for growth and development. Nitrogen, phosphorus and potassium are the most important among the elements that are essential to potato. Most of Ethiopian soil Fertility has already declined due to continuous cropping, abandoning of fallowing, increase use of manure for fuel consumption and crop rotation (Tilahune *et al.*, 2007).

The Lowest soil fertility is the major constraint limiting to potato production in Ethiopia. Farmers should tackle this problem through the application of both organic and inorganic fertilizes, which amend the soil environment (Place *et al*., 2003).

Potato is dramatically responsive to Nitrogen fertilization, which is usually the most limiting essential nutrient for potato growth, especially on sandy soils (Errebhi *et al*., 1998). According to many researchers, the application of N fertilizer can play a great role in the vegetative growth of potato (White *et al*., 2007).

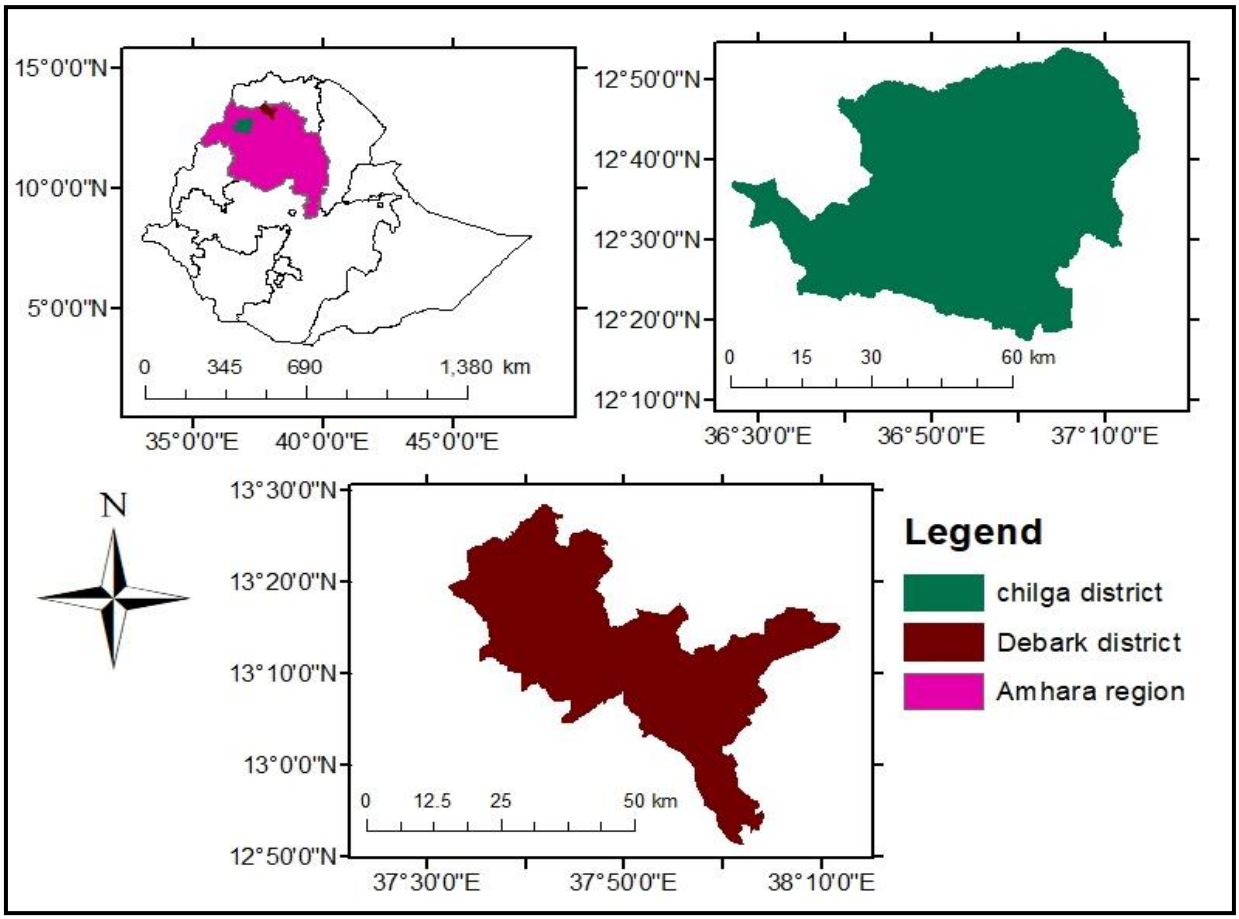
The application of suitable amount of nitrogen fertilizer is a major factor in soil fertility management, because the overload of this fertilizer will lead to decrease tuber quality, delay plant maturity, decrease tuber yield, dried matter storage into aerial parts rather than tubers (Hashemidezfooli *et al*., 1998). So, the development of new methods using the appropriate concentration of N fertilizer has become necessary for potato producers.

