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Effect of Nitrogen and Phosphors Application on Yield and Yield Components of Improved Potato (Solanum tuberosum L.) Cultivars at Holetta, Central Highlands of Ethiopia

Medemedemiyaw Nekinikie Nigussie Dechassa
Ethiopian Agriculture Research Institute, Holetta Agriculture Research Centre

Abstract
An experiment was conducted at Holetta in 2012 main cropping season to study the effect of different nitrogen and phosphorus levels on yield components and yield of potato. The treatments consisted of two potato varieties (Jalenie and Gudanie), four levels of nitrogen (0, 55, 110 and 165 kg N ha^{-1}) and three rates of phosphorus (0, 90 and 180 kg P_2O_5 ha^{-1}). The experiment was laid out as a randomized complete block design with a factorial arrangement of 2× 4 x 3 with three replications. The study results indicated that increasing the rate of nitrogen from 0 to 165 kg N ha^{-1} significantly increased fresh total biomass from 583 to 789 g/hill, similarly application of P significantly increased marketable tuber number by 19.72%. However N and P did not influence average tuber weight, dry total biomass, harvest index and unmarketable tuber yield. At the highest rate of nitrogen and phosphorus combination, highest marketable tuber yields were obtained for Jalenie variety (25.09 t ha^{-1}) and Gudanie variety (30.52 t ha^{-1}) as compared to control treatment (Jalenie 11.41 t ha^{-1}) and (Gudanie 13.93t ha $^{-1}$). The partial budget analysis data showed that the highest net benefit and marginal rate of return 41180 birr ha^{-1} and 217% and 52176 birr ha^{-1} and 54 % for the variety Jalenie and Gudenie were obtained from N and P applied at 165 N kg ha^{-1} with 180 kg P_20_5 kg ha^{-1} respectively. Therefore increasing the application of both nitrogen and phosphorous to the rate of 165 kg N ha^{-1} and 180 P_2O_5 kg ha^{-1} for the two varieties maximizes total and marketable yield and also have acceptable minimum marginal rate of return.

1. Introduction

Potato (*Solanum tuberosum* L.) is the major world food crop in terms of quantities produced and consumed worldwide, ranking fourth after maize, rice and wheat with an estimated production area of 19 million hectares with the production of 324 million metric ton per year at an average yield of 17 t ha^{-1} (FAOSTAT, 2010). In Ethiopia For many years, potato production was limited to homesteads as a garden crop and its average tuber yield was almost constant between 6-8 t ha^{-1} in the last 20-30 years while the area planted with potato under rain fed increased from 30,000 ha to about 59,508.67 ha (CSA, 2011/12).

One of the major problems constraining the development of an economically successful potato production is nutrient deficiency (Fageria and Baligar, 2005). Similarly, one of the major factors constraining potato production in Ethiopia is nutrient depletion and poor soil management practices (Tamire, 1982; Berga et *al.,* 1994).

Because of its shallow root system and short crop duration, potato is low in nutrient uptake efficiency and is, therefore, its nutrient requirement is very high (Nigussie *et al.*, 2003). Potato requires a steady supply of nutrients (Stark *et al*., 2004). Potato requires high amounts of fertilizer not only because of high nutrient demand, but also because they have a shallow and inefficient rooting system (Munoz *et al*., 2005). Depending on the soil type, variety, crop rotation, moisture supply and management practices, a normal potato crop may remove an estimated 90 to 120 kg ha^{-1} of N and 13.8 to 25.8 kg ha^{-1} P from the soil (Sikka, 1982)

For many years, a blanket application of fertilizer was used for potato production irrespective of soil type. This was used for over 15 years before a detailed study was done at Holetta on Nitosol in 1988 and 1989 for N and P using a medium maturing variety Sissay (Geberemedhin *et al*., 2008). The recommended rate (110 N and 90 P_2O_5 kg ha^{-1}) have been used for more than 20 years for Nitosol. Newer potato cultivars are becoming more widely grown However, little information is available on the nutrient requirements of these newer cultivars on nitosol of the intended study area. *M*oreover, fertilizer recommendations should be revised based on the soil test every 4 to 5 years and new recommendations should be formulated as required since soil nutrients are dynamic and may change with time and location. In addition, plant species or varieties of the same species may have different nutrient requirements owing to differences in nutrient uptake and use efficiency. Thus, the same recommendation rates may not be optimal for enhancing the productivity of all cultivars of crops for many years (Marschner, 1995; Mengel and Kirkby, 2001).

