Evaluation of Potassium Fertilizer on Yield and Yield Components of Potato under Irrigation on Nitisols in Central Highlands of Ethiopia

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Abstract
Nutrient deficiency is a major constraint for potato (*Solanum tuberosum* L.) production in Ethiopia. Potato response to potassium fertilizer declined with widespread deficiencies of nutrients other than N and P, farmers are discouraged to apply such fertilizer recommendations. This study was, therefore, conducted for two years (2018-2019) on nitisols under irrigation to evaluate the response of potato to potassium (K) fertilizer rates. The treatments were five (Negative control, recommended NPS, recommended NPS, recommended NPS + 3liter K /ha, recommended NPS + 5 liter K/ha, recommended NPS + 7liter K/ha). The experiment was arranged in a randomized complete block design replicated four times on farmers' fields. Results revealed that potato yield responded differently to the applied potassium fertilizer rates. Applications of 100% NP fertilizer with 5liter/ha potassium fertilizer had a significant ($p<0.05$) effect on marketable tuber and total tuber yield of potato. In general application of liquid potassium fertilizer (100% NP fertilizer with 5liter/ha K) indicates positive response on dray matter and specific gravity. In conclusion, based on the findings of the experiment with application of 5L/ha liquid potassium fertilizer with 100% recommended NP fertilizer are economically optimum for potato production.
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INTRODUCTION
Potato (*Solanum tuberosum* L.) plays a vital role in achieving food and nutrition security due to its high yielding capacity, presence of various suitable agro-ecological zones in Ethiopia, the availability of labor for production, and market accessibility with added value for its produce [1] . Potatoes can be used for a variety of purposes such as a fresh vegetable for cooking at home, as raw material for processing into food products, food ingredients, starch and alcohol, animal feed and as seed tubers for growing the next cropping season. The demand of consumers is changing from fresh tubers to processed products and large quantities of potatoes are being processed to meet the rising demand for convenient food and snacks. The major drivers behind this trend include expanding urban populations, rising incomes, diversification of diets, and lifestyles that leave less time for preparing the fresh product for consumption [2].

In Ethiopia, in 2017/2018 cropping season, the area under potato crop was 69,610 ha with the average national yield of 13.9 t ha^{-1}[3], which is still far less than other countries such as New Zealand (50.2 t ha^{-1}) and North America (41.2 t ha^{-1}). Even yield potential of potato has been reported to reach about 100 t ha^{-1}[4]. This is attributed to several factors such as poor soil fertility and agronomic practices, storage problems, low market prices at harvest, diseases and insect pests. Fresh potato tubers deteriorate quickly in tropical and subtropical environments, especially in the lowlands.

Maintaining a high yielding potential in potatoes requires soil health and fertility management. Soil health depends on physical and chemical properties and functions, organic matter and biological activity, which are fundamental to sustaining agricultural production and determine, in their complexity, soil fertility and productivity [2] [5]. Anthropogenic activities are main causes of soil fertility degradation and nutrient depletion which influence significantly food production and food security in Ethiopia [6]. Inappropriate soil fertility management is the cause of food shortage and malnutrition of huge number of people which is also associated with human health impact [7].The requirements of crop fertilization need to be correctly estimated according to the expected yield, the potential of the variety planted and the intended use of the harvested crop [2]. Before application of fertilizers, farmers should perform, where possible, a soil test to identify soil biophysical and chemical properties. Soil tests help assess fertility and indicate deficiencies that need to be addressed. Potatoes require high fertilizer rates but low utilization efficiency [2].

Nutrient imbalance and unbalanced application of plant nutrients is the principal factor affecting yield and quality of crops. For instance, excessive application of nitrogen fertilizer reduces crop yield, increases cost of production and pollutes the environment, especially soil and ground water is acidified [8]. Crop production with suboptimal levels or without fertilizer application is the common practice in Ethiopian farmers. Although the crop requirement of potassium is higher than N and P rates [9]; [10], potato is produced without its application in most

areas. This is because potassium is believed to be sufficient in most Ethiopian soils, and as a result information about the requirement of potassium fertilizer for potato production is scarce. However, potato is grown mainly in the highland areas of the country where severe soil fertility depletion is predominant. Achieving optimum plant nutrient applications is an essential strategy as it determines yield and varies with soil, crop and water availability to the crop for optimum yield and profit. Therefore, this field trial was conducted to determine the effect of potassium fertilizer on yield and yield components of potato.