To enhance the productivity of potato soil fertility management has to be the primary role of the producers. Different experiments conducted in Ethiopia show that application of nutrient has a positive relation to producing a higher yield of potato(Kahsay& Moral, 2019) However, enhancing farmers to produce higher yield of potato application of appropriate fertilizer is a key issue needed in the study area. Therefore, the objective of this study was to determine the optimum rate of nitrogen and phosphorus to improve yield and yield components of potato in the Central and North Gondar Zones, Ethiopia

Materials and Methodss

Description of Study Area: The study was conduct in 2018/2019 and 2019/2020 cropping

North Gondar zone at Debark and Chiliga Districts. Debark district is located in 12.854^0N 13.482^0N and 37.535^0E 38.197^0E The altitude of Debark district 2885 meter above sea level. It has tepid to cool moist highland agro-ecology. The minimum and maximum temperature of the study area is 3.7 °C and 23.1°C and it receives 1231 mm mean annual rainfall annually. Chilga district is located in 12.290^0N 12.903^0N and 36.446^0E 37.232^0E and the midland agro-ecology with the altitude of 2146 meter above sea level. The minimum and maximum temperature of the area is 19°C and 27 °C and its average annual rainfall is 1050 mm.



Picture 1 Map of Debark and Chilga districts

Planting Materials and Experimental Methodology

Adapted and recommended variety of Irish potato called Gudane and Jaleni used for the experiment for Chilga and Debark respectively in main season. Twelve treatment combinations were randomly replicate three times in factorial randomized complete block design. The treatment had three levels of phosphorous (0, 46 and 69) and four level of nitrogen (0, 46, 92 and 138) $kgha^{-1}$ used. Source of nitrogen was in the form of urea, while P in the form of (TSP). Nitrogen applied in split, half during sowing and the rest half at flowering stage. The gross plot size measured 2.8 m x 2.4 m ($6.72m^2$). Four rows and eight plants per row were plant with 70cm between rows and 30cm between plants and spacing of 1.5 m between blocks and 1m between plots. Harvested plot size was 2.4.m *1.4 m or two rows was harvest.

Collected Data: The following data were collected number of tuber per hill, number of stem per plant, plant height (cm), marketable yield per hectare (ton), and total yield per hectare (ton), price of fertilizer (ETB) during planting and price of potato at harvesting time.

Statistical Analysis: Analysis of variance for the collected parameters performed as the methods using SAS computer software version 9.0 for (RCBD) and treatments mean comparison done by list significance difference (LSD) at 5% confidence level.

Economic Analysis: It was performed the following the CIMMYT partial budget analysis methodology (CIMMYT 1988). Average potato tuber yield were consider for the analysis. Total variable cost, gross benefit and net benefit were calculated.

To estimate the total variable costs, mean market prices of NP was assess at the time of planting and market price of potato tuber was estimate after harvest. The prices of potato tuber were calculated by adjusting the average market prices of those tubers downward by 10 percent of on farm tuber yield. To compare the costs that varied with the net benefits, marginal analysis done. The marginal analysis involves dominance analysis, net benefits curve fitting and calculating the marginal rate of return (MRR). The treatment, which, is none dominate and have a MRR of greater or equal to 100%and the highest net benefit was consider as economically profitable.

