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Response of potato (*Solanum tuberosum* L.) to nitrogen and phosphorus fertilizers at Sekota and Lasta districts of Eastern Amhara, Ethiopia

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Abstract

Background: Production and productivity of potato in Ethiopia is far below the world average because of soil fertility problem, pest, disease, and agronomic factors. Nutrient depletion because of soil erosion is a serious problem in Ethiopian highlands. Annually, 122 kg ha^{-1} nitrogen, 13 kg ha^{-1} phosphorous and 82 kg ha^{-1} potasium were estimated to deplete from Ethiopia (Haileslassie et al. 2005). From the essential nutrients especially, nitrogen and phosphorus are the most important influential elements for production of potato but they are deficient in most Ethiopian soils and thus an application of these nutrients could increase significantly the crop yields. Therefore, the experiment was conducted at Sekota and Lasta Lalibela districts (Woleh and Kechin Abeba irrigation command areas) of eastern Amhara, Ethiopia to investigate the effects of nitrogen and phosphorus fertilizers for yield and yield component of potato under irrigation condition.

Methods: Four rates of nitrogen (0, 46, 92, and 138 kg N kg ha^{-1}) and phosphorus (0, 23, 46, and 69 Kg P_2O_5 kg ha^{-1}) were combined with factorial arrangement and laid out in randomized complete block design with three replications.

Results: The result of the study revealed that nitrogen and phosphorus had a significant effect on plant height, marketable, and total yield of potato at Kechin Abeba. But phosphorus did not show a significant effect on plant height and unmarketable yield at Sekota district of Woleh irrigation command area. The highest yield 45.55 t ha^{-1} was obtained from combined application of 138 N and 23 P_2O_5 in Lalibela 17.12 and 16.99 t ha^{-1} were found from application of 138 N with 46 P_2O_5 kg ha^{-1} and 138 N with 23 P_2O_5 kg ha^{-1} from Sekota district of Woleh irrigation command area respectively.

Conclusions: The application of 138 kg ha^{-1} N with 23 kg ha^{-1} P_2O_5 is the appropriate rates for optimum productivity of potato at Lalibela (Kechin Abeba) and Sekota (Woleh) irrigation command areas and the same agro-ecology.

Keywords: Nitrogen, Phosphorous, Marketable yield, Unmarketable yield, Total yield, Potato

Background

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crop in the world. In the volume of production, it ranks fourth in the world after maize, rice, and wheat, with an estimated production area of 18.9 million hectares (Naz et al. 2011). Its yield in sub-Sahara Africa is below 10 t ha^{-1} while the attainable yields with good crop management are well above 30 t ha^{-1}. In Ethiopia, due to soil fertility problem, lack of good quality seed, inadequate application of fertilizer, pest and disease, irregularity of water supply and scheduling it's productivity is very low (Haverkort et al. 2012, Emana and Nigussie 2011). In addition to this continuous cropping without replacing the removal nutrient from crop biomass and another organic source is a major problem of nutrient depletion in Ethiopia (Haileslassie et al. 2005).

Plants require essential nutrient for their optimum growth and development, among them N and P are the

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most important one because they are required in large quantities. The deficiency of these nutrients are manifested in the detrimental effects on the growth and development of the plants (Tisdale et al. 1995).

To meet the demand for the growing world population, fertilizer plays an indispensable role in achieving optimum crop production and productivity (Mengel and Kirkby 1996). Application of nitrogen and phosphorus fertilizers have a good yield response for different crops including potato in Ethiopia. Research conducted by Firew et al. (2016) showed that combined application of nitrogen and phosphorus fertilizers had increased the yield of potato by 12.26 t ha^{-1} as compared to control (0 N, 0 P). Similarly, Wubengeda et al. (2016) reported that by increasing the rates of the two (N and P) nutrients the yield and yield components of potato was increased. Desalegn et al. (2016) also, reported that increasing the rates of nitrogen and phosphorus can enhance the tuber yield by 361 and 358% as compared with unfertilized treatment. Generally, the above-mentioned studies showed that appropriate agronomic practices including site specific fertilizer recommendation plays a significant role in potato production. However, in the study areas, farmers utilized inorganic fertilizers application with a blanket recommendation to increase the potato production. A site-specific fertilizer recommendations play a significant role in potato production. But, there was no appropriate fertilizer rate recommendation for potato in the study areas. Therefore, the experiment was conducted to determine the optimum rates of nitrogen and phosphorus fertilizers for potato production at Sekota and Lasta districts of Amhara Region Ethiopia.