Materials and Methods
Experimental Site
The experiment was conducted in the District of Welmera, Adea Berga and Ejere West Shewa Zone of Oromia National Regional State for three consecutive cropping seasons (2018 and 2019). The experiment site is located at 09^0 $03'$ N latitude and 38^0 $30'$ E longitude, 30, 60 and 32km west of Addis Ababa respectively, at an altitude of about 2400m above sea level. The mean annual rainfall of the study area was 1100mm of which about 85% falls from June to September and the rest from March to May. The mean annual temperature is about 14.3^0c, with the mean maximum and minimum temperatures of 21.7^0c and 6.9 ^{0}c respectively (Holeta Agricultural Research Center Meteorological Report, unpublished data).

Figure 1: Maps of the study area
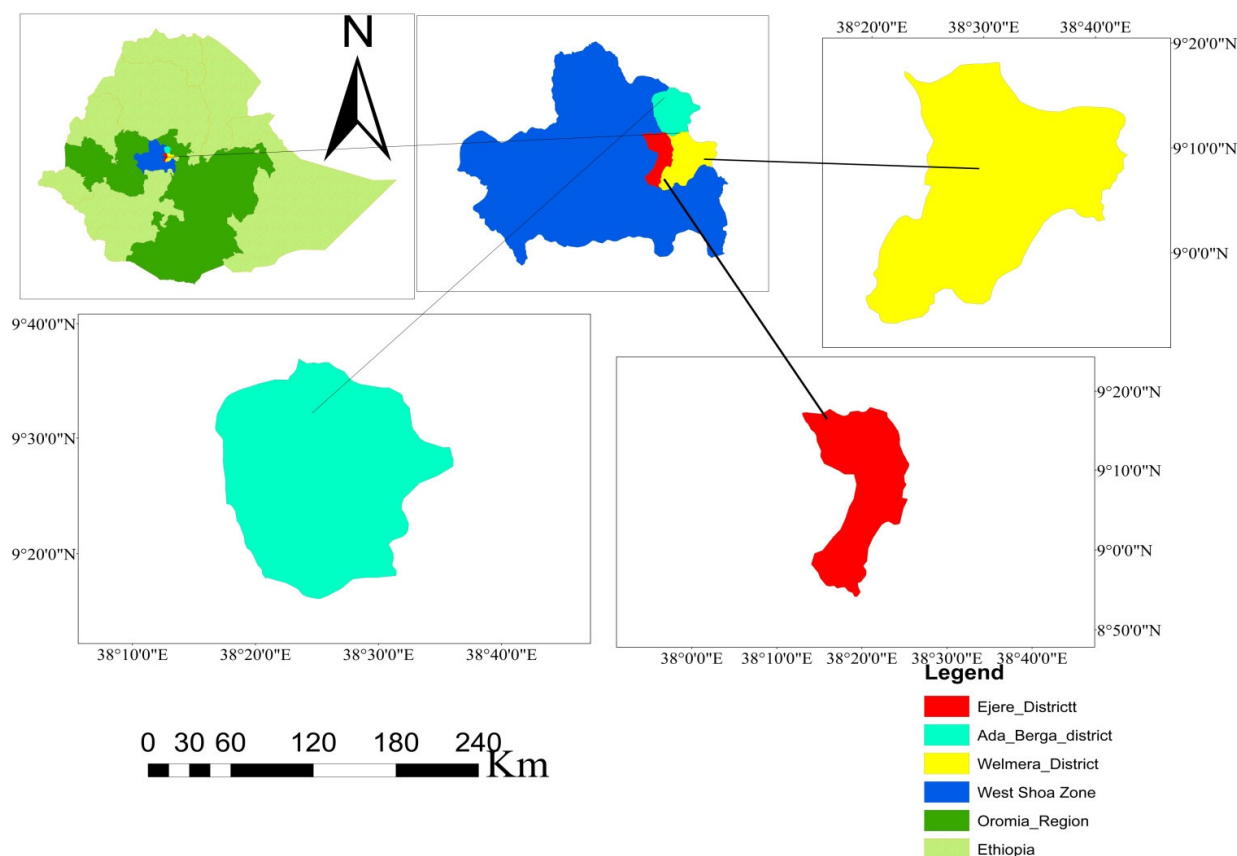
Experimental procedure
The crop was given irrigation water every two weeks, i.e., the time interval between the two successive irrigation was 14 days, and irrigation was mostly given after the depletion of 50% of soil moisture. The reason why this irrigation interval chosen was that the crop did not suffer from water stress.