Soil Sampling and Analysis: Composite soil samples were collect diagonal pattern at depth of 0 30 cm before planting for each site. Samples were air-dried, ground sieved. Total nitrogen was determined using the Kjeldahl method (Bremner & Mulvaney, 1982) while the available phosphorus was determined following the Olsen procedure (Olsen & Sommers, 1982).Soil pH was determined in a 1:2.5 soil to water suspension following the procedure outlined by Sertsu and Bekele (2000). Soil organic carbon content was determine by the wet digestion method using the Walkley and Black procedure (Nelson & Sommers, 1982). The exchangeable potassium was measure by flame photometer after extraction of the samples with ammonium acetate solution at pH-7 following the procedures described by Sahalmedhin and Taye (2000).soil particle size is determine density of soil-water suspension measured with Bouyoucos hydrometer method (Sahalmedhin and Taye,2000)

Results and Discussion

Soil physicochemical properties of the study sites

The results revealed that soil pH of research sites at Debark ranged between 5.6 - 5.65 (Table 1) and classified as moderately acidic (Hazelton and Murphy, 2016). Soil organic carbon ranged from 1.79-1.87 and medium in content based the classification of Tekalign (1991). Available phosphorus ranged from 33.27 - 34.61 and fall under very high category following Cottenie (1980). The total nitrogen ranged from between 0.22 0.28 and lies in the medium to high range (Tekalign 1991). The Cation Exchange Capacity was high (35.82 47.48) based on Tekalign (1991). Based on FAO (2006) , ex. K^+ content was low to medium, ex. Na^+ was low to medium ex. Ca^{++} was very high, and ex. Mg^{++} was very hig (Table 1).

Table 1. Soil physico-chemical properties at Debark

		2018		**2019**	
Soil property	Unit	Site 1	Site 2	Site 1	Site 2
Total nitrogen	%			0.22	0.28
Available P	P/PPM	34.61	33.27	25.29	14.37
pH	H2O	5.6	5.65	5.58	5.58
OC	%	1.87	1.79	2.53	2.46
CEC	Cmol/kg Ammon. Acet.	47.48	42.45	39.57	35.82
Ex. K+	Cmol/kg Ammon. Acet.	0.95	1.12	0.55	0.29
Ex. Na+	Cmol/kg Ammon. Acet.			0.28	0.35
Ex.Ca+	Cmol/kg Ammon. Acet.			24.72	23.86
Ex. Mg+	Cmol/kg Ammon. Acet.			12.84	9.52
Soil proportion					
Sand	%	21.28	39.28	20.72	30.72
Clay	%	34	22	38	30
Silt	%	44.72	38.72	41.28	39.28
Textural class	%	clay loam	loam	Clay loam	Clay loam

Similalry, the soil pH of the experimental sites at Chilga ranged between 5.33-5.73 (Table 2) and classified as moderately acidic (Hazelton and Murphy, 2016). In addition, soil organic carbon of the experimental sites varies between 1.71-2.13% and was medium in content (Tekalign, 1991). Available phosphorus also ranged between 5.83-11.65 ppm and rated as low according to Cottenie (1980) and medium Olsen, (1982). Moreover, the total nitrogen content of the study sites at Chilga was moderate to high (0.2 to 0.34 %)

(Tekalign, 1991). Furthermore, the CEC of the soils of the experimental sites was classified as high (Tekalign 1991). Based on FAO classification ex K^+ was medium to high, ex. Na^+ was medium, ex. Ca^{++} 15.52 23.33 high to very high, and ex. Mg^{++} very high (Table 2).

Table 2. Soil physicochemical properties at Chilga

Soil property		2018		2019	
	Unit	Site 1	Site 2	Site 1	Site 2
Total nitrogen	%			0.2	0.34
Available P	P/PPM	5.83	5.95	10.28	11.65
pH	H2O	5.73	5.33	5.45	5.67
OC	%	1.71	1.87	2.75	2.13
CEC	Cmol/kg Ammon. Acet.	41.45	43.01	34.11	35.14
Ex. K+	Cmol/kg Ammon. Acet.	1.15	0.72	0.35	0.63
Ex. Na+	Cmol/kg Ammon. Acet.			0.33	0.63
Ex.Ca+	Cmol/kg Ammon. Acet.			15.52	23.33
Ex. Mg+	Cmol/kg Ammon. Acet.			16.16	8.99
Soil Proportion					
Sand	%	31.28	29.28	24.72	26.72
Clay	%	30	32	46	36
Silt	%	38.72	38.72	29.28	37.28
Textural class	%	clay loam	clay loam	Clay	Clay loam

