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Phosphorous use efficiency of widely grown potato (*Solanum tuberosum L.*) varieties in Ethiopia

Momina Aragaw[1,a,*], Tesfaye Abebe[2,b], Tadele Amare[3,c], Walleign Worku[4,d]

[1]*Debre Tabor University, Department of Horticulture, Ethiopia*
[2]*Holetta Agricultural Research Center, Potato Breeder, Ethiopia*
[3]*Adet Agricultural research Center, Senior soil researcher, Ethiopia*
[4]*Hawassa University, College of Agriculture, Ethiopia*
[*]*Corresponding author*

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ABSTRACT

This proposal was initiated to assess the response of potato varieties (Dagim, Belete, Gudenie, Jalenie, Zengena, and Ater Ababa) to phosphorus application and use efficiency under screen house with plastic pots. There were seven phosphorous levels (150% recommended (3.9 g P pot^{-}), 125% recommended (3.3 g P pot^{-}), recommended (2.6 g P pot^{-}), 75% of the recommended (2.0 g P pot^{-}), 50% of the recommended (1.3 g P pot^{-}), 25% of the recommended (0.7 g P pot^{-}) and the control) per variety. The experiment was conducted in completely randomized design (CRD) with three replications with a total of 42 treatments at Adet Agricultural research center, Ethiopia. Most parameters studied significantly changed with varieties and P-rates. Belete variety and 2 g P pot^{-1} showed the highest values in soil available phosphorous (52.6 mg P kg-1 and 49.53 mg P kg-1, respectively,) and Belete variety and 3.9 g P pot^{1}showed highest values in plant phosphorous concentration (3.48 mg g^{-1} and 3.98 mg g^{-1}, respectively). The highest phosphorous uptake (PAE) (14.81 mg plant^{-1}) was recorded in Belete variety. This variety could be considered as responsive cultivar. The highest phosphorous acquisition efficiency (PAE) (92.35 kg kg^{-1}) was recorded in Belete variety, and phosphorous use efficiency (33.63 and 37.58 mg g^{-1}) was recorded in Dagim and Ater Ababa varieties, respectively. Dagim variety can be used when external phosphorous applications become limited. Evaluation of the existing varieties of potato for their phosphorous use and uptake efficiency could potentially increase the future potato yield without excess P application.
Key words:

[a] kirkime@gmail.com https://orcid.org/0000-0002-8040-5117
[b] fayedesta60@gmail.com https://orcid.org/0000-0002-9510-6929
[c] tadele17b@yahoo.com https://orcid.org/0000-0002-6498-2184
[d] walelignworku@yahoo.co.uk https://orcid.org/0000-0003-0367-306X

Introduction

Globally, potato (*Solanum tuberosum L.*) is the third most consumed crop behind rice and wheat. Potato yield in sub-Saharan Africa is below 10 t/ha while the attainable yield potential with good crop management and quality seed tubers of improved varieties is well above 30 t/ha (Anton et al., 2012). Most potato growers in Ethiopia use traditional crop management practices for potato production. This contradicts with potato's high demand for soil nutrients. Potato responds very well especially to phosphorus (P) fertilization, and is not tolerant to low P soil (Dechassa et al., 2003).

Moreover, the soil fertility is declining due to continuous cropping, abandoning of fallowing, reduced crop rotation, removal of nutrients together with the harvested crops, reduced use of animal manure and crop residue due to their use as fuel and erosion coupled with low inherent fertility (Kılıç and Korkmaz, 2012). Low level of soil organic matter combined with little land coverage resulted in many production problems like low yield of potato (Israel et al. 2016; Eleroğlu and Korkmaz, 2016).

In 2019/20, 91.03% of the potato farms in Ethiopia were fertilized with NPS (16.99%), urea (6.67%) and NPS and Urea together (23.64%), mixed fertilizer (11.82%), mixed and Urea together (13.55%) while the rest were fertilized with organic fertilizer only (18.36%) or did not receive fertilizer at all (8.97%) (CSA, 2020). An increase in the price of fertilizer and awareness problem hinder fertilizer adoption in the country in one hand and use at the recommended rate on the other. Moreover, climate change challenges nutrient use efficiency of plants as it has a direct effect on plant growth and yield (Mcdonald et al., 2014).

Phosphorus is one of the essential elements for plant growth and major drivers of world crop production (Korkmaz et al. 2021). Despite low available soil P, plants have evolved various physiological and biochemical systems for adaptation to P-deficiency stress, particularly in indigenous species (Korkmaz et al., 2009). Efficiency of phosphorus utilization is dependent on genetic variability within the crop (Daoui et al., 2014; Lee, 2013). Use of P efficient cultivars in agricultural industry could greatly reduce the consumption of P resource and upgrade crop production (Lee, 2013). The requirements of high fertilizer rates, increment in area coverage and environmental concerns makes improving PUE a relatively high priority in its production (Hopkins, 2013). Different studies reported that potato varieties differ in fertilizer use efficiency (Voss et al., 2003; Lee, 2013).

P is the most limited nutrient in the soil after nitrogen. P may not be available to the plants because of soil fixation to satisfy the soil demand of P first (Korkmaz et al., 2009). Potato has high P requirement for optimum growth due to their inability to acquire P effectively from the soil; thus P deficient soils will result in yield losses (Dechassa et al., 2003). This may be due to a direct effect of P supply on biomass partitioning between shoots and roots and physiological functions (Lambers et al., 2006). P deficiency causes reduction in plant growth i. e. reduction in shoot and root growth that contributes to poor foliage development (Colomb et al., 1995) to absorb photosynthetically active radiation (Plenet et al., 2000). Besides the size and vigor of the root system, that can affect the P uptake efficiency as indicated by Taiz et al. (2015).