The experiment included five selected treatments: 1) control; 2) recommended nitrogen, phosphorus and sulfur (NPS) rate (75 kg/ha N, 39.3 kg/ha P and 16.5 kg/ha S); 3) recommended NPS rate + 3Liter potassium fertilizer/ha; 4) recommended NPS + 5 Liter potassium fertilizer/ha; and 5) recommended NPS rate + 7 Liter potassium fertilizer/ha. The experiment was set in randomized complete block design with four replications. The size of each experimental plot was 3 m by 4 m (12 m^2) with 4 plant rows and the spacing between rows were 75 cm and between plants was 30 cm. The spacing between plots and blocks was 1.0 m and 1.5 m, respectively. The recently released potato variety (Belete) was used for this study which was released in 2009 from Holetta Agricultural Research Center. Planting was done in the first week of January using irrigation.

The potassium fertilizer was applied as foliar starting one month after planting for six times and then every

two weeks after the first application. NPS fertilizer was applied as side banding at planting time while the recommended rate of urea was applied in two splits i.e. half at planting and the other half at tillering stage. Other recommended agronomic practices such as weed, pest and disease control were applied uniformly for all treatments. The average plant height was measured from each plot of five randomly selected plants. The two central rows were harvested to determine the total and marketable yield of potato.

Data management and analysis

Days to flowering: was recorded as number of days from emergence to the time when 50 percent of the plant population in each plot produced flowers.

Plant height (cm): was measured by taking five randomly reselected plants per plot as the distance in cm from the soil surface to the top most growth point of aboveground at full maturity.

Leaf area index: To determine leaf area, five plants (hills) from each plot were randomly taken at 50 percent flowering. Then, three leaf samples were measured using leaf area meters. By multiplying the average leaf area with the respective leaf number of the plant, total leaf area was calculated. Leaf area index was calculated by dividing total leaf area to the respective land area occupied by plants.

Stem number: Five plants per unit area were counted at 50% flowering.

Days to maturity: Number of days from emergence to maturity was recorded when 95% percent of the plants of different treatments were ready for harvest as indicated by the senescence of the haulms.

Marketable tuber yield (tons/ha): included marketable and healthy tubers with size categories greater than 25 g.

Unmarketable tuber yield (tons/ha): unmarketable tubers included unhealthy tubers as well as healthy tuber weighing less than 25g.

Total tuber yield (tons/ha): total tuber yield was recorded as the sum of all marketable and unmarketable tubers.

Specific gravity of tubers (gcm^{-3}): To determine the specific gravity, tubers of all size categories weighing about two kilograms were randomly taken from each plot, washed with water. The sample was then first weighed in air and then re-weighed suspended in water. Specific gravity was then determined using the following formula [11].

$$\text{Specific Gravity} = \frac{Weight\ in\ air}{Weight\ in\ air - Weight\ in\ water}\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed at harvest. The tubers were then sliced and dried in an oven at 65^{0}C for about 72hrs until a constant weight is obtained. The dry weight was recorded and the dry matter percent calculated according to [12].

$$\text{Dry matter (\%)} = \frac{Weight\ of\ sample\ after\ drying(g)\ x\ 100}{Initial\ weight\ of\ sample(g)}\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

The data were subjected to analysis of variance using the general linear model procedure (PROC GLM) of SAS statistical package version 9.3 (SAS Institute Cary, NC). The total variability for each trait was quantified using pooled analysis of variance over years using appropriate models. Means for the effects of treatments (n = 5) were compared using the MEANS statement with the least significant difference (LSD) test at the 5% level.

Economic analysis

For economic evaluation, partial budget and marginal analyses were used based on the local market price of the potato total tuber yield and fertilizer cost [13]. The economic analysis was performed to investigate the economic feasibility of the treatments. The average yield was adjusted downwards 10% to reflect the difference between the experimental plot yield of and the production yield by farmers. The partial budget, dominance and marginal rate of return were calculated to determine the economic feasibility of the Final-K fertilizer for potato production under irrigation condition. The partial budget was calculated using an average yield that was adjusted downwards by 10%, because we assumed that farmers would get ~10% less yield than is achieved on an experimental site. The average open market price for potato (4 Ethiopian Birr (ETB) per kg) and the official prices for N (Urea) and P (NPS) were used for the analysis (urea-N: 13 Birr/kg, NPS: 15 Birr/kg, Final-K: 150 birr/Liter and labor cost for spraying Final-K fertilizer: 120 Birr/day). Thus, the total variable costs were calculated from the cost of Urea-N, NPS, Final-K and labor cost applied.

