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Effects and economically feasible rates of nitrogen and phosphorus fertilizers on potato (*Solanum tuberosum* L.) production for rainy season

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Potato is very important food and cash crop in Ethiopia. However, a factor like poor soil fertility is a critical challenge of its productivity. Nitrogen (N) and phosphorus (P) are first and second essential macro-elements and are limiting nutrient in potato production. Therefore, a field experiment was conducted to assess response of N and P fertilizers and select economically feasible fertilizer rate for a rainy season. Four levels of N (0, 55, 110, 165 kgha^{-1}) and 4 levels of P (0, 45, 90, 135 kgha^{-1}) were combined in 4×4 factorial arrangement in randomized complete block design with 3 replications. Raising the application of NP fertilizer levels to 165 and 135 kgha^{-1} delayed days to flowering (9.48 and 4.46 days), while maturity extends 14 and 10.18 at Dabark and Dabat, respectively. Application of 110 to 90 and 165 to 45 kgha^{-1} NP increased marketable tuber number by 122 and 119%, respectively. Similarly, 165 to 90 and 165 to 45 kgha^{-1} NP raised marketable tuber yield by 141.8 and 127.5%. However, both 165 to 90 and 165 to 45 kgha^{-1} NP had MRR below acceptable level (<100%). In contrary, application of 110 to 90 kg ha^{-1} NP resulted in 136.6 and 125.4% marketable tuber yield increment and MRR of 1993.72% for Dabark and 1376.5% for Dabat location. Therefore, application of 110 to 90 kgha^{-1} NP was proven to have high MRR and can be used for the studied areas.

Key words: Marginal rate of return, *Solanum tuberosum*, marketable tuber yield, interaction effect, main effect.

INTRODUCTION

There have been several scientific advances in the field of agriculture and food security, yet there are still several challenges in many countries mainly sub-Saharan Africa developing countries including Ethiopia are not able to be food secured. The demand of food is likely to rise significantly as a result of population growth. To meet the ever increasing demand for food, roots and tuber crops including potato can play a major role in addressing this issue and feed millions of people. Especially, in Ethiopia root and tuber crops are part of the traditional food systems of the people. Hence, there is enormous possibility for millions of poor farmers to boost production and their livelihood using root and tuber crops which are strategic crops for the country's economy (Amsalu et al., 2008).

Potato (*Solanum tuberosum* L.) is the fourth most

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Table 1. Pre planting soil laboratory analysis result.

Parameter	Value at Dabat	Value at Dabark
pH	5.65	5.91
Total nitrogen (%)	0.239	0.192
Available phosphorus (ppm)	10.65	26.91
Organic matter (%)	5.57	4.47
EC (mS/cm)	0.14	0.17
Cation Exchange Capacity ($Cmol_c$/kg)	43.87	40.44

important crop and consumed all around the world and is one of the main favorite vegetable in Ethiopia. It is a very important food and cash crop in the country especially when the grains get depleted from the store. It is a very nutritious food which requires less land, grows quickly and easily even in harsh conditions. It has double cropping advantages and its utilization in different forms (Muthoni and Nyamongo, 2009). Ethiopia has favorable agro ecology and wide production area for potato. However, the national productivity is still very low (CSA, 2016) as compared to the potential of the crop. There are various factors that contribute to the low yields of potatoes. Poor soil fertility is one of the principal factors hampering potato production in Ethiopia (Gebremedhin et al., 2008; Adane et al., 2010).

It is obvious that growth, yield and quality of potato are greatly affected by its nutritional management. The potato has a shallow rooting system to exploit fully the nutrients and it is also heavy feeder. Among the nutrients, N and p are the first and the second essential macro elements and are the limiting nutrient in potato production thus has a great influence on crop growth, tuber yield and its quality (Trehan et al., 2008). N is a constituent of numerous organic molecules in plant such as proteins, nucleic acids and alkaloids, enzymes, chlorophyll-a, chlorophyll-b, etc. (Pushpalatha et al., 2017). Hence, a mature crop of potato yielding 25 to 30 t/ha tubers removes 120 to 140 kg N/ha. Also for potato production, phosphorus is another limiting nutrient and a healthy crop of potato removes about 25 to 30 kg P_2O_5 (Trehan et al., 2008). Moreover, P and N are susceptible to loses, principally through immobilization, volatilization, leaching and runoff under poor agronomic management (Hopkins et al., 2014; Rens et al., 2018). Hence, application of N and P fertilizers becomes indispensable to meet the needs of the crop.

To apply those macro nutrients there should be clear and economical feasible recommendation. However, there was no such recommendation around Dabat and Dabark districts of North Gondar Administrative Zone which is very potential for potato production. There was national blanker fertilizer recommendation but the soil and the agroecologist vary from area to area moreover the recommendation was done before a decade. Therefore, the present study was conducted to assess the response of potato to different rates of N and P fertilizers and to select economically feasible combination of fertilizer rate for rainy season potatoes production of the study areas.

MATERIALS AND METHODS

This study was conducted at Dabat and Dabark district of North Gondar Administrative Zone during 2016 to 2018 main cropping seasons. Belete (CIP-393371.58) potato variety obtained from Holeta Agricultural Research Center was used for this experiment. It is one of the potential potato cultivars for both districts in North Gondar zone of Ethiopia and it is the most NP efficient variety than others in all efficiency indices (Hailu et al., 2017; Solomon et al., 2019). Four levels of nitrogen: 0, 55, 110 and 165 kg and four levels of phosphorus: 0, 45, 90 and 135 kg/ha were combined in 4×4 factorial arrangements in randomized complete block design with three replications. All management practices were applied as per the general recommendations for potato (Gebremedhin et al., 2008).