Therefore, nitrogen and phosphorus fertilizer requirements of improved potato varieties, namely, Gudanie and Jalenie that are being widely cultivated in the central highlands of Ethiopia should be determined for their optimum yield. Hence, this research was carried out with the objective to determine the response of two improved potato varieties to different rates of mineral nitrogen and phosphorus fertilizers to yield components and yield of potato.

2. Material and Methods

The experiment was conducted at Holetta Agricultural Research Center (HARC), West Shewa Zone of Oromiya Regional State, Ethiopia, during the main cropping season of 2012 to study the effect of different nitrogen and phosphorus levels on yield components and yield of potato.The area is characterized by mean annual rainfall of 1100 mm and mean relative humidity of 60.6%. The pre-planting soil test result of the study area showed that 10.40 ppm available phosphorus, 4.8 pH , 0.16 % total nitrogen and 1.32 % organic carbon. The treatments consisted of two potato varieties [Gudanie (CIP-386423.13) and Jalenie (CIP-37792-5)], four levels of nitrogen (0, 55, 110 & 165 kg N ha^{-1}) and three levels of phosphorus (0, 90 & 180 kg P_2O_5 ha^{-1}). The experiment was laid out as a Randomized Complete Block Design (RCBD) in a factorial arrangement with three replications per treatment. Thus, there were 2 x 4 x 3 = 24 treatment combinations. Each plot had an area of 4.50 m x 3.60 m. The spacing between adjacent plots and blocks was 1.0 m and 1.5 m, respectively. Urea [(CO $(NH_2)_2$] containing 46% N and triple superphosphate (TSP) containing 46% P_2O_5 were used as a source of nitrogen and phosphorus, respectively. Application of all phosphorus was done by banding the granules of the fertilizer at the depth of 10 cm below the seed tuber at planting. Nitrogen was applied in three splits [1/4th at planting, 1/2 at mid-stage of the plant (30 days after planting), and 1/4th at the initiation of tubers (at the start of flowering)]. All recommended cultural practices were adopted to manage the experimental field. All the data were subjected to Analysis of variance (ANOVA) using the Generalized Linear Model of the SAS statistical package (SAS Inst., Cary, NC, 2002) version 9.0. All pairs of treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance. Partial budget analysis was done using CIMMYT manual (CIMMYT, 1988).

3. Results and Discussion

3.1. Yield Components of Potato

3.1.1. Tuber number per hill

Total and marketable tuber numbers were highly significantly ($P < 0.01$) influenced by the main effects of nitrogen only. However, unmarketable tuber number was significantly ($P < 0.05$) influenced by the interactions effect of variety and phosphorus only (Table 1)

3.1.1.1. Marketable Tuber Number

The main effect of nitrogen fertilizer application highly significantly ($P < 0.01$) influenced marketable tuber number whereas the main effect of variety, phosphorus and the interaction effects of the three factors had no significant effect marketable tuber number (Table1). Marketable tuber number significantly increased with application of 55 kg N ha^{-1} however there was no significant increase at the highest application rate of nitrogen without affecting the unmarketable tuber number significantly (Table 2). This could be probably due to the fact nitrogen can trigger the vegetative development. This result is in line with the finding of Iserael *et al*. (2012) who confirmed that application of nitrogen increased the number of tubers produced per hill. Similarly, increasing the level of applied phosphorus also increased marketable tuber number per hill).

3.1.1.2. Unmarketable tuber number

The most numerous unmarketable tuber numbers were produced by the Jalenie variety at all phosphorus levels and by the Gudanie variety at 0 kg P_2O_5 ha^{-1}. The least numerous unmarketable tubers were produced by the Gudanie variety at the highest (180 kg P_2O_5 ha^{-1}) level of phosphate supply.. The number of unmarketable tubers decreased with an increase in phosphorus application rates. This reduction was significant over the control with the application of 90 and 180 kg P_2O_5 ha^{-1} which did not show a significant variation among them. The application of 90 and 180 kg P_2O_5 ha^{-1} reduced the number of unmarketable tubers/hill by 12.8% and 14.9 % over the control (Table 2). Similarly Zelalem *et al*. (2009) and Iserael *et al*. (2012) found that phosphorus fertilizer increased the marketable tuber number which directly decreased the number of unmarketable tuber.