A dominance analysis was used to indicate the most economically viable options, which was done by arranging the treatments according to increasing total variable costs. The net benefit for each treatment was calculated by subtracting the total variable costs from the revenue provided by the crop. If the net benefit of a treatment was less than that of a treatment with lower total variable costs, then the treatment was considered to be dominated, and the treatment with the higher total variable costs and lower net benefit was rejected [13].

RESULT AND DISCUSSION

Soil chemical properties after harvesting

The laboratory analysis results of soil chemical properties of the trial sites after harvesting potato are presented in Table 1. The average pH of the experimental fields was 5.15, which was strongly acidic in reaction. The result indicated that soil organic carbon (OC), total nitrogen (TN), available phosphorus (av. P), and exchangeable

cations were in the medium range [14]. The treatments had no significant effect on the status of soil pH and soil nutrients. Exchangeable potassium (K) levels below 0.2 cmol (+)/kg suggest that a plant response to the application of K fertilizer is possible, particularly where heavy removal of K by harvesting occurs [14]. Generally, the availability of both macro-and micronutrients is reduced at pH < 5.0. In this study, the level of potassium has been found to be moderate, thus the response of potato to external K application could be unlikely. But, since potato is heavy feeder that requires more nutrients than other crops addition of plant nutrients in optimum amount is essential both to increase and sustain yield and maintain soil nutrient status at optimum level.

Table 1: Soil chemical properties of the experimental sites after harvesting

Treatments	pH	OC (%)	TN (%)	Av. P (mg kg^{-1})	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g
Negative	5.16	1.63	0.15	9.20	11.45	3.27	0.45	0.03
Recommended NPS	5.14	1.63	0.16	11.59	10.41	2.84	0.45	0.02
Recommended NPS + 3 Lt K/ha	5.07	1.87	0.17	10.75	10.04	3.16	0.46	0.02
Recommended NPS + 5 Lt K/ha	5.23	1.99	0.16	11.06	10.13	3.04	0.43	0.02
Recommended NPS + 7 Lt K/ha	5.17	1.99	0.15	10.92	11.09	3.07	0.41	0.02
Mean	5.15	1.82	0.16	10.70	10.63	3.08	0.44	0.02

Growth Parameters of Potato

The analysis of variance over two years revealed that the treatments significantly ($P < 0.05$) affected days to flowering, plant height, stem number, days to physiological maturity at 95% and leaf area index of potato. The highest plant height (~69 cm), stem number (26.2) and leaf area index (5.8) were recorded at the application rate of 7 liter ha^{-1} liquid potassium fertilizer with recommended NPS fertilizer rate (Table 2). [15] Reported that potato plant height was significantly affected by fertilizer application and positively correlated with yield parameters, indicating that higher potato plant height contributed to higher potato yield. [16] who reported that environmental factors like nutrient status of the soil, available moisture and intercepted radiation significantly influence plant heights.

While, the highest number of days to flowering (78.8) and days to maturate (122.4) were recorded at zero rate of potassium. This result is in agreement with that of [17]who stated that days required to flowering is highly dependent on gene factors and governed by many environmental factors, nutrient, mainly temperature and light. The number of days required to flowering is one of the important parameter for potato farmers due to the fact that it enables the grower to forecast its harvesting scheme as well as the marketing plan [18]. [19]also stated that days to maturity of potato varieties varied from 90 to 120 days and the variation is accounted for by variety, soil fertility status, growing environment and cultural practices.

Table 2: The effects of potassium fertilizer on some potato growth parameters

Treatments	Days to flowering at 50%	Plant height (cm)	Stem number	Days to physiological maturity at 95%	LAI
Control	78.8[a]	54.8[b]	16.4[c]	122.4[a]	3.2[c]
Recommended NPS	75.6[b]	65.9[a]	22.6[b]	112.6[b]	4.6[b]
Recommended NPS + 3Lt K/ha	76.4[b]	66.7[a]	21.5[b]	114.3[b]	4.8[b]
Recommended NPS + 5Lt K/ha	75.3[b]	66.7[a]	25.6[b]	112.8[b]	5.2[ab]
Recommended NPS + 7Lt K/ha	74.7[b]	68.9[a]	26.2[b]	113.8[b]	5.8[a]
LSD(0.05)	2.38	3.84	3.91	2.06	0.84
CV (%)	7.6	10.4	6.2	8.7	14.3

Means followed by the same letter within a column are not significantly different at 5 % level of significance. LSD= Least significant differences; CV=coefficient of variation.