Materials and methods

Description of the study area

Experiment was conducted in 2015 and 2017 irrigation season at two sites; Sekota district Woleh and Lasta district Kechin Abeba. The sites are located (11° 57′ 31.14″ and 12° 31′44.57″, 39° 04′01.07″ and 39° 02′55.6″ longitude with an altitude of 2120 m and 2101 m above sea level), respectively (Fig. 1). The schemes (Woleh and Kechin Abeba) can irrigate an area of 137.25 and 75 ha of land respectively. The topographical feature of the area is characterized by mountainous, plateaus, and hills. Soil erosion is a common problem in these areas. Due to this reason the fertility status of the soil is very low (Table 1). Mixed agriculture is a common farming system in the study areas.

Experimental treatments, design and procedures

Four levels of nitrogen (0, 46, 92, 138 kg ha^{-1}) and phosphorus (0, 23, 46, 69 kg ha^{-1}) were arranged in a factorial combination, giving a total of 16 treatments set in a Randomized Complete Block Design (RCBD) with three replications. The entire rate of P_2O_5 and the half rate of N fertilizers were applied at the time of planting. The remaining half of N was applied 45 days after planting. Urea (46% N) and Triple Super Phosphate (46% P_2O_5) were used as fertilizer sources for N and P, respectively. Medium size and well-sprouted potato tubers were planted at a spacing of 75 cm between rows and 30 cm between plants. The total plot size was 3 m × 3 m (9 m^2), the spacing between plots and replications were 0.5 and 1 m, respectively. Cultural practices like cultivation, weeding and ridging were practiced as per recommendation. Watering was done within 5 days interval based on the recommendation and Gera potato variety was used for the study.

Data collection and analysis

Plant height (cm), marketable tuber yield (ton), unmarketable tuber yield (ton) and total tuber yield (ton) were collected from the middle rows of the experimental plots. Data were subjected to analysis of variance using proc GLM (general linear model) procedure of SAS 9.0 software (SAS 2004). Treatments means were compared with LSD at 5% significance level.

To determine the nutrient content of the soil before planting, composite soil samples were collected from 0 to 20 cm depth using the Edelman auger from the experimental sites. Samples were air-dried and ground to pass through a 2-mm sieve to get the fine earth fraction (<2 mm separates). Particle size distribution (sand, silt, and clay separate) was determined by hydrometer method as outlined by Bouyoucos (1962). Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Carter and Gregorich 2008). Organic carbon of the soil was determined following the wet digestion method as described by Walkley and Black (1934). Total nitrogen was determined by the Kjeldahl digestion, distillation and titration method (Bremner and Mulvaney 1982) and available phosphorus was determined by the standard Olsen method (Olsen et al. 1954).

Partial budget analysis

Partial budget analysis was carried out for every treatment based on CIMMYT (1988) to indicate the economic superiority of alternative treatments over the control treatment. Fertilizer cost and mean price of potato were collected from the districts. The average yield was adjusted downward by 10% from the exact yield to reflect the difference between the experimental yield and yield of farmers. MRR (%) was calculated as changes in net benefit divided by changes in cost.