The study area has a clay loom soil which was plowed 3 times using oxen. Prior to planting, representative soil samples were taken using an auger from the top 0 to 30 cm and combined into a composite sample. Working samples were analyzed in the laboratory using the standard procedure for each of the soil pH, organic carbon, total N, available phosphorus, and cation exchange capacity (CEC). The experimental field was divided into three blocks each containing 16 plots and a plot size of 9 m^2. Sprouted tubers in the diffused light store (DLS) were planted by hand in rows 75 cm apart and with 30 cm between plants within rows (Zelalem et al., 2009; Israel et al., 2012). Blocks were separated by 1.5 m. There were 4 rows/plot for each treatment. Data were collected from the middle 2 rows; the outermost rows and terminal plants were borders. The entire rate of phosphorus and half the rate of nitrogen was applied at the time of planting and the remaining half of nitrogen was applied 45 days after planting. Urea (46%N) and triple super phosphate, TSP (46% P_20_5) fertilizers were used as sources of N and P. Earthening up and weeding were each carried out 3 times by hand during the growing period (Table 1).

Data collection and analysis

Data collected on growth parameters such as days to 50% flowering and maturity, plant heights, number of stem per plant and yield parameters such as total tuber number, marketable and unmarketable tuber number, marketable, unmarketable and total tuber yields (t ha^{-1}) were checked for constant variance and normality and subjected to analysis of variance using SAS version 9.2 statistical software (SAS, 2008). Treatment means were compared using LSD value at 5% significant level.

Table 2. Days to flowering, maturity, plant height and number of stem as affected by the main effect (combined over year).

Treatment	Dabark (2016-2018)				Dabat (2016-2018)			
Nitrogen (kg ha^{-1})	**DTF**	**DTM**	**PHT**	**NST**	**DTF**	**DTM**	**PHT**	**NST**
0	60.37^{b}	115.02^{c}	56.07^{c}	4.49^{b}	60.06^{c}	118.8^{c}	51.62^{c}	3.86^{c}
55	61.39^{b}	120.66^{b}	59.32^{b}	5.65^{a}	62.9^{b}	122.15^{b}	58.85^{b}	4.19^{c}
110	63.08^{a}	122.97^{a}	64.4^{a}	5.5^{a}	62.38^{b}	123.2^{b}	64.67^{a}	5.12^{a}
165	63.6^{a}	125.2^{a}	63.4^{a}	5.88^{a}	64.15^{a}	125.16^{a}	64.1^{a}	4.7^{b}
Significance level	**	**	**	**	**	**	**	**
P_2O_5 (kg ha^{-1})								
0	59.56^{c}	119.64	55.29^{c}	5.14	61.05^{c}	120.32^{b}	54.27^{c}	4.06^{b}
45	62.35^{b}	120.04	62.62^{ab}	5.74	62.05^{b}	121.44^{b}	57.74^{b}	4.41^{b}
90	62.52^{b}	121.81	63.58^{a}	5.26	63.5^{a}	123.67^{a}	62.52^{a}	4.95^{a}
135	64.02^{a}	122.37	61.69^{b}	5.42	62.89^{ab}	123.89^{a}	64.73^{a}	4.45^{b}
Significance level	**	ns	**	Ns	**	**	**	**
CV (%)	3.2	5.37	5.11	21.71	1.88	2.25	9.82	15.76
LSD (5%)	1.14	3.74	1.79	0.67	0.67	1.59	3.39	0.4
Mean	62.11	120.9	60.8	5.39	62.37	122.33	59.81	4.47

DTF=Days to flowering, DEM=days to maturity, PHT=plant height (cm), NST=number of stem per plant, ^{ns}Non-significant, **Highly significant ($p<0.01$).

Partial budget analysis was employed for economic analysis of fertilizer application using a technique described by CIMMYT (1988). The marketable tuber yield data was adjusted by bringing down 10% to minimize plot management effect by the research or to reflect the actual farm level performance. To estimate the total costs, mean market prices of urea and DAP, cost of fertilizer transportation and labor for application of fertilizer were taken from market assessment at the time of planting and market price of potato tubers was taken after harvest.

RESULTS AND DISCUSSION

Days to 50% flowering and maturity

At Dabark site, the main effect of N and P was significantly influenced by the number of days to flowering and maturity than their interaction. As the level of nitrogen rose from 0 to 165 kg ha^{-1}, days to 50% flowering was late by 3 days (Table 2). Likewise, as the rate phosphorous increased from 0 to 135 kg ha^{-1} the days to 50% flowering was delayed by 4 day as compared to untreated potato plant. Only the main effect of nitrogen fertilizer rate showed a significant effect on the days to maturity and as the level of nitrogen increased from 0 to 165 kg ha^{-1} maturity was delayed by 10 days.

At Dabat, the main effects of nitrogen and phosphorus as well as their interaction effect were significantly influenced both days to flowering and days to maturity. The main effects revealed that as the level of N increased days to flowering and maturity extended. Similarly, as the rate of P increased up to 90 kg ha^{-1} the number of days to both traits increased but increasing the rate above this level did not create significant difference. On the other hand, the interaction effect revealed that an application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous delayed the number of days to flowering by about 20% followed by 165 kg ha^{-1} with 90 kg ha^{-1} phosphorous which delayed 13.2% as compared to unfertilized plant (Table 3). Similarly, days to maturity was prolonged by 9 days when 165 kg ha^{-1} nitrogen with 90 and 45 kg ha^{-1} phosphorous fertilizer were applied as compared to unfertilized plant.