3.1.1.3. Total tuber number

Increasing the rate of applied nitrogen from 0-165 kg ha^{-1} increased total tuber number by 32% (Table 2). However there was no significant increase beyond 55 kg N ha^{-1}. This can be attributed to increased vegetative growth of the potato plant. The current result is in consistent with the work of others researchers (Mahmodabad *et a*l., 2010 and Iserael et al., 2012) who had reported that an increase in nitrogen application increases total tuber number. In the present study however, increasing the level of applied phosphorus not significantly increased total tuber number per hill.

3.1.2. Average Tuber weight

The tuber weight showed significant difference due to the main effect of variety. However, the main effects of nitrogen and phosphorus and the interaction effect of the three factors had no significant effect on average tuber weight (Table 1). However there was an increasing trend (69 to 75 g) as the application of N increased (Table 2). The average tuber weight of Gudanie exceeded that of Jalenie by 25.5%. The higher tuber weight in case of Gudanie seemed to be influenced by the genetic makeup of the variety as both varieties were grown under similar environmental conditions. Among the growth condition, environmental factors that favour cell division and cell expansion such as mineral nutrition, optimum water supply were reported to enhance tuber size (Lynch and Tai, 1989; De La Morena *et al.*, 1994).

3.1.3. Harvest index

The main and interaction effects of variety, nitrogen and phosphorus on harvest index were found to be not significant (Table 2). However, the harvest index of the varieties ranged between 80 and 87% (Table 1). This result is consistent with the proposition of Hofius and Boernke (2007) that, when potatoes are strongly induced to tuberize, their harvest index can exceed 80%, which is nearly double that of grain crops. Vos and Haverkort (2007) also demonstrated that average the harvest index of potato is about 0.75, compared with approximately 0.5 for cereals.

3.2. Tuber Yield

3.2.1. Marketable tuber yield

The main effects of nitrogen, phosphorus, and variety significantly ($P < 0.01$) influenced the marketable tuber yield. Similarly, the interaction effects of nitrogen x variety, phosphorus x variety as well the three-way interaction of nitrogen x phosphorus x variety significantly ($P < 0.01$) influenced marketable tuber yield of the potato crop (Table 1). Increasing the rate of phosphorus across the increasing rate of nitrogen increased the marketable tuber yield of both potato varieties. Thus, the maximum marketable tuber yields of both Jalenie and Gudanie were obtained at the combined application of 165 kg N ha^{-1} and 180 kg P_2O_5 ha^{-1}. However, this was not significantly different to the combined application of 110 kg N ha^{-1} and 180 kg P_2O5 ha^{-1}. This means nitrogen and phosphorus acted synergistically to promote increased production of marketable tubers. Similar to the current finding, Israel *et al.* (2012) and FAO (2000) reported that without phosphorus application, nitrogen efficiency declined thus indicating an interaction between these two nutrients. The observed higher yield response with increasing the levels of both fertilizers indicated the importance of higher rates of N and P fertilizers to obtain higher marketable yields.

3.2.2. Unmarketable tuber yield

Significant differences in unmarketable tuber yield were observed between the two varieties (Table 1). For Jalenie (0.961 t ha^{-1}) and Gudanie (1.115 t ha^{-1}) unmarketable tuber yield were produced (Table 2. In contrast, the unmarketable tuber yield was not significantly affected by the main and the interaction effects of N and P levels (Table 1). This result seemed to suggest that unmarketable tuber yield might be controlled more effectively by genotype. Unmarketable tuber yield is more importantly controlled through manipulating other factors such as disease incidence, harvesting practices, etc, rather than mineral nutrition (Berga et al., 1994).

