Response of Potato (Solanum tu□erosumL.) to nitrogen and phosphorus at Sekota and Lasta districts of Eastern Amhara, Ethiopia

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Abstract

Production and productivity of potato in Ethiopia is far below the world average due to soil fertility depletion, pest and diseases. Nutrient depletion because of soil erosion is a serious problem in Ethiopian highlands including Wag-Lasta areas. Essential nutrients like, nitrogen and phosphorus are the most important influential element for the production of potatoes. However, 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 of eastern Amhara, Ethiopia with the objective of investigating the effects of nitrogen and phosphorus fertilizers for yield and yield component of potato under irrigation conditions. Four rates of nitrogen (0, 46, 92, and 138 kg N ha^{-1}) and phosphorus (0, 23, 46, and 69 Kg P_2O_5 ha^{-1}) were combined with factorial arrangement and laid out in a randomized complete block design with three replications. 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 the combined application of 138 N and 23 P_2O_5 in Lalibela and 17.12 & 16.99 t ha^{-1} were found from the application of 138 kg N ha^{-1} with 46 kg P_2O_5 ha^{-1} and 138 kg N ha^{-1} with 23 kg P_2O_5 ha^{-1} from Sekota district of Woleh irrigation command area respectively. Therefore, the application of 138 kg ha^{-1} N with 23 kg ha^{-1} P_2O_5 is the appropriate nutrient rates for optimum productivity of Potato at Lalibela (Kechin Abeba) and Sekota (Woleh) irrigation command areas and the similar agro-ecologies.

Key words: Marketable yield, Nitrogen, Phosphorous, unmarketable yield, Total yield

Introduction

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 depletion, lack of good quality seed, inadequate application of fertilizers, pests and disease, irregularity of water supply and traditional irrigation schemes and schedules LW¶V SURGXFWLYLW\ LV YHU\ O Haverkort et al., 2012 and Emana and Nigussie, 2011). In addition to this, continuous cropping without replacing the removed nutrients from crop biomass and another organic source is a major problem of nutrient depletion in Ethiopia (Haileslassie *et al.,* 2005).

Plants require essential nutrients for their optimum growth and development, among them N and P are the most important ones because they are required in large quantities. The deficiency of these nutrients is 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). Applications 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) nutrient the yield and yield components of potato was increased. Desalegn *et al.,* (2016) also, reported that increasing the rates of nitrogen and phosphorus can enhances 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 with a blanket recommendation to increase potato production. Site-specific fertilizer recommendations play a significant role in potato production. But, there was no appropriate fertilizer rate recommendation for potatoes 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.

Material and Methods

Description of the study area

The 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° D ¶ B ¶¶ °D Q G ¶ BD ¶¶ O D W L W X G H ¶¶ E D Q G DDE ¶¶ O R Q J L W X G H of 2120 and 2101 meter above sea level (m.a.s.l), respectively (Fig 1). The schemes (Woleh and Kechin Abeba) can irrigate an area of 137.25 ha 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 the areas. Due to this reason fertility status of the soil is very low (Table 1). Mixed agriculture is a common farming system in the study areas.

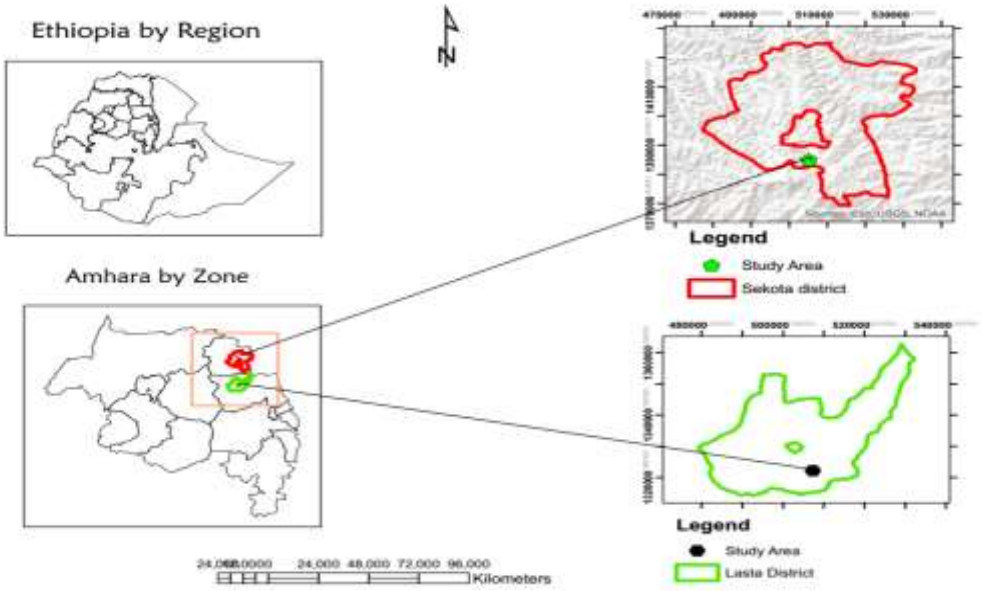

Figure 1. Map of the study area

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 3mx3m (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 variety was used for the study.

Soil physical and chemical properties Analysis

To determine the nutrient content of the soil before planting, composite soil samples were collected from 0-20 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 (1965). Soil pH was determined from the filtered suspension of 1:2.5 soil 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).

Data collection and analysis

Plant height (cm), marketable tuber yields (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.

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 variable cost.

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. According to Landon, (1991) soil pH rating is classified as neutral and slightly alkaline whereas, the electrical conductivity of the sites was free from salt (Landon 1991). Organic carbon content of the trial sites was very low and low at Woleh and Kechin Abeba respectively whereas, total nitrogen was at low category (Tadesse 1991). This might be due to the fact that the area had a long history of agriculture without replacing the complete removal of cover crop and burning crop residue as fuel which are the main cause for nutrient losses. According to Olsen (1954), the available phosphorous was high in both sites.

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	32.7	33.7	33.7	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 and ppm; parts per million

Interaction effect of N and P nutrients on tuber yield and yield components of potato

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

Whereas at Woleh irrigation command area except plant height significant interaction was observed on the other stated parameters (Table 4). The main effects of nitrogen and phosphorous fertilization were significantly influenced the marketable , unmarketable and total yield of potato but, phosphorous had no effect on the plant height. 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.

Table 2. ANOVA for the effect of N and P on the yield and yield parameters of potato (2015)

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
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				

*Where, ns: non-significant and *: significant.*

Table 3. ANOVA for the effect of N and P on the yield and yield parameters of potato 2017 at kechin Abeba

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield(t ha^{-1})	Total yield (t ha^{-1})
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
Error	32	15.56	4.50	1.20	4.72
Total	47				

*Where, ns: non-significant and *: significant.*

Table 4. Combined ANOVA for the effect of N and P on the yield and yield parameters of potato at Woleh

Source of variation	DF	Mean square values			
		Plant Height (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
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				

*Where, ns: non-significant and *: significant*

Plant height

Plant height was significantly affected by the application of nitrogen and phosphorous fertilizers in Kechin Abeba (Table 2 and 3). The highest plant height 72.58 cm was recorded from the application of 138 kg ha^{-1} N in the 2017 irrigation season whereas the highest plant heights 54.85 cm was recorded from application of 92 kg ha^{-1} N in the year of 2015. The increasing rate of nitrogen and phosphorus fertilizer in the irrigation season of 2015 increases plant height by 14.81 and 4.97cm 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 in this particular site was in line 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 10.5cm respectively. Similarly, Israel *et al.,* (2012), Alemayehu *et al.,* (2015) and Fayera, (2017) have found that increasing the application of nitrogen and phosphorus significantly increased the plant height of potatoes.

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

N level kg ha^{-1}	Plant height (cm) (at Kechin Abeba)		Plant height (cm) (at Woleh)		
	2015	2017	2015	2017	Combined over year at Woleh
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

*Where, ns: non-significant and *: significant*

In Woleh the main effect of nitrogen fertilization had significantly influenced plant height of potatoes but, their interaction exhibited a non-significant effect (table 4). The highest plant height (49.82cm) was obtained from applied fertilizer rates of 138 kg ha^{-1} N at Woleh while the lowest plant height (43.15) was obtained from the control treatment (Table 5). The a S S O L F D W L R Q R I S K R V S K R U Rsignificant effect on the plant height during the study (Table 5). The current study Woleh site was in line with Sanjana *et al.,*

(2014) 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 effects of nitrogen and phosphorus fertilizer application affected the marketable yield of potatoes 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 & 19.57 t ha^{-1}) were recorded from 138 kg ha^{-1} nitrogen combined with phosphorus at a rate of 23 kg ha^{-1} in 2017 and 2015 respectively (Table 6) whereas the lowest marketable yield (17.71 t ha^{-1}) and (8.1 t ha^{-1}) was recorded from treatment (0, 69 NP) in 2017 and 2015 respectively. The increasing rate of phosphorous alone decreases potato tuber yield by 28 and 14 % in 2015 and 2017 irrigation season. 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 2015 in the irrigation command area. But, the superior treatment in the year of 2015 and 2017 irrigation seasons were showed a similar trend.

In the 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 a Q G L W ¶ V S R V V L E O H W R L Q F U H D by well-scheduled irrigation programs throughout the growing season (Liu *et al.,* 2006). Similarly, (Demlie, 2012) observed that 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 and 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 because nitrogen supply plays a major role in the growth and development of plants as well as yield. This is because nitrogen is an essential constituent of protein and chlorophyll (Sandhu et al. 2014). Besides, phosphorus

performs plants functions such as a forming of the macromolecular structures such as nucleic acids (RNA and DNA) and in the phospholipids of cell membranes (Marschner 2002). The current study is in agreement with previous studies such as 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.

Table 6. Effect of N and P on marketable potato tuber yield at Kechin Abeba 2015 and 2017

	2015				2017			
	P_2O_5 t ha^{-1}				P_2O_5 t 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			

Where, ns: non-significant,: significant, **: highly significant, t; ton*

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

	P_2O_5 t 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			

*Where, ns: non-significant and *: significant, t; ton*

Unmarketable and total yield of potato

Both the main and interaction effect of nitrogen and phosphorus fertilizer application had affected the unmarketable and total yield of potato significantly at Woleh but, at Kechin Abeba only the application of nitrogen affected significantly the unmarketable and total yield of potato (Table 2, 3, and 8). The highest unmarketable yield (2.88 & 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 yields of 25.39 and 38.82 t ha^{-1} at Kechin Abeba was recorded at a rate of 138 kg ha^{-1} N in 2015 and 2017 respectively. In the case of Woleh the highest total yield (19.39 t ha^{-1} & 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 & 14.21 t ha^{-1}) were obtained from the unfertilized treatment in the years of 2015 and 2017 respectively. Similarly highest unmarketable yield was obtained from the application of N 138 and P_2O_5 46 kg ha^{-1} (Table 8).

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

	Kechin Abeba				Woleh					
N level kg ha^{-1}	Unmarketable yield		Total yield		Unmarketable yield			Total yield		
	2015	2017	2015	2017	2015	2017	Combined	2015	2017	Combined
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

*Where, ns: non-significant and *: significant*

Partial budget analysis

Application of nitrogen and phosphorous at a rate of 138 kg $ha^{í1}$ and 23 kg $ha^{í1}$ respectively gave the highest marketable yield (15.29 t ha^{-1}) and net benefit (164597 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 one 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.

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	97614	0	97614	
0	23	11	9.9	108900	580	108320	1845.86
46	0	11.66	10.49	115434	1008	114426	1426.64
0	46	10.77	9.69	106623	1160	105463	D
46	23	13.49	12.14	133551	1588	131963	3023.62
0	69	11.76	10.58	116424	1740	114684	D
92	0	12.04	10.83	119196	2016	117180	D
46	46	14.28	12.85	141372	2168	139204	1248.45
92	23	15.23	13.70	150777	2596	148181	2097.43
46	69	13.61	12.24	134739	2748	131991	D
138	0	15.99	14.39	158301	3024	155277	1657.94
92	46	14.58	13.12	144342	3176	141166	D
138	23	16.99	15.29	168201	3604	164597	1606.90
92	69	14.15	12.73	140085	3756	136329	D
138	46	17.12	15.40	169 488	4184	165304	121.90
138	69	16.76	15.08	165924	4764	161160	D

D stands for dominated treatment

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 result showed that by applying nitrogen and phosphorous at rates of 138 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 gave a yield advantage of 108.21% and 121.12% over the control treatment at Woleh and Kechin Abeba irrigation command area. Therefore, the application of 138 kg ha^{-1} N and 23 kg P_2O_5 ha^{-1} is the appropriate rate for optimum productivity of Potato for Woleh and Kechin Abeba under irrigation and the same agro-ecologies.

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