Yield and yield component of potato

The analysis of variance over two years and locations revealed that the treatments significantly ($P < 0.01$) affected marketable and total tuber yields of potato. Application of potassium (*Final K*) in liquid form at different levels significantly ($P < 0.05$) influenced marketable and total tuber yield. Marketable tuber yield ranged from 13.7-27.5

t/ha and total tuber yield from 23.5-37.7 t/ha. The maximum marketable tuber yield (27.5 t/ha) and total tuber yields (37.7 t/ha) of potato were recorded from the recommended NPS rate plus 5 liter ha^{-1} of liquid potassium fertilizer application rate, while the lowest yields of both parameters were recorded from the control treatment without application of fertilizer.

Yield and yield components of potato respond to inorganic and organic fertilizers. The application of the recommended NPS rate and the same NPS rate plus liquid K fertilizer at different levels markedly increased potato marketable yield by 86% and 89-101% compared to the recommended NPS rate and the control without any fertilizer application, respectively. However, the marketable tuber yield due to the application of the recommended NPS rate with liquid K fertilizer at three levels was only 2-8%, compared to the recommended NPS rate, indicating that the contribution of liquid K fertilizer application to the yield increment of potato was insignificant (Table 3). On the other hand, yield and yield components of potato significantly responded to application of nitrogen and phosphorus fertilizers [15].

Table 3: Response of potassium liquid fertilizer on plant height, unmarketable, marketable tuber yield and total tuber yield of potato

Treatments	Unmarketable tuber yield (ton/ha)	Marketable tuber yield (ton/ha)	Total tuber yield (ton/ha)
Control	9.99	13.68c	23.5c
Recommended NPS	9.63	25.53b	35.16b
Recommended NPS + 3Lt K/ha	10.63	25.94ab	36.56ab
Recommended NPS + 5Lt K/ha	10.21	27.51a	37.72a
Recommended NPS + 7Lt K/ha	9.98	26.56ab	36.55ab
LSD(0.05)	NS	1.95	1.79
CV (%)	26.2	14.3	9.3

Means followed by the same letter within a column are not significantly different at 5 % level of significance. LSD= Least significant differences; CV=coefficient of variation.

Number of tuber categories

The analysis of variance over two years revealed that the treatments significantly ($P < 0.05$) affected small, medium and large tuber number of potato (Table 4). The highest small tuber number (23.01 per 5 plants) was recorded from the negative control treatment. While the maximum value of medium and large tuber numbers were recorded at the application rate of 7 liter ha^{-1} potassium fertilizer with recommended NPS fertilizer rate.

Table 4: Effects of potassium fertilizer on tuber number in tuber categories of potato

Treatments	Small tuber Number /5plants	Medium tuber Number/5 plants	large tuber Number / 5plants
Control	23.01[a]	14.1[c]	4.6[e]
Recommended NPS	13.8[b]	19.6[b]	14.08[d]
Recommended NPS + 3Lt K/ha	8.8[c]	24.6[ab]	20.27[c]
Recommended NPS + 5Lt K/ha	7.4[c]	26.5[a]	24.62[b]
Recommended NPS + 7Lt K/ha	5.7[c]	28.3[a]	32.28[a]
LSD(0.05)	1.22	2.37	3.16
CV (%)	9.6	12.4	16.5

Means followed by the same letter within a column are not significantly different at 5 % level of significance. LSD= Least significant differences; CV=coefficient of variation.

Tuber Size Distribution

The effects of potassium fertilizer were significantly (P < 0.05) influenced yield of small, medium and large-sized tubers (Table 5). The highest yield of small-sized tuber (17.2 ton ha^{-1}) was recorded at negative control treatment and the highest yield of medium-sized tuber (24.02 ton ha^{-1}) was obtained from the application of recommended NPS with 3Lt ha^{-1} treatments. While, the maximum value of large-sized tuber (11.33 ton ha^{-1}) was recorded from recommended NPS with 5Lt ha^{-1} of potassium fertilizer application.