Effect of Nitrogen and Phosphorus on Potato Plant Height

Analysis of variance shown that the application of N has significantly affected the plant height of potato while P did not influence (Table. The fertilization of nitrogen at a rate of 138 kg N ha-1 increased plant height by 21.6 cm and 18.2 cm compared to the control at Debark and Chilga districts below (table 3 and 4) respectively. The response to the N fertilization attributed to stem elongation which able to height increment. This study results showed that similar with the finding of (Yibekal, 1998 and Zelalem *et al*.; 2009) who reported, nitrogen fertilization increased potato plant height. Other previous studies support the current finding Israel *et al*.; (2012), Fayera (2017), and Alemayehu *et al*. (2015) they obtained that the application of nitrogen fertilizer has a significant effect on plant height. They also found that the plant height of potato increasing with an increase in nitrogen levels.

Effect of Nitrogen and Phosphorus Fertilizer on Potato Tuber Number.

The application of NP fertilizer has a significant effect on the number of tubers per hill at Debark (table 3). The maximum (13.9) and minimum (10.5) tubers obtained through (138/0) kg N ha^{-1}, in addition to that, the maximum (13.5) and minimum (12.2) tubers were recorded at the rate of (69/0) kg ha-1 P respectively

Likewise, Chilga District (table 4) shown below, on the application of N maximum 8.9 and minimum 5.9 tuber number per hill have obtained. Whereas, the application of P have not affected tuber number per hill.

According to Amzallag *et al*., (1992), application of nitrogen has significant effects on tuber formation through its effect on Gibberellins biosynthesis and phytohormone balance in the potato. Other studies indicated that application of nitrogen to potatoes before tuber initiation; increases the number of tubers per plant and mean fresh tuber weight (Kanzikwera et al., 2001).

Number of Stem per Hill: The application of nitrogen did significantly influence the number of stems per hill. Increasing the level of nitrogen from 0 to 138 kg ha-1 increased stem number per hill from 5.6 to 7.3. The highest (7.3) and the lowest (5.6) number of stem per hill was obtained on the rate of 138 kg N ha^{-1} and control plot, respectively. On the contrary, P fertilization was not significantly affected.

The present finding in line with, Birtukan B, (2007) have described that the lowest stem number of potato was obtained from the control plot (0/0 N/P).

Effect of Nitrogen and Phosphorus on Potato Tuber Yield

The application of nitrogen fertilizer significantly affected tuber yield and tuber yield components of potato (table 3). Increasing the application rates of nitrogen resulted in increasing the total tuber yield from 22.0 to 36.3-ton ha^{-1}.The highest yield obtained at 92 and 138 kg nitrogen ha^{-1} while the lowest yield obtained at zero nitrogen. Therefore, in study area of Debark district 92kgha^{-1} N is biological yield and economically feasible. This result is in line with the finding of Zelalem *et al*., (2009) and (Zewide, et al., 2012) who reported that, the application of more nitrogen had opportunity for additional gain in total tuber yield of potato. Increasing the application rate of phosphorus from 0-69 kg P_2O_5 ha^{-1}

statistically, have not significant difference on the total tuber yield consequently available phosphorus in the soil was recorded sufficient amount (cottenie 1980).

At Chilga district, the application of nitrogen and phosphorus fertilizer significantly affected tuber yield and tuber yield components of potato (table 4). Application of phosphorus fertilizer increases from 0 to 69 kgha^{-1} statistically significant difference on the total tuber yield that is from 16.7 to 21.5 ton ha^{-1}. Whereas the least and the highest tuber yield of potato 13.7 ton and 25.3 tons ha^{-1} was record through the application of 0 and 138 N kgha^{-1} respectively. The experiment confirmed that application of nitrogen and phosphorus can improve soil productivity and increases the production of potato. This study is in line with Kahsay and Moral (2019) and Powon. (2005) who reported that, the application of adequate nutrients (nitrogen and phosphorus) is the option to maximize production and productivity of potato. While, the highest yield was obtained at 138 kg N and 46 kg P_2O_5 ha^{-1} which, 25.3ton ha^{-1} but the lowest yield was obtained at (0/0) NP. Therefore, for Chilga, district the application of 138kgha^{-1}N and 46 kgha^{-1} P_2O_5 is recorded the highest potato tuber yield.