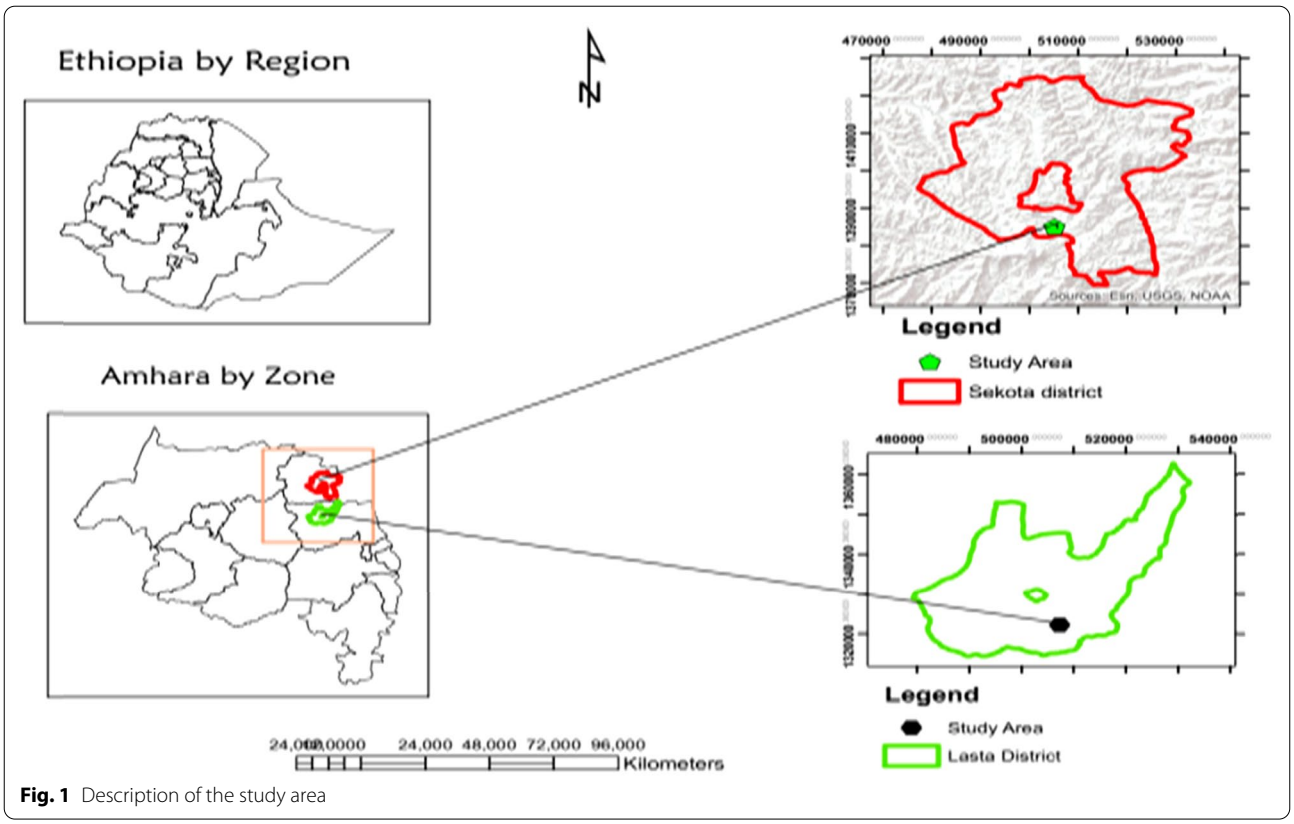

Fig. 1 Description of the study area

Fig. 2. Field performance of potato at Kechin abeba

Results and discussion

Pre planting soil property of the study sites

At Woleh, soil pH, EC and total nitrogen were numerically higher than at Kechin Abeba, but organic carbon and available phosphorus were low (Table 1). The sites had a textural class of clay loam and soil pH value of the surface soil at Woleh and Kechin Abeba were 7.3 and 7.6 respectively (Table 1). According to Landon (1991) soil pH rating is classified as neutral and slightly alkaline whereas, the electrical conductivity of the study sites were free from salt. Organic carbon content of the trial sites were very low and low at Woleh and Kechin Abeba respectively whereas, total nitrogen was at low category (Tadesse 1991). This might be the area had a long history on agriculture without replacing the complete removal of cover crop and burning crop residue as fuel which are the main cause for nutrient loses. According to Olsen et al. (1954), the available phosphorous was high in both sites.