3.2.3. Total tuber yield

Similar to marketable yield, increasing the rate of phosphorus across the increased rate of nitrogen application increased the total tuber yields of both varieties. The maximum tuber yields were obtained in the treatments with the highest rates of combined nitrogen and phosphorus application. However, the optimum total tuber yields were obtained at the combined application of 110 kg N ha^{-1} and 180 kg P_2O_5 ha^{-1} which was not significantly different to the highest combination. Application of 165 kg N ha^{-1} combined with 0, 90 &180 kg P_2O_5 ha^{-1} resulted in the highest total tuber yield for the Gudanie variety. The optimum total tuber yield of Gudanie was obtained already at the combination of 0 kg P_2O_5 ha^{-1} and 165 kg N ha^{-1} (Table 3). This indicates that nitrogen played a more synergistic role than phosphorus in increasing total tuber yield of Gudanie. For the Jalenie variety, this phenomenon was not distinctly obvious. Consistent with the results of this study, Fikre Dessie (2012) reported that nitrogen uptake of Gudanie was much higher than that of Jalenie. Similarly, Sattelmacher *et al.* (1990) reported that there was a difference in nitrogen uptake efficiency between two potato varieties, which was attributed to differences in root morphology. On the other hand, the consistent increase in marketable tuber yields of both varieties across the increased rates of both fertilizers indicates that phosphorus played a more prominent role than nitrogen in enhancing the marketability of tubers

4. Partial Budget Analysis

Generally, the highest marketable yield for variety Jalenie and Gudenie (25.09 and 30.52 t ha^{-1}) was obtained at 165+180 kg N/P_2O_5 ha^{-1} respectively. However, in order to propose this result for farmers, it is necessary to estimate the minimum rate of return acceptable to farmers in the recommendation domain. According to CIMMYT (1988), the minimum acceptable MRR should be between 50 and 100% .considering the price of inputs and produce during the experimentation period i.e. 2012 and assuming 10 % decrease in potato price and 10% increase in agro inputs' prices. The partial budget analysis (Tables 4 and 5) indicated that, a maximum net benefit of about 41180 birr ha^{-1} with MRR (217.25%) was obtained from application of 165 kg N ha^{-1} and 180 kg P_2O_5 ha^{-1}, However, the highest MRR (1196%) and (1076%) with the least costs were obtained from 110 kg N ha^{-1} +90 kg P_2O_5 ha^{-1}, and 55 kg N ha^{-1} +90 kg P_2O_5 ha^{-1} resulting in a net benefit of about 38389 birr ha^{-1} and 38212 birr ha^{-1} respectively for the variety Jalenie. According to the MRR analysis, on average for each l birr ha^{-1} invested in fertilizer, the recovery was 1 birr, plus an extra 11.96 birr ha^{-1} and 10.76 birr ha^{-1} in net benefits for 110 kg N ha^{-1} +90 kg P_2O_5 ha^{-1} , and 55 kg N ha^{-1} +90 kg P_2O_5 ha^{-1} for the variety Jalenie, respectively. However in the same area Endale *et a*l.(2005) reported that the cost of recovery was 54 birr ha^{-1}. There was almost similar with that of variety Gudenie in the current study, which was recorded on average for each 1 birr/ ha^{-1} invested in fertilizer the recovery was 37 birr ha^{-1}. Likewise for the variety Gudanie, the maximum net benefit was recorded from the application of 165 kg N ha^{-1} and 180 kg P_2O_5 ha^{-1} which was 52176 birr ha^{-1} with the MRR value of 53.90% .However, the highest MRR (3707%) was registered from the use of 110 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1}, which gave a net benefit of about 46104 birr ha^{-1}.Therefore the most attractive rates with acceptable minimum MRR was 165 kg N ha $^{-1}$ with 180 kg P_2O_5 ha^{-1} , which is also profitable with the highest net benefit and are suggested for both varieties .

5. Conclusions and Recommendation

Fertility status of soils and crop response to different soil fertility amendments is one of the most important factors for increasing production and productivity of any crop. To achieve this objective a study was carried out to examine the effect of N and P application on the yield and yield components of potato (*Solanum tuberosum* L.). On this experiment it was observed that the main effects of applied N and P and their interaction effects were found to be significant for total and marketable yield (t ha^{-1}), Fresh total biomass, Weight and number of all category of tuber size, Accordingly it was also noted in this study that, among the yield components, increases in total and marketable tuber number was responsible for the observed yield advantage. In contrast, the application of N and P did not create considerable effect on Harvest index and unmarketable yield.