This may be due to the application of nitrogen fertilizer which may result to a chance to increase the nitrogen uptake and this increase has a positive effect on chlorophyll concentration, encourage the vegetative growth, increased the amount of solar radiation intercepted, prolonged the canopy life of the plant, enabled the potato plant to maintain physiological activity for an extended period, thereby continuing photosynthesis. Therefore, a plant which received more nitrogen will mature later in the season than a crop that received less N because later growth is related to excessive haulm development while early tuber growth to less abundant haulm growth (Mulubrhan, 2004; Najm et al., 2010). On the other hand, application of higher rate of phosphorus may enhance the development of roots particularly lateral and fibrous rootlets which may support the active above ground vegetative growth in provision of water and like.

The observations of the current investigation was in

Table 3. The interaction effects of nitrogen and phosphorous on days to 50% flowering and days to maturity (Dabat site).

P_2O_5 (kg ha^{-1})	Days to 50% flowering				Days to maturity			
	Nitrogen (kg ha^{-1})				Nitrogen (kg ha^{-1})			
	0	55	110	165	0	55	110	165
0	56.48^{f}	62.38^{cd}	61.93^{d}	63.36^{bc}	117.13^{fg}	118.96^{ef}	121.03^{cde}	124.15^{abc}
45	59.33^{e}	62.83^{bcd}	62.73^{bcd}	63.3^{bcd}	120.86^{de}	122.98^{bcd}	124.53^{ab}	126.33^{a}
90	62^{d}	62.73^{bcd}	62.86^{bcd}	63.96^{b}	122.03^{bcde}	122.23^{bcd}	125.11^{ab}	126.18^{a}
135	62.43^{cd}	63.65^{bc}	61.95^{d}	65.96^{a}	112.26^{g}	124.41^{ab}	122.11^{bcde}	123.98^{abcd}

LSD=1.35 and 3.18, for days to 50% flowering and days to maturity, respectively.

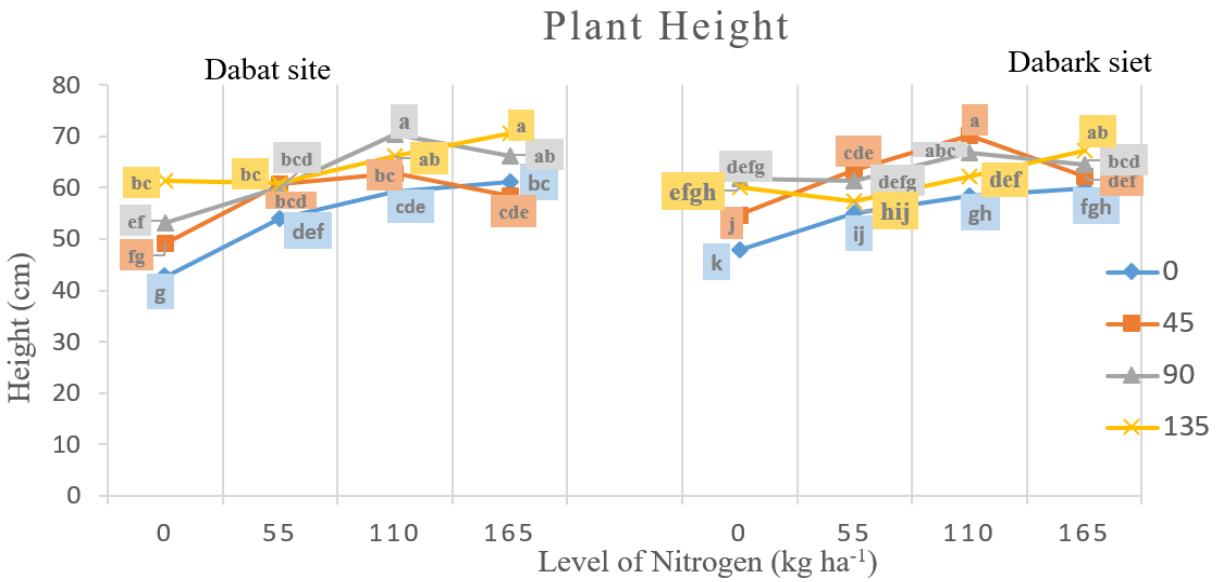

Figure 1. The interaction effect of N and P on plant height at Dabat and Dabark, LSD = 6.78 and 3.59, respectively.

conformity with the previous findings of Zelalem et al. (2009) who reported a significant 4 and 9 days delayed flowering and maturity due to increase of the rate of 0 to 207 kg N/ha, respectively. The same author also mentioned, increasing phosphorous application from 0 to 60 kg/ha prolonged the days to flowering by about 2 days. The study partially agrees with Firew et al. (2016) who reported that the main effect of nitrogen and phosphorous had significant effects on days to maturity rather than their interaction and the increased application rate of nitrogen delayed days to maturity up to 32% but increased application of phosphorus reduced days to maturity. On the other hand, Niguse (2016) reported that the application of phosphorous fertilizer significantly influenced days to flowering and maturity where the application at the rate of 89.7 kg ha^{-1} is delayed by 3 and 7 days, respectively. Also Girma et al. (2017) reported the significant effect of nitrogen on days to flowering and maturity which delayed 7 and 12 days, respectively due to increasing of the rate of 0 to 138 kg N ha^{-1}.