Table 3. Effect of Nitrogen and Phosphorus on combined mean value of growth and yield of potato at Debark district over two years (2018 and 2019)

Nitrogen (kg ha^{-1})	Plant height (cm)	Number of stem/hill	Number of tuber/hill	marketable yield(tha^{-1})	Total yield (tha^{-1})
0	51.9^{d}	5.6^{b}	10.5^{b}	20.3^{c}	22.0^{c}
46	63.7^{c}	6.8^{a}	13.0^{a}	27.8^{b}	29.8^{b}
92	69.7^{b}	7.3^{a}	13.7^{a}	33.3^{a}	35.6^{a}
138	73.5^{a}	7.3^{a}	13.9^{a}	33.7^{a}	36.3^{a}
LSD(0.05)	3.5	0.6	1.1.	2.8	2.7
P_2O_5 (kg ha^{-1})					
0	65.3	6.8	12.2^{b}	28.7	30.7
46	64.4	6.6	12.6^{ab}	29.0	30.9
69	64.3	6.9	13.5^{a}	28.7	31.2
LSD(0.05)	NS	NS	0.9	NS	NS
CV (%)	11.6	20.6	18.3	2.4	18.6

Table 4. Effect of Nitrogen and Phosphorus on combined mean value of growth and yield of potato at Chilga district over two years (2018 and 2019)

Nitrogen ($kgha^{-1}$)	Plant height (cm)	Number of stem/hill	Number of tuber/hill	marketable yield(tha^{-1})	Total yield (tha^{-1})
0	44.6c	6.71	5.9^{c}	13.0^{d}	13.7^{d}
46	49.5c	6.38	7.8^{b}	16.7^{c}	17.7^{c}
92	56.0b	6.58	8.4^{ab}	21.1^{b}	22.2^{b}
138	62.8a	6.63	8.9^{a}	24.2^{a}	25.3^{a}
LSD (0.05)	5.8	0.78	0.7	2.8	2.9
P_2O_5 (kg ha^{-1})					
0			6.3	15.8^{b}	16.7^{b}
46			8.4	20.1^{a}	20.9^{a}
69			8.4	20.5^{a}	21.5^{a}
LSD (0.05)	NS	NS	NS	27.1	2.6
CV (%)	16.3	17.8	16.8	2.4	27.6

Partial Budget Analysis: Economic analysis was done to identify the most profitable NP fertilizer rate. The partial budget analysis showed that, the application of different rate of NP fertilization is economically feasible. In the current finding, the application of 92 kg ha^{-1} N had the highest net benefit (242786.8 ETB ha^{-1}) and the highest MRR (38821 %) was record. In addition to that, it gave an acceptable rate of return above 100% below (table 5). According to Horton (1987), the greater the increase in net income and the higher rate of return is the more economically attractive the fertilizer rate is. The author further explained that the fertilizer rate is acceptable only if the return is higher than 1.0. The application of 92 kg ha^{-1} N had 62.57% yield advantage over the control. Therefore, the application of this

rate will boost the yield of potato production and increase the income of the farmers. Whereas partial budget analysis showed that below (table 6), the application of (138 /46) kgha-^{1} N and P_2O_5 had given the net benefit (169976.0 ETB ha^{-1}) and the highest MRR (1967%) was record next to (138/69) kg ha^{-1} N/P_2O_5 had the highest net benefit (187008.3 ETB ha^{-1}) and the MRR (1901 %) was record. The application of 46 and 69 P_2O_5 with 138 kgha^{-1} N had 43.11 and 39.18% yield advantage over control respectively. Therefore, the application of 46 P_2O_5 and 138 kg N ha^{-1} had the highest MRR and yield advantage.