As the rate of nitrogen increasing from 0 to 165 kg N ha^{-1} significantly increased fresh total biomass from 583 to 789 g/hill. .Similarly application of P significantly increased marketable tuber number by 19.72% .The combined effect of 165 kg of N ha^{-1} and 180 kg P_2O_5 ha^{-1} increased number and weight of large and medium-sized tubers as comparing to the control from 1.93 to 4.63 no/hill and 238.17 to 461.83 g/hill and from 1.97 to 2.57 no/ hill and 113.5 to 120.27 g/hill respectively. At the highest rate of nitrogen and phosphorus combination, highest marketable tuber yields were obtained for Jalenie variety (25.09 t ha^{-1}) and Gudanie variety (30.52 t ha^{-1}) as compared to control treatment (Jalenie 11.41 t) and (Gudanie 13.93 t ha $^{-1}$).The partial budget analysis data showed that the highest net benefit and marginal rate of return 41180 birr ha^{-1} and 217% MRR and 52176 birr ha^{-1} and 54 % for the variety Jalenie and Gudenie were obtained from N and P applied at 165 N kg ha^{-1} with 180 kg P_20_5 ha^{-1} respectively .

Therefore increasing the application of both nitrogen and phosphorous to the rate of 165 kg N ha^{-1} and 180 P_2O_5 kg ha^{-1} for the two varieties maximizes total and marketable yield and also have acceptable minimum marginal rate of return. That means the blanket recommendation rate of 110 kg N ha-^{1} (165 kg Urea ha^{-1}) and 90 kg P_2O_5 ha^{-1} or 195 kg DAP ha^{-1}) is no longer tenable for enhancing potato production in the region.

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Table 1. Analysis of variance for yield and yield component of potato as influenced by variety, nitrogen and phosphorus

	Source of variations									
variable	R	N	P	Variety	NxP	N xV	P x V	NxPxV	Error	CV(%)
Df	2	3	2	1	6	3	2	6	46	
MTY	2.48	269.90**	208.92**	502.49**	3.54	16,75**	32.18**	15.72**	78.61	9.09
UMTY	0.384	0.005	0.002	0.42	0.05	0.034	0.095	0.042	0.06	24.5
TTY	4.81	272.17**	207.41**	532.30**	3.28	15.50**	30.14**	15.53**	3.94	8.87
MTNO	7.482	11.938**	2.130	0.011	3.301	1.675	4.156	2.769	2.423	25.7
UMTNO	210.0	0.007	0.055	0.023	0.005	0.009	0.03**	0.003	0.006	19.75
TTNO	8.307	11.465**	1.596	0.067	3.382	1.672	4.273	2.781	2.448	24.2
ATW	146.8	165.	32.7	4863**	143.8	74.7	76.1	41.7	122.8	15.3
HI	602.6	218.9	43.6	465.1	207.2	133.1	2.8	37.7	160.0	15.2

MTY = Marketable tuber yield; TTY = Total tuber yield; UMTY = Unmarketable tuber yield; MTN O= Marketable tuber number ;UMTNO= Un marketable tuber number ;TTTN = Total tuber number; ATW = Average tuber weight; HI= Harvest index , df=degree of freedom; CV= coefficient of variation; V x N=Variety nitrogen interaction, V x P= Variety phosphorus interaction, N x P= Nitrogen phosphorus interaction, V x N x P= Variety nitrogen and phosphorus interaction.

Table 2. Effect of nitrogen and phosphorus rates on marketable tuber number, unmarketable tuber number, total number tuber, unmarketable tuber yield, average tuber weight and Harvest index of potato varieties

Treatments	Marketable Tuber Number (/hill)	Unmarketable tuber Number (/hill)	Total Number tuber (/hill)	Unmarketable tuber yield (t ha^{-1})	Average Tuber weight (g/tuber)	Harvest index (%)
Variety						
Jalenie	6.06	0.43	6.49	0.961b	64.4b	80.6
Gudanie	6.03	0.40	6.43	1.115 a	80.8a	85.7
LSD(0.05	NS	NS	NS	0.1207	5.26	NS
Nitrogen kg Nha^{-1})						
0	5.00b	0.44	5.44b	1.018	69.5	80.0
55	5.82ab	0.41	6.23ab	1.028	70.5	80.4
110	6.59a	0.40	6.99a	1.055	75.1	85.6
165	6.78a	0.41	7.19a	1.051	75.2	86.8
LSD(0.05)	1.04	NS	1.050	NS	NS	NS
Phosphorus (kg P_2O_5 $ha^{-1)}$						
0	5.7	0.47a	6.17	1.024	73.6	84.0
90	6.26	0.41b	6.67	1.052	71.3	81.6
180	6.15	0.40 b	6.55	1.037	72.8	83.9
LSD(0.05)	NS	0.05	NS	NS	NS	NS
CV%	25.73	19.76	24.2	24.5	15.3	15.2