Plant height

The current study revealed that nitrogen, phosphorus and their interaction significantly influenced the height of potato at both locations. The main effects of nitrogen at Dabark and Dabat showed that as the rate increased 0 to 110 kg ha^{-1} plant height increased by 8 and 13 cm at respective locations but there was no apparent significant increment above this rate (Table 2). Similarly, phosphorous increased the height by 15% at Dabark and 19% at Dabat as the level increased from 0 to 90 and 135 kg ha^{-1}, respectively. On the other hand, the interaction effect of both nutrients showed that the height of the plant increased as the level of nitrogen increased along with phosphorous (Figure 1). The maximum plant height (70.63 cm) at Dabat site was recorded from the application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous as closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1}. These rates resulted in 65.2 and 64.9% height difference, respectively as compared to untreated

Table 4. Marketable and total number of tuber, marketable and total yield of potato as affected by the main effect (N and P).

Treatment	Dabat (2016-2018)				Dabark (2016-2018)			
Nitrogen (kg ha^{-1})	**NMT**	**TTN**	**YMT**	**TTY**	**NMT**	**TTN**	**YMT**	**TTY**
0	4.69^{c}	13.05^{a}	17.47^{c}	22.78^{b}	5^{c}	13.6^{ab}	17.86^{b}	23.09^{b}
55	5.55^{b}	13.47^{a}	19.48^{b}	24.4^{b}	6.01^{b}	14.08^{a}	18.87^{b}	23^{b}
110	6.87^{a}	11.9^{b}	24.03^{a}	28.92^{a}	7.15^{a}	12.44^{b}	24.05^{a}	27.81^{a}
165	6.81^{a}	11.77^{b}	23.99^{a}	28.99^{a}	7.16^{a}	13.33^{ab}	24.37^{a}	28.75^{a}
Significance level	**	**	**	**	**	*	**	**
Phosphorus (kg ha^{-1})								
0	5.7b^{c}	14.02^{a}	18.25^{c}	24.23^{c}	5.81^{b}	15.19^{a}	17.82^{c}	23.31^{c}
45	5.19^{c}	13.23^{a}	19.2^{c}	24.61^{c}	6.01^{b}	13.63^{b}	21.58^{b}	25.71^{b}
90	7.27^{a}	11.51^{b}	22.28^{b}	19.55^{a}	6.9^{a}	12.94^{b}	22.8^{ab}	27.14^{a}
135	5.77^{b}	11.42^{b}	25.24^{a}	26.7^{b}	6.59^{a}	11.9^{b}	22.95^{a}	26.49^{ab}
Significance level	**	**	**	**	**	**	**	**
CV (%)	15.94	11.19	13.81	11.1	14.91	15.03	10.89	8.9
LSD (5%)	0.55	0.81	1.69	1.68	0.54	1.15	1.33	1.31
Mean	5.98	12.55	21.24	26.27	6.33	13.36	21.29	25.66

NMT=Number of marketable tuber, TTN=total tuber number, YMT=yield of marketable tuber, TTY=total tuber yield, ^{ns}nonsignificant, *Significant at 5%, **Significant at 1%.

plant. While at Dabark, the maximum plant height (70.16 cm) was recorded from the application of 110 kg ha^{-1} nitrogen along with 45 kg ha^{-1} which resulted to 46.7% height increment.

This might be due to the obvious positive effect of nitrogen in enhancing vegetative growth which seemed to be more superior due to the presence of phosphorus that may stimulate the growth and development of roots for efficient water and other important nutrient uptake. In line with this idea Brady and Weil (2002) reported that phosphorous is required in large quantities in young cells, like root and shoot tips, where high metabolism, cell division and development is rapid.

The current finding is in agreement with Firew et al. (2016) who had reported significant effect of nitrogen, phosphorus and their interaction that resulted in 79.3 cm height difference due to the combined application of 168 kg N ha^{-1} with 138 P_2O_5 kg ha^{-1} as compared to untreated/plot. Similarly, Zelalem et al. (2009) reported 24 and 10.5 cm height difference due to the application of 207 kg N/ha and 60 kg P/ha, respectively as compared to the untreated. Also, Israel et al. (2012) found that increasing application of nitrogen and phosphorus significantly increased plant height.

Stem numbers

The main effect of nitrogen affected the number of main stems per plant rather than phosphorous or their interaction at Dabark. The unfertilized potato had lesser number of stems and significantly differed from fertilized plants. However, there was no significant difference among fertilized plants. On the other hand, at Dabat the main effect of both N and P significantly influenced the number of stems but not their interaction (Table 2). Application at lower rate mean that nitrogen up to 55 kg ha^{-1} or phosphorous up to 45 kg ha^{-1} did not create a significant effect on the number of stems but raising the rate to 110 and 90 kg ha^{-1}, respectively had significant influence on stem numbers. The maximum number of stem (5.88 and 5.12) was recorded from application of 165 and 110 kg ha^{-1} N at Dabark and Dabat, respectively. The current finding is in agreement with Jamaati-e-Somarin et al. (2009) who confirmed the effect of N on the number of stems and they stated that an application of N levels up to 110 kg/ha N_2 increased the number of stems; but further increases in N above this level did not affect the numbers of the stem.