Table 5. Partial budget analysis at debark

Treatments (P_2O_5,N) respectively	Marketable yield (tha^{-1})	Adjusted yield (tha^{-1})	fertilizer Application Cost (ETB)	fertilizer Cost (ETB)	Total variable cost (ETB)	Gross benefit (ETB)	Net benefit (ETB)	dominance analysis	MRR (%)*
(0,0)	21.1	19.0	0.0	0.0	0.0	151920	151920.0		
(46,0)	19.5	17.5	0.0	1558.5	1558.5	140162.4	138603.9	D	
(0,46)	25.0	22.5	700.0	1456.6	2156.6	180302.4	178145.8		1216
(69,0)	20.5	18.4	0.0	2337.8	2337.8	147362.4	145024.7	D	
(46,46)	29.5	26.5	700.0	3015.1	3715.1	212342.4	208627.3		1955
(0,92)	34.3	30.8	900.0	2913.2	3813.2	246600	242786.8		34821
(69,46)	28.8	25.9	700.0	3794.4	4494.4	207360	202865.7	D	
(46,92)	33.1	29.8	900.0	4471.7	5371.7	238262.4	232890.7	D	
(0,138)	34.3	30.9	1100.0	4369.8	5469.8	246902.4	241432.6	D	
(69,92)	32.6	29.3	900.0	5251.0	6151.0	234417.6	228266.7	D	
(46,138)	34.1	30.7	1100.0	5928.3	7028.3	245397.6	238369.3	D	
(69,138)	32.8	29.5	1100.0	6707.6	7807.6	236282.4	228474.9	D	

*:MRR is marginal rate of return

Table 6. Partial budget analysis at chilga district

Treatment arrangement (P_2O_5, N)	marketable yield (t ha^{-1})	Adjusted yield (t ha^{-1})	fertilizer Application Cost (ETB)	fertilizer Cost (ETB)	Total variable cost (ETB)	Gross benefit (ETB)	Net benefit (ETB)	dominance analysis	MRR (%)*
(0,0)	10.9	9.8	0.0	0.0	0.0	73278.0	73278.0		
(46,0)	15.7	14.1	0.0	1791.5	1791.5	105826.5	104035.0		1716
(0,46)	13.8	12.4	700.0	1327.5	2027.5	93001.5	90974.0	D	
(69,0)	12.4	11.2	0.0	2687.3	2687.3	83922.8	81235.5	D	
(46,46)	20.8	18.7	900.0	2655.0	3555.0	140400.0	136845.0		1860
(0,92)	16.9	15.2	700.0	3119.0	3819.0	113852.3	110033.3	D	
(69,46)	19.6	17.6	700.0	4014.8	4714.8	132003.0	127288.3	D	
(46,92)	17.7	15.9	1100.0	3982.5	5082.5	119252.3	114169.8	D	
(0,138)	21.5	19.4	900.0	4446.5	5346.5	145273.5	139927.0		172
(69,92)	21.0	18.9	900.0	5342.3	6242.3	141527.3	135285.0	D	
(46,138)	26.2	23.6	1100.0	5774.0	6874.0	176850.0	169976.0		1967
(69,138)	28.9	26.0	1100.0	6669.8	7769.8	194778.0	187008.3		1901

* MRR is marginal rate of return

Conclusion and Recommendation

Potato is one of the most widely cultivated vegetable crops in the highlands of Ethiopia. Production and productivity of potato are very low when compared to the world national average yield. Among different factors, soil fertility and nutrient management are the key factors affecting crop productivity and soil nutrient depletion. To improve the production and productivity of potato soil fertility management has to be the principal role of the producers. Different experiments conducted in Ethiopia show that application of different nutrients has a positive relation to producing a higher yield of potato. The current experimentations confirmed that adequate application of nutrients increase the production

of potato and economic feasibility. Therefore, application of 92 kgha^{-1} nitrogen fertilization is recommend for high lands of Debark district and similar agro ecology. Even if application of phosphorus fertilizer, have not significant effect on potato, tuber yield in case of Debark, it should be applied the least (23 kgha^{-1} P_2O_5) for soil fertility maintenance. Whereas as at Chilga district and similar agro ecology the application of 138kgha^{-1} nitrogen and 46 kg ha^{-1} phosphorus is, recommend.

Acknowledgements

The authors would like thank to Gondar Agricultural Research Center and Amhara Region Agricultural Research Institute for their financial support and Adet Agricultural Research Center for supporting potato tuber seed (Gudeni and Jaleni Varity). In addition, the authors would like to thank Gondar Agricultural Research Center, Soil fertility caseteam for their valuable involvement to the achievement of the study.

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