Means followed by the same letters within a column are not significantly different from each other at P≤ 0.05 according to LSD; LSD = Least significant difference; NS= Not significant; CV= Coefficient of variation

Table 3. Interaction effect of variety, nitrogen and phosphorus on marketable and total tuber yield

		Marketable tuber yield(t ha-^{1})		Total tuber yield (t ha^{-1})	
		Varieties		Varieties	
N kg ha^{-1}	P_2O_5 (kg ha^{-1})	Jalenie	Gudanie	Jalenie	Gudanie
0	0	11.41 m	13.93lm	12.36 m	15.17lm
55		12.24 lm	22.31efg	13.15 lm	23.43efg
110		14.69 lk	24.93cdef	15.77 lk	25.82cdef
165		18.50ij	27.47abc	19.62 ij	28.55abc
0	90	14.39 klm	21.01ghi	15.10 ml	22.05ghi
55		20.88 ghi	21.84fgh	21.84 ghij	22.95efgh
110		21.70 gh	25.51cd	22.69 fghi	26.87cd
165		22.54 defg	27.22bc	23.42fg	28.44abc
0	180	18.98 hij	17.52jk	19.94 hij	18.70jk
55		21.51 ghi	26.39bc	22.60 fghi	27.38cb
110		22.74 defg	29.38ab	23.67defg	30.46ab
165		25.09 cde	30.52a	26.02 cde	31.59a
	LSD(0.05)	3.16		3.27	
	CV%	9.09		8.87	

Means followed by the same letter within a column are not significantly different from each other at P≤ 0.05 according to LSD: CV= Coefficient of variation

Table 4 Partial budget, analysis for fertilizer rate trial on marketable yield of Jalenie potato variety.

N/P_2O_5 levels	Unadjusted marketable Yield t ha^{-1}	Adjusted marketable Yield t ha^{-1}	Gross Benefit (Adjusted)	Total Variable Cost birr ha^{-1}	Net Benefit birr ha^{-1}	Marginal Rate of return (MRR %)
0/0	11.41	10.269	23105	-	23105	-
0/90	14.39	12.951	29140	2566	265740	308.04
55/90	20.88	18.792	42282	4065	38217	1075.87
165/0	18.5	16.65	37463	4498	32965	D
110/90	21.7	19.53	43943	5554	38389	1196.00
165/180	25.09	22.581	50807	9627	41180	217.25

D: Stands for dominated treatment, The marketable tuber yield was adjusted by 10% adjustment coefficient and the marginal rate of return (MRR) and net benefits are calculated by adding 10% birr/kg increase from the current fertilizer price. Field price of potato, Urea, and DAP was 2.00 birr kg^{-1} 11.40 birr kg^{-1} 14.53 birr kg^{-1} respectively.

Table 5. Partial budget analysis for fertilizer rate trial on marketable yield of Gudenie potato variety

N/P_2O_5 levels	Unadjusted marketable Yield t ha^{-1}	Adjusted marketable Yield t ha^{-1}	Gross Benefit (Adjusted) birr ha^{-1}	Total Variable Cost birr ha^{-1}	Net Benefit birr ha^{-1}	Marginal Rate of return (%)
0/0	13.93	12.54	28208	0	28208	0
55/0	22.31	20.08	45178	1499	43679	1032.05
110/0	24.93	22.44	50483	2999	47484	1733.26
165/0	27.47	24.72	55627	4498	51128	2532.97
0/180	17.52	15.77	35478	5129	30349	D
110/90	25.51	22.96	51658	5554	46104	3707.00
165/180	30.52	27.47	61803	9627	52176	53.90

D: Stands for dominated treatment, The marketable tuber yield was adjusted by 10% adjustment coefficient and the marginal rate of return (MRR) and net benefits are calculated by adding 10% birr kg^{-1} increase from the current fertilizer price. Field price of potato, Urea, and DAP was 2.00 birr kg^{-1} 11.40 birr kg^{-1} 14.53 birr kg^{-1} respectively.