Number of marketable tubers

The number of marketable per plant was significantly influenced by the fertilizer rate of nitrogen and phosphorous as well as their interaction. In the present study, as a main effect raising the rate of N up to 110 kg ha^{-1} increased the number of marketable tubers but did not have significant effect after this rate at both locations whereas raising the level of phosphorous up to 135 kg ha^{-1} provided the maximum number of marketable tubers at both locations (Table 4). The interaction effect of

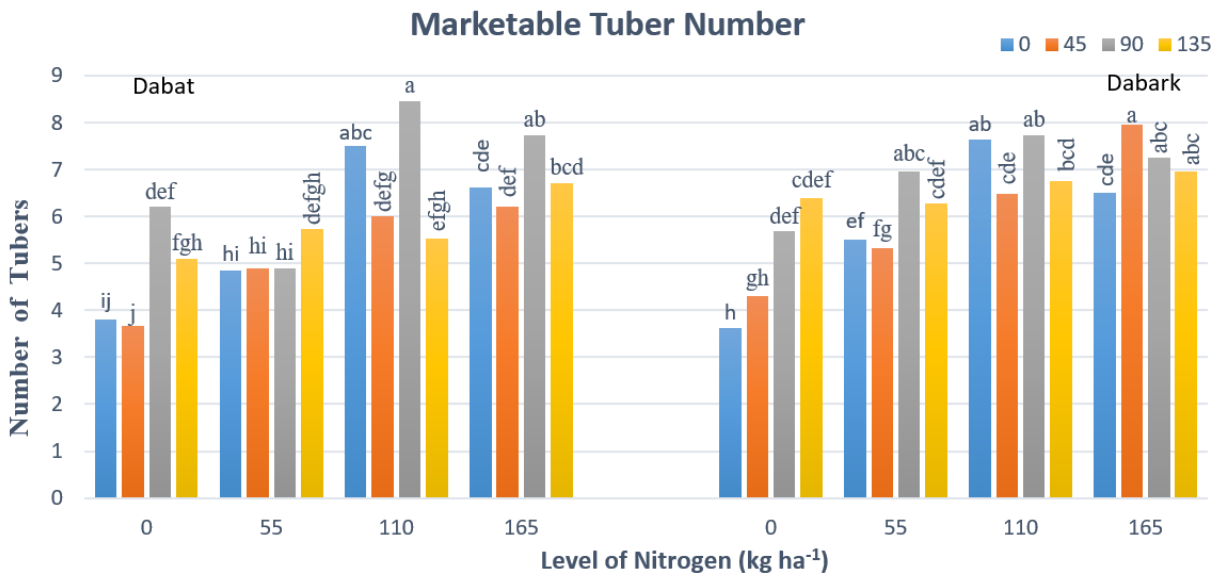

Figure 2. The interaction effect of nitrogen and phosphorous on marketable tuber yield at Dabat and Dabark (LSD =1.1 and 1.09 respectively).

nitrogen and phosphorous at Dabat site showed that the number of marketable tubers were increased by 122% as the rate raised up from 0 to 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous (Figure 2).

At Dabark site, the maximum number of marketable tubers (7.95) were recorded from the application of 165 kg ha^{-1} nitrogen along with 45 kg ha^{-1} phosphorous closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous which were not statistically different. These rates resulted in 119 and 113% increment of marketable tuber number as compared to unfertilized plants.

This may be due to decrease in the number of the small size tubers and increased weight of individual tubers because of accumulation of more photo assimilate in the tuber that resulted from more vegetative growth and good root performance. It may also be linked to solar radiation intercepted and more photos assimilate production initiated from application of nitrogen and phosphorous. In this connection, Trehan et al. *(*2008) reported that the potato plants with sufficient nitrogen were characterized by vigorous growth, increased leaf area index and large tuber size as well as numbers.

The result of the current study is in conformity with Israel et al. (2012) who reported 20.49 to 56.36% marketable number of tuber increment was due to the application of N and P. Similarly, Firew et al. (2016) reported a significant influence of N and P on the number of marketable tuber and raising the rate of N from 0 to 56 kg ha^{-1} resulted in 8.4% increment while increasing phosphorus rate from 0 to 138 Kg ha $^{-1}$ increased by 67%. Rens et al. (2018) reported that as the rate of nitrogen fertilizer increase, the number of larger tuber sized potato increased. Also, Niguse (2016) reported that the application of phosphorous fertilizer affects the number of tuber per plant.

Total tuber number

The rate and type of fertilizer significantly influenced the number of total tuber per plant. The main effect of nitrogen and phosphorous level revealed that above 55 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1}, respectively decreased the number of total tuber significantly at both locations (Table 4). Similarly, the interaction effects of the two nutrients showed that the total number of tubers was decreased as the combined level of nitrogen and phosphorous increased as compared to untreated and lesser fertilizer rate (Figure 3). For both location, the maximum number of total tuber was found from untreated plant and the minimum of total tuber number were from the application of 135 kg ha^{-1} phosphorous with 0 nitrogen. Here, as the rate of fertilizer increase, the number of marketable tuber increases but the number of total tuber decreases. It was clear that untreated plants gave 17.31 total number of tuber from which 3.81 were marketable tuber at Dabat, whereas 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous gave 12.31 total number of tubers from which 8.46 were marketable tuber.