Improved potato varieties that have been recently released in Ethiopia may differ in nutrient use efficiency, and could have different optima of balanced macro-nutrient requirements for maximum yield and good quality seed tubers (Shunka et al., 2016). The PUE associated with P uptake has been identified for several species, but little work has been done on potato (Barker and Pilbeam, 2020).

The research support in terms of provision of improved agronomic practices for potato is weak (Burton et al., 2008). There is also lack of adequate scientific data on the response of improved potato varieties to P application rates with regard to yield and quality. Evaluation of the available improved varieties of potato for their P-use efficiency could help to potentially increase the future potato yield without excess P application. Variety specific P recommendation findings are also important for the future breeding works. Moreover, such information might help to address the existing different economic landscape of farming communities instead of developing one fit for all technologies for potato growers of varied economic landscape. Therefore, the objective of this research was to assess the response of widely grown potato varieties to mineral phosphorus application on yield, yield components and nutrient use efficiency and fill information in this area on released potato varieties in Ethiopia.

Materials and Methods

Description of the Study Area

This trial was conducted at Adet Agricultural Research Center (AARC) under screen house. The Research Center is located in west Gojjam zone of Amhara Regional State, North West Ethiopia. It is located at a longitude of 37^0 28' 38''E and latitude of 11^0 16' 16''N and at an altitude of 2240 meters above sea level. The mean annual rainfall, maximum and minimum temperatures were 1250 mm, 34°C and 24°C, respectively (North Western Meteorological station, 2018).

Experimental Materials, Planting and Management Practices

Widely grown potato varieties (mini tubers) in the NW Amhara (Dagim, Belete, Gudenie, Jalenie, Zengena and Ater Ababa) were used in this experiment. These varieties were planted on sandy loam soil having a pH of 7.1 and available phosphorous of 11.78 ppm in a plastic pot (30 cm top diameter X 20 cm depth X 16 cm bottom diameter) filled with 18 kg air-dried soil collected from 30 cm. The critical soil phosphorous concentration on Nitosol soil for potato is 15 ppm (Girma et al., 2018). There were seven phosphorous levels per variety i.e. 150% recommended (3.9 g P pot-1), 125% recommended (3.3 g P pot-1), recommended (2.6 g P pot-1), 75% of the recommended (2.0 g P pot-1), 50% of the recommended (1.3 g P pot-1), 25% of the recommended (0.7 g P pot-1) and without phosphorous. The experiment was conducted in completely randomized design (CRD) with three replications with a total of 42 treatments. All recommended agronomic practices were carried out as per recommendation. The bulk soil was amended with recommended N (8g Urea pot^{-1}) and 1/3 of the Urea was used at planting, 1/3 at two weeks after emergence and the remaining 1/3 at start of flowering. Each pot was irrigated to deliver 400 ml water every week to reach field capacity and avoid moisture stress on growing plants.

Data Collected and Analysis

Specific Leaf Weight (SLW) was calculated by the formula (Lee, 2013):

$$SLW=\frac{\text{Leaf Dry Mass (mg)}}{\text{Leaf Area (cm2)}}$$

Relative biomass (RB) was calculated as follows (Lee, 2013):

$$RB=\frac{DM_t}{DM_{ck}}$$

Where DM_t is the dry weight of tissue in a given treatment and DM_{ck} is the mean of dry weight at zero P applied.

P uptake was calculated by the following formula (Akhtar *et al.,* 2008)

$$\text{P uptake/plant} = \text{P concentration X Dry matter}$$

Where P uptake is in mg/plant, P concentration is in mg g-1 and dry matter is in g/plant

Plant P concentration can be done in the laboratory after the digestion with H_2SO_4 (O'Dell, 1993).

The calculated P uptake can be taken to calculate Phosphorus use efficiency as follows (Elloitt and White, 1994):

$$PUE=\frac{\text{Shoot dry matter (g/plant)}}{\text{P (mg/plant)}}$$

P acquisition efficiency (PAE) can be calculated as stated by Parentoni and Júnior (2008):

$$PAE=\frac{Pt(kg)}{Ps\ (kg)}$$

Where Pt is P in the plant (kg) per Ps is kg of soil available P (kg).

All data collected were checked for ANOVA Assumptions and subjected to analysis of variance using SAS Version 10.1 statistical software (SAS, 2008). Means that differed significantly were separated using the LSD (5%) procedure. Simple linear correlations between parameters were computed.

Results

Days Taken to Physiological Maturity

Highly significant (P<0.01) genotypic and P-rate variability was observed. The longest (120.86) and shortest (116.0) days taken to physiological maturity were recorded in Belete and Ater Ababa varieties, respectively. The longest days taken to physiological maturity were recorded from the control (125 days) and the shortest was from the highest P-rate. The interaction of varieties and P-rates was also significantly (P<0.01) affected days to physiological maturity. The maximum days to physiological maturity was recorded in Belete variety with 3.9 g P pot-1 phosphorous application (127 days) (Table 1).

Leaf Area, Leaf Dry Mass and Specific Leaf Weight

Leaf area, leaf dry mass and specific leaf weight were highly significantly (P<0.01) affected among genotypes of potato and phosphorous rates. But, their interaction was non-significant. The maximum leaf area and leaf dry mass was recorded in Belete variety (23.2 cm^{-2} and 105 mg, respectively) (