A significant interaction (N*P) were observed for plant height and marketable yield in both years but total tuber yield was interacted in the year of 2015 at Lalibela, Kechin Abeba irrigation command area (Tables 2 and 3). Main effect of nitrogen was significantly affect all parameters in both years but, the main effect of phosphorous was affect only the marketable and total yield of potato in 2017 irrigation season. In the year 2015, the main effect of phosphorous was affected marketable, total yield and plant height of potato.

Whereas at Woleh irrigation command area except plant height significant interaction were observed on

the other stated parameters (Table 4). The main effects of nitrogen and phosphorous fertilization were significantly influences the marketable yield, unmarketable yield and total yield of potato but, plant height was not affected by the application of phosphorous.

Plant height

Plant height was significantly affected by application of nitrogen and phosphorous fertilizers in Kechin Abeba (Tables 2 and 3). The highest plant height 72.58 cm was recorded from the application of 138 N kg ha^{-1} in the 2017 irrigation season whereas the highest plant height 54.85 and 51.90 cm was a record from by application of 92 N and 69 P_2O_5 kg ha^{-1} in the year of 2015. In all parameters, the 2017 cropping season exceeded the 2015 production year (Fig. 2). This is probably due to variation in irrigation water availability in the year between 2015 and 2017 (Table 5). There was a shortage of irrigation water in the year of 2015 irrigation season in the command area. The increasing rate of nitrogen and phosphorus fertilizer in the irrigation season of 2015 increases plant height by 14.81 and 4.97 cm whereas, in the irrigation season of 2017 application of nitrogen alone at a rate of 138 kg ha^{-1} increases plant height by 16.14 over the control treatment. The current study is inline with Zelalem et al. (2009) who reported that nitrogen and phosphorus at a rate of 207 and 60 kg ha^{-1} increases plant height by 24 cm and 10.5 cm respectively. Similarly, Israel et al. (2012), Alemayehu et al. (2015) and Fayera (2017) and have found that increasing the application of nitrogen and phosphorus significantly increased plant height of potato.

In Woleh the main effect of nitrogen fertilization was significantly influenced the plant height of potato but, their interaction exhibited a non-significant effect (Table 4). The highest plant height (49.82 cm) was obtained from applied fertilizer rates of 138 N kg ha^{-1} at Woleh while the lowest plant height (43.15) was obtained

Table 1 Soil sample result before planting

Sites	pH	EC	OC %	TN %	Avai.P ppm	Particle size distribution			
						Sand %	Silt %	Clay %	Textural class
Woleh	7.6	0.13	0.43	0.04	15.45	32.66	33.65	33.69	Clay loam
Kechin Abeba	7.3	0.12	0.55	0.02	18.04	30	30	40	Clay loam

EC electrical conductivity, *OC* organic carbon, *TN* total nitrogen, *Avai.P* available phosphorous, *ppm* parts per million

Table 2 ANOVA for the effect of N and P fertilizers on the plant height (cm), marketable yield, unmarketable yield and total yield (t ha^{-1}) of potato 2017 at Kechin Abeba

Source of variation	DF	Mean square values			
		Plant height (cm)	Marketable yield	Unmarketable yield	Total yield
N	3	638.44*	418.95*	5.60*	451.10*
P	3	5.56^{ns}	67.91*	0.27^{ns}	65.04*
N*P	9	45.77*	69.57*	0.82^{ns}	71.06^{ns}
Error	32	15.56	4.50	1.20	4.72
Total	47				

ns non-significant, * and ** significant and highly significant respectively

Table 3 ANOVA for the effect of N and P fertilizers on the plant height (cm), marketable yield, unmarketable yield and total yield (t ha^{-1}) of potato 2015

Source of variation	DF	Mean square values			
		Plant height	Marketable yield	Unmarketable yield	Total yield
N	3	518.94*	101.55*	4.14*	138.09*
P	3	92.15*	11.94*	1.11^{ns}	12.04*
NXP	9	44.91*	12.75*	0.89^{ns}	12.57*
Error	32	19.38	2.50	0.57	3.81
Total	47				

ns non-significant, * and ** significant and highly significant respectively

Table 4 Combined ANOVA for the effect of N and P fertilizers on the plant height (cm), marketable yield, unmarketable yield and total yield (t ha^{-1}) of potato at Woleh