Similarly, at Dabark, 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous gave 6.95 marketable tubers among a total of 12.48 tubers while the untreated gave 17.21 total tubers among which 3.63 were marketable. Probably, this might be due to less nutrient availability that causes lesser vegetative growth, lesser photo assimilate and less starch to be stored that resulted in smaller tubers. This

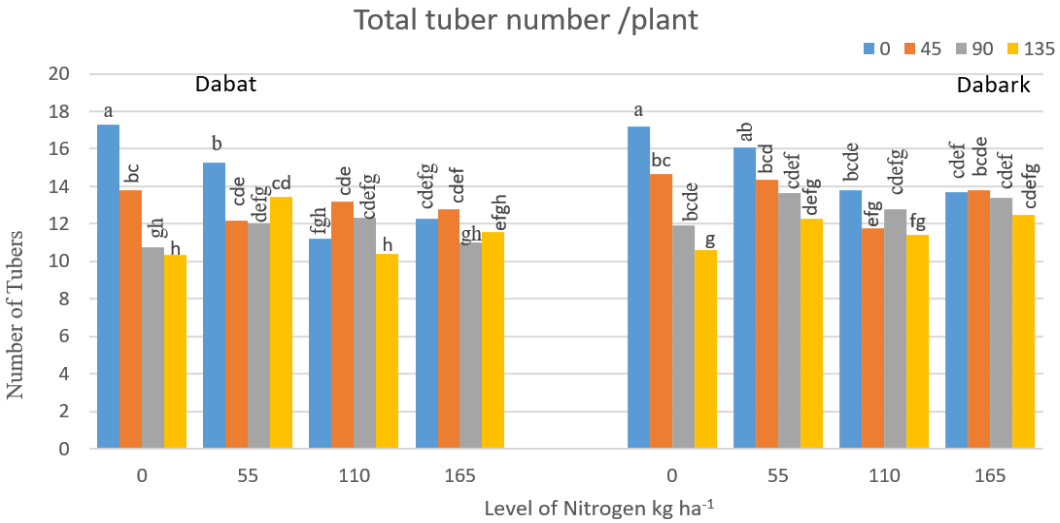

Figure 3. The interaction effect of nitrogen and phosphorous on total tuber number at Dabat and Dabark (LSD= 1.62 and 2.31, respectively).

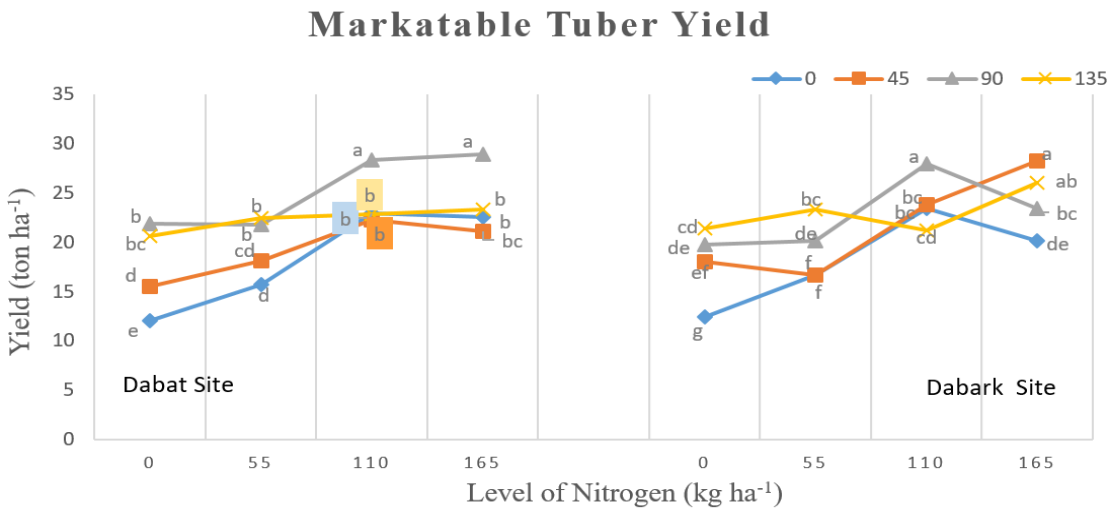

Figure 4. The interaction effect of nitrogen and phosphorous on marketable tuber yield at Dabat and Dabark, LSD = 3.38 and 2.67, respectively.

result is in line with the finding of Mutubuki et al. (2015) who reported that as the rate of nitrogen increase, the total number of tubers was decreased significantly. Also, Firew et al. (2016) reported a significant influence of the interaction of nitrogen and phosphorous that revealed 25.9% decline in total number of total tubers as the rate of fertilizer increased from 0 to 168 kg N ha^{-1} with 138 kg ha^{-1} P_2O_5.

Marketable tuber yield

Nitrogen, phosphorous and their interaction affected marketable tuber yield of potato significantly. The result showed that increasing the rate of nitrogen and phosphorous increased the marketable tuber yield. At Dabat, an application of 0 to 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous results in 141.8% marketable tuber yield increment, closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous that resulted in 136.6% increment (Figure 4). However, the application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous resulted in 24.6% lesser yield as compared to the 165 kg ha^{-1} nitrogen and 90 kg ha^{-1} phosphorous.

At Dabark, the maximum marketable tuber yield was recorded from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous. Each of these fertilizer combinations resulted in 127.5 and 125.4% increment of marketable tuber yield as compared to untreated plant.