Table 5: Effects of potassium fertilizer on some yields of small, medium, and large-sized tubers of potato

Treatments	Small-Sized tuber (ton/ha)	Medium-Sized tuber (ton/ha)	Large-Sized tuber (ton/ha)
Control	17.2[a]	5.0[c]	1.3[c]
Recommended NPS	5.18[b]	22.83[a]	7.15[b]
Recommended NPS + 3Lt K/ha	4.86[b]	24.02[a]	7.68[b]
Recommended NPS + 5Lt K/ha	4.25[b]	21.14[ab]	12.33[a]
Recommended NPS + 7Lt K/ha	3.67[c]	21.37[b]	11.68a
LSD(0.05)	1.36	2.07	2.18
CV (%)	8.4	12.7	14.2

Means followed by the same letter within a column are not significantly different at 5 % level of significance.
LSD= Least significant differences; CV=coefficient of variation.

Quality parameters

The analysis of variance revealed that the treatment effects were significant for and specific gravity potato tuber dry matter. The highest tuber dry matter of 23.42% and specific gravity of 1.48 were recorded at the recommended NPS rate plus 5 liter ha^{-1} liquid K fertilizer rate (Table 6). This implies that specific gravity is one of the most important traits in potato crop that may provide a faster and easier measure of dry matter content [20]. This is consistent with [21] who reported that the positive correlation between specific gravity and tuber dry matter content signifies that specific gravity is a true indicator of the amount of dry matter of tubers. Potassium is the nutrient taken up by potato in higher amount; the nutritive values of potato tubers were significantly affected by potassium application [22]. Both the N and P content of potato tubers increases as the K application rate increases.

Table 6: Response of potassium liquid fertilizer on some potato tuber quality parameters

Treatments	Dry mater (%)	Specific gravity
Control	22.36c	1.33c
Recommended NPS	22.95b	1.41b
Recommended NPS + 3Lt K/ha	23.18ab	1.40b
Recommended NPS + 5Lt K/ha	23.42a	1.48a
Recommended NPS + 7Lt K/ha	23.38a	1.47a
LSD(0.05)	0.33	0.054
CV (%)	2.49	6.62

Means followed by the same letter within a column are not significantly different at 5 % level of significance.
LSD= Least significant differences; CV=coefficient of variation.

Economic analysis

As it is indicated in (Table 7) the net farm benefit was calculated taking possible field variable costs and all benefits (total tuber yield). Application of final liquid K fertilizer at 5L/ha with 100% recommended NPS fertilizer resulted in the highest net benefit (129117birr) and marginal rate of return (1292%). Based on the economical recommendation of [13] which stated that farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum acceptable rate of return. Hence, use of Final-K liquid fertilizer at 5L/ha rate with 100% recommended NPS fertilizer would be desirable for potato producers in the study areas under irrigation condition.

Table 7: Final K fertilizer effect on partial budget and marginal rate of return for potato production.

Testaments	NPS (kg/ha)	Urea (kg/ha)	Mean GY (kg/ha)	Adj GY (kg/ha)	Gross benefit (ETB/ha)	NPS (cost)	Urea (cost)	Sprayer cost	Final -K	Total cost (ETB/ha)	Net benefit (ETB/ha)	MRR (%)
Negative	0	0	23500	21150	84600	0	0	0	0	0	84600	
Rec NPS	236	165	35160	31644	126576	3540	2145	0	0	5685	120891	638.4
Rec NPS + 3Lt K/ha	236	165	36560	32904	131616	3540	2145	240	450	6375	125241	630.5
Rec NPS + 5Lt K/ha	236	165	37720	33948	135792	3540	2145	240	750	6675	129117	1292
Rec NPS + 7Lt K/ha	236	165	36550	32895	131580	3540	2145	240	1050	6975	1246.05D	

CONCLUSION

Use of potassium fertilizer at the appropriate rate with other plant nutrients plays a key role in resisting plant diseases, improving the yield and quality of potato. Potato plants well supplied with K have also been found to withstand frost better than plants low in potassium. In this study, application of liquid potassium fertilizer with recommended NPS fertilizer rate significantly improved the growth, yield and quality of potato on Nitisols of central highlands of Ethiopia. Therefore, application of Final-K liquid fertilizer at 5Liter ha^{-1} with 100% recommended NPS fertilizer rate is recommended for potato production in the study area and other similar areas

under irrigation condition.

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