Source of variation	DF	Mean square values			
		Plant height	Marketable yield	Unmarketable yield	Total yield
N	3	193.65*	159.35*	5.79*	233.68*
P	3	35.86^{ns}	17.02*	2.76*	30.54*
NXP	9	51.45^{ns}	221.53*	1.33*	9.44*
Error	57	34.54	3.32	0.35	3.44
Total	72				

ns non-significant, * and ** significant and highly significant respectively

Table 5 Effect of nitrogen and phosphorus on plant height (cm) at Kechin Abeba and Woleh sites

	Plant height (at Kechin Abeba)		Plant height (at Woleh)		
	2015	2017	2015	2017	Combined
N level kg ha^{-1}					
0	40.05	55.86	46.63	39.66	43.15
46	46.67	61.94	48.89	41.95	45.42
92	54.85	68.14	51.13	43.65	47.39
138	52.35	72.58	53.13	46.50	49.82
LSD $_{(0.05)}$	3.24*	3.28*	3.18*	5.69*	3.39*
P_2O_5 level kg ha^{-1}					
0	46.93	65.34	49.28	42.07	45.67
23	49.45	63.75	50.36	40.44	45.40
46	45.65	64.66	50.64	45.59	48.11
69	51.90	64.81	49.50	43.66	46.58
LSD$_{(0.05)}$	3.24*	3.28 ^{ns}	ns	ns	ns
CV	9.08	6.10	7.43	15.95	12.65

ns non-significant, * and ** significant and highly significant respectively

from the control treatment (Table 5). The application of phosphorous fertilizer didn't show a significant effect on the plant height during the study (Table 5). This might be the fact that nitrogen plays a most important role in various physiological processes. The current study inlined with Banjare et al. (2016) who reported that increasing the rate of nitrogen up to 375 kg ha^{-1} increases the plant height of potato.

Marketable yield

Both the main and interaction effect of nitrogen and phosphorus fertilizer application were affect the marketable yield of potato significantly at Kechin Abeba and Woleh. The increasing rate of nitrogen and phosphorus significantly increases the marketable yield of potato in both sites. The highest marketable yield (45.55 and 19.57 t ha^{-1}) were recorded from 138 kg ha^{-1} nitrogen is combined with phosphorus at a rate of 23 kg ha^{-1} in 2017 2015 respectively (Table 6) whereas the lowest marketable yield (17.71 t ha^{-1}) and (8.1 t ha^{-1}) was recorded from zero nitrogen and 69 P_2O_5 in 2017 and 2015 respectively. Increasing rate of phosphorous alone decreases potato tuber yield by 28 & 14% 2015 and 2017 irrigation seasons. The marketable yield of potato gained in the year of 2017 irrigation season was exceeded the irrigation season of 2015. This is probably due to irrigation water availability in the year between 2015 and 2017. There was irrigation water scarcity in the year of 2015 in the irrigation command area. But, the superior treatment in the year of 2015 and 2017 irrigation season were showed similar trends.

In case of Woleh the highest marketable yield (17. 12 t ha^{-1}) was recorded from 138 kg ha^{-1} nitrogen combined with phosphorus at a rate of 46 kg ha^{-1} whereas the lowest marketable yield (8.16 t ha^{-1}) was recorded from the control treatment (0, 0 NP kg ha^{-1}) (Table 7). There was tuber yield reduction in Woleh and Kechin Abeba in 2015 by half as compared to tuber yield gained in 2017 Kechin Abeba. This was attributed to the fact that water is the most important limiting factor for potato production and it's possible to increase production levels by well-scheduled irrigation programs throughout the growing season (Liu et al. 2006). Similarly, (Gebresillassie 2012) observed that 4.09 t ha^{-1} 64% and 39% tuber yield reduction were recorded from the application of 25%, and 50% (deficit) of the total crop water requirement at all stages, respectively. Therefore, this yield reduction observed in Woleh and Kechin Abeba in 2015 was most probably due to irrigation water scarcity because, water is essential for the germination of seeds, growth of plant roots, and nutrition, photosynthesis, transpiration, to maintain the turgidity of cell walls and multiplication of soil organisms. However, the marketable yield was increased by 24.95 t ha^{-1} and 8.96 t ha^{-1} over control treatment at Kechin Abeba and Woleh respectively. This might be due to the fact that nitrogen supply plays a major role in growth and development of plants as well as yield because it is an essential constituent of protein and chlorophyll (Sandhu