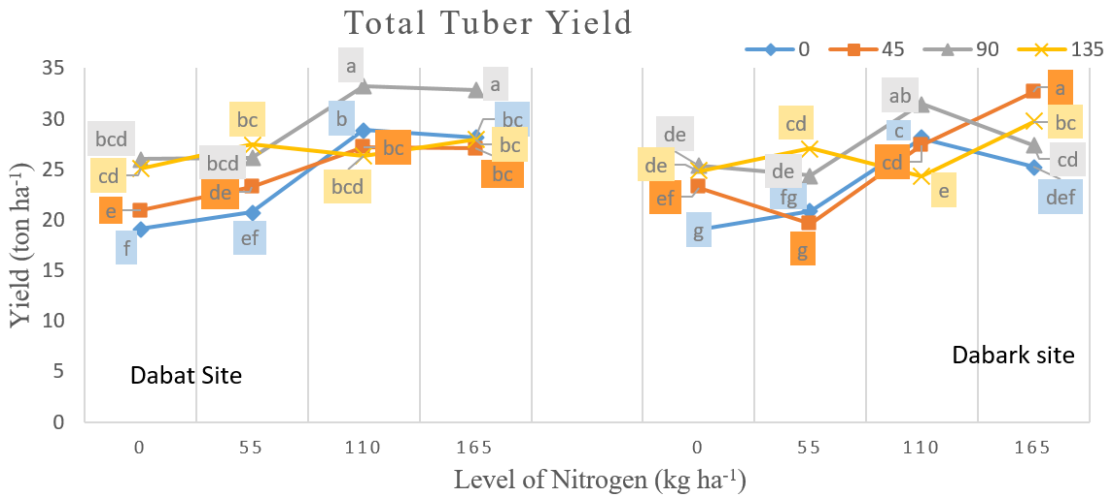

Figure 5. The interaction effect of nitrogen and phosphorous on total tuber yield at Dabat and Dabark, LSD= 3.36 and 2.63, respectively.

Both of these rates were not statistically significant to each other. But the application of 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous decreased the marketable tuber yield by 20.05% as compared to 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous application.

This may be associated with vigorous vegetative growth and the positive interaction and complementary effect between nitrogen and phosphorus in affecting and increasing the marketable tuber yield of potato in the study areas. This is supported by FAO (2000) that reported without phosphorus application, nitrogen efficiency declined thereby indicating interaction between these nutrients.

This result is in agreement with the findings of Desalegn et al. (2016) who had reported a significant interaction effect of nitrogen and phosphorous which resulted in 4 times marketable tuber yield increment as the rate increase from 0 to 140 kg ha^{-1} nitrogen and 90 kg ha^{-1} phosphorous. Similarly, Qadri et al. (2015) and Hailu et al. (2017) reported that as the rate of nitrogen and phosphorous application had increased the marketable tuber yield was increased significantly. Niguse (2016) reported that the application P significantly affects the marketable tuber yield and resulted in 20% increment as the rate increased from 0 to 89.7 kg/ha while the total tuber yield increased by 19.2%.

Total tuber yield

Total tuber yield was significantly affected by the main and interaction effect of N and P fertilizers. As the main effect reveals increasing level of nitrogen up to 55 kg/ha, did not significantly affect it in both locations (Table 4). Likewise, increasing the rate of phosphorous up to 45 kg/ha did not have significant effect at Dabat but not at Dabark. However, raising the level of both nutrients above these rates affected total tuber yield significantly. On the other hand, the interaction effect revealed the maximum total tuber yield (33.2 t/ha) was found from the application of 110 kg ha^{-1} nitrogen along with 90 kg ha^{-1} phosphorous at Dabat while the maximum total yield (32.66 t/ha) of Dabark was from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous (Figure 5). Due to the application of 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous the total yield increased by 73.8% at Dabat followed by 71.7% from the application of 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous. Similarly, at Dabark, 71.4% yield increment was recorded from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous followed by 65.1% increment that resulted from the application of 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous.

The decline in yield, as the level of fertilizer increases, indicates the optimum rate of nitrogen and phosphorus for better tuber yield was already attained and it was not agronomically necessary and beneficial to increase the rate of the fertilizer further. The present study trend showed that, as the rate of fertilizer application increased the marketable tuber number and marketable tuber yield increased which raised the total tuber yield. This is in support with Gitari et al. (2018) that found the strong and positive correlation of tuber yield with N and P levels.

The result is in agreement with the previous study of Qadri et al. (2015) who reported that the marketable tuber yield and total tuber yield increased as the amount and accessibility of nitrogen and phosphorous nutrient increased. Also Israel et al. (2012) and Desalegn et al. (2016) reported significant effects of nitrogen and phosphorous fertilizer to increase the total tuber yield of potato. Pushpalatha et al. (2017) reported that nitrogen had a significant effect on potato tuber yield and

Table 5. Partial budget analysis fertilizer rate for the Dabark site combined over the year (2016-2018).

Treatment combination		Marketable yield (kg/ha)	Adjusted yield (kg/ha)	Gross field benefit	Fertilizer cost	Labor for fertilizer application	Fertilizer transport cost	Total variable cost	Net benefit	Marginal net benefit	Marginal variable cost	Marginal Rate of Return (Eth. Birr)
N_2	P_2O_5											
0	0	12400	11160	55800	0	0	0	0	55800	-	-	-
0	45	17960	16164	80820	1150	180	60	1390	79430	23630	1390	1700
55	0	16650	14985	74925	1647	225	140	2012	72913[d]	-	-	-
55	45	16650	14985	74925	2248	300	120	2668	72257[d]	-	-	-
0	90	19750	17775	88875	2300	360	120	2780	86095	6665	1390	479.49
110	0	23350	21015	105075	2745	420	150	3315	101760	15665	535	2928.04
55	90	20080	18072	90360	2849	420	150	3419	86941[d]	-	-	-
110	45	23730	21357	106785	3346	540	180	4066	102719	959	751	127.69
55	135	23300	20970	104850	3470	480	165	4115	100735[d]	-	-	-
0	135	21350	19215	96075	3450	540	180	4170	91905[d]	-	-	-
165	0	20080	18072	90360	3979	660	220	4859	85501[d]	-	-	-
110	90	27950	25155	125775	4093	660	220	4973	120802	18083	907	1993.72
165	45	28220	25398	126990	4670	780	250	5700	121290	488	727	67.12
110	135	21180	19062	95310	4814	780	250	5844	89466[d]	-	-	-
165	90	23410	21069	105345	5413	840	300	6553	98792[d]	-	-	-
165	135	26000	23400	117000	6123	960	330	7413	109587[d]	-	-	-

Price of Urea=1098 birr qt^{-1}, DAP=1150 birr qt^{-1}, field price of potato=500 qt^{-1}, d=dominated.

application of 125 kg/ha nitrogen results 96.3% yield increment.