Table 6 Effect of nitrogen and phosphorus on tuber marketable yield of potato t ha^{-1} at Kechin Abeba 2015 and 2017

	2015				2017			
	P_2O_5 kg ha^{-1}				P_2O_5 kg ha^{-1}			
N kg ha^{-1}	0	23	46	69	0	23	46	69
0	11.26	11.66	11.87	8.10	20.60	21.89	23.66	17.71
46	16.76	17.91	17.56	12.96	23.82	28.53	28.93	27.24
92	15.01	15.68	19.23	14.29	26.54	19.67	29.23	33.52
138	14.95	19.57	17.02	16.77	14.95	45.55	37.70	29.35
$LSD_{(0.05)}$	2.63*				3.53**			
CV	10.52				7.58			

* and ** significant and highly significant respectively

Table 7 Combined analysis of potato marketable yield t ha^{-1} at Woleh

	P_2O_5 kg ha^{-1}			
N kg ha^{-1}	0	23	46	69
0	8.16	11.00	10.77	11.76
46	13.66	13.49	14.28	13.61
92	12.04	15.23	14.58	14.15
138	15.99	16.99	17.12	16.76
$LSD_{(0.05)}$	3.15*			
CV	14.55			

et al. 2014) and phosphorus performs functions in plants, such as a structural element forming part of the macromolecular structures such as nucleic acids (RNA and DNA) and in the phospholipids of cell membranes (Marschner 2002). The current study was in agreement with previous study Zelalem et al. (2009), Israel et al. (2012), Gebremariam (2014), and Alemayehu et al. (2015), who reported that increasing rate of nitrogen increases marketable tuber yield significantly. Similarly, Desalegn et al. (2016) observed an increment of potato marketable yield with increasing of NP fertilizer in southern Ethiopia.

Unmarketable and total yield of potato

Both the main and interaction effect of nitrogen and phosphorus fertilizer application were affect the unmarketable and total yield of potato significantly at Woleh but, at Kechin Abeba only the application of nitrogen was affect significantly the unmarketable and total yield of potato (Tables 2, 3, and 5). The highest unmarketable yield (2.88 and 4.06 t ha^{-1}) was recorded at a rate of 92 kg ha^{-1} N in the year 2015 and 2017 respectively at Kechin Abeba (Table 8). Phosphorus fertilizer application did not affect the total yield of potato in the year of 2017 but, in the year of 2015, the highest yield was recorded at an application rate of 23 kg ha^{-1} P_2O_5. The highest total yield (25.39 and 38.82 t ha^{-1}) was recorded at a rate of 138 kg ha^{-1} N. In the case of Woleh the highest total yield (19.39 t ha^{-1} and 16.84 t ha^{-1}) was obtained from the application of 138 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 and the lowest (11.80 and 14.21 t ha^{-1}) were obtained from the unfertilized treatment. Similarly highest unmarketable yield was obtained from the application of N 138 and P_2O_5 46 kg ha^{-1} (Table 8).

Partial budget analysis

Application of nitrogen and phosphorous at a rate of 138 kg ha^{-1} and 23 kg ha^{-1} respectively gave the highest marketable yield (15.29 t ha^{-1}) and net benefit (164,597 Ethiopian Birr) at Woleh irrigation command area (Table 9). The MRR (1606.90%) was gained from the treatment of 138 N and 23 P_2O_5 kg ha^{-1}, this implies that for each Birr that invested in the new technology, the producer can receive to recover the one Birr invested plus an additional return of 16.06 Ethiopian birr.

Conclusion and recommendation

Application of nitrogen and phosphorus fertilizer had a significant effect on the tuber yield of potato. This study confirmed that nitrogen and phosphorus fertilizers and their interaction had a sound and promising impact on marketable and total tuber yield of potato. The obtained result showed that by applying nitrogen and phosphorous at rate of 138 kg N ha^{-1} and 23 kg ha^{-1} P_2O_5 had gave a yield advantage of 108.21% and 121.12%over the control treatment at Woleh and Kechin Abeba irrigation command area. Therefore, application of 138 kg N and 23 kg P_2O_5 ha^{-1} is the appropriate rate for optimum productivity of Potato for Woleh and Kechin Abeba irrigation command areas and the same agro-ecologies.

Table 8 Effect of nitrogen and phosphorus on unmarketable and total yield (t ha^{-1}) of potato at Woleh

	Kechin Abeba				Woleh					
	Unmarketable yield		Total yield		Unmarketable yield			Total yield		
	2015	2017	2015	2017	2015	2017	Combined	2015	2017	Combined
N level kg ha^{-1}										
0	1.45	2.87	12.18	23.88	1.32	1.65	1.48	12.76	10.84	11.80
46	2.14	2.47	18.44	30.29	2.41	1.96	2.18	18.83	12.45	15.64
92	2.88	4.06	20.94	31.68	2.34	1.89	2.11	18.04	14.66	16.35
138	2.31	3.36	25.39	38.82	3.19	2.17	2.68	20.60	18.18	19.39
$LSD_{(0.05)}$	0.58*	0.91*	1.01*	1.80*	0.41*	0.39*	0.34*	1.11*	1.41*	1.07*
P_2O_5 level kg/ha										
0	2.37	3.14	16.87	34.53	19.45	1.71	1.83	15.52	12.90	14.21
23	2.40	3.23	18.61	30.85	20.83	1.91	2.00	18.99	13.51	16.25
46	1.75	3.38	17.23	29.31	33.88	1.83	2.61	18.69	15.00	16.84
69	2.26	3.02	16.24	29.98	18.38	2.22	2.03	17.03	14.71	15.87
$LSD_{(0.05)}$	0.58*	Ns	1.01*	2.54*	4.13*	0.39*	0.34*	1.11*	1.41*	1.07*
CV	34.51	34.35	11.33	6.96	20.82	24.87	28.08	7.41	12.10	11.75

Table 9 partial budget analysis at Woleh

N	P_2O_5	Unadjusted yield (t ha^{-1})	Adjusted (t ha^{-1})	Gross benefit (Ethiopian Birr)	Costs that varies (Ethiopian Birr)	Net benefit (Ethiopian Birr)	MRR%
0	0	9.86	8.874	97,614	0	97,614	
0	23	11	9.9	108,900	580	108,320	1845.86
46	0	11.66	10.49	115,434	1008	114,426	1426.64
0	46	10.77	9.69	106,623	1160	105,463	D
46	23	13.49	12.14	133,551	1588	131,963	3023.62
0	69	11.76	10.58	116,424	1740	114,684	D
92	0	12.04	10.83	119,196	2016	117,180	D
46	46	14.28	12.85	141,372	2168	139,204	1248.45
92	23	15.23	13.70	150,777	2596	148,181	2097.43
46	69	13.61	12.24	134,739	2748	131,991	D
138	0	15.99	14.39	158,301	3024	155,277	1657.94
92	46	14.58	13.12	144,342	3176	141,166	D
138	23	16.99	15.29	168,201	3604	164,597	1606.90
92	69	14.15	12.73	140,085	3756	136,329	D
138	46	17.12	15.40	169,488	4184	165,304	121.90
138	69	16.76	15.08	165,924	4764	161,160	D

D dominated treatment

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Authors' contributions
WS and MM conceptualized this study, WS and TE collects necessary data, WS analyzed, interpreted the data, and wrote the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The data used to support the findings of this study can be accessed from the corresponding author upon request.

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The authors declare no competing interests.

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