Partial budget analysis

The partial budget analysis revealed that fertilizer application of N and P gave the highest gross profit, net return and marginal rate of return compared to the unfertilized plot. From the tested and un-dominated nutrient treatments, the highest net profit per hectare 121290 and 123587 Ethiopia birr were recorded from the application of 165 kg ha^{-1} N with 45 kg ha^{-1} P at Dabark and while 165 kg ha^{-1} N with 90 kg ha^{-1} P at Dabat, respectively (Tables 5 and 6). The lowest net benefit of 55800 and 53820 birr were recorded from unfertilized plot at Dabark and Dabat sites, respectively.

On the other hand, the calculations of marginal rate of return (MRR) realized that among undominated treatment combination, the MRR% from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous at Dabark and 55 kg ha^{-1} nitrogen and 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous at Dabat were below the minimum acceptable MRR (100%); that is, 67.12, 44.7 and 76.6%, respectively. The maximum MRR for Dabat was 15087.5% found from the application of only 90 kg ha^{-1} phosphorous while for Dabark 2928.04% was found from the application of 110 kg ha^{-1} nitrogen only. The application of 110 to 90 kg ha^{-1} nitrogen and phosphorous combinations gave MRR of 1993.72% for Dabark and 1376.5% for Dabat location. Application beyond this rate did not give MRR greater than 100% because of increased cost. Hence, application of 110 to 90 kg ha^{-1} nitrogen and phosphorous combination had the highest net benefit and acceptable marginal rate of return for both locations.

Conclusion

The present study of two years at two locations results showed that application of nitrogen and phosphorous had a significant effect on potato, these nutrients had positive and significant effect on growth, yield and yield components except

Table 6. Partial budget analysis fertilizer rate for the Dabat site combined over the year (2016-2018).

Treatment combination		Marketable yield (kg/ha)	Adjusted yield (kg/ha)	Gross field benefit	Fertilizer cost	Labor for fertilizer application	Fertilizer transport cost	Total variable cost	Net benefit	Marginal net benefit	Marginal variable cost	Marginal rate of return (Eth. Birr)
N_2	P_2O_5											
0	0	11960	10764	53820	0	0	0	0	53820	-	-	-
0	45	15450	13905	69525	1150	180	60	1390	68135	14315	1390	1029.9
55	0	15650	14085	70425	1647	225	140	2012	68413	278	622	44.7
55	45	18100	16290	81450	2248	300	120	2668	78782	10369	656	1580.6
0	90	21880	19692	98460	2300	360	120	2780	95680	16898	112	15087.5
110	0	22860	20574	102870	2745	420	150	3315	99555	3875	535	724.3
55	90	21730	19557	97785	2849	420	150	3419	94366d	-	-	-
110	45	22180	19962	99810	3346	540	180	4066	95744d	-	-	-
55	135	22460	20214	101070	3470	480	165	4115	96955d	-	-	-
0	135	20580	18522	92610	3450	540	180	4170	88440d	-	-	-
165	0	22550	20295	101475	3979	660	220	4859	96616d	-	-	-
110	90	28300	25470	127350	4093	660	220	4973	122377	22822	1658	1376.5
165	45	21050	18945	94725	4670	780	250	5700	89025d	-	-	-
110	135	22780	20502	102510	4814	780	250	5844	96666d	-	-	-
165	90	28920	26028	130140	5413	840	300	6553	123587	1210	1580	76.6
165	135	23310	20979	104895	6123	960	330	7413	97482d	-	-	-

Price of UREA=1098 birr qt^{-1}, DAP=1150 birr qt^{-1}, field price of potato=500 qt^{-1}, d=dominated.

days to flowering and maturity which were delayed up to 9.48 and 9.2 days, respectively. However, application of high amount of N in line with P like from 110 to 90 and 165 to 45 kg/ha N and P increased the number of marketable tuber by 122 and 119% at Dabat and Dabark, respectively. Similarly, application of 165 to 90 and 165 to 45 kg/ha nitrogen and phosphorous raised the marketable tuber yield by 141.8 and 127.5%. On the other hand, total tuber yield increased by 74.1 and 72.7% from the application of 165 to 90 and 165 to 45 kg/ha nitrogen and phosphorous as compared to unfertilized plots. The effect of N and P was evidenced by partial budget analysis which revealed high marginal rate of returns. Even though, 165 to 45 and 165 to 90 kg ha^{-1} nitrogen and phosphorous were high yielder, their MRR was below the acceptable level. On the contrary, 110 to 90 kg ha^{-1} nitrogen and phosphorous combinations gave economically viable MRR. Also, this rate had high marketable number of tubers and yield. Therefore, it can be concluded that the application of 110 to 90 kg ha^{-1} nitrogen and phosphorous and can be used by farmers and other stakeholders for the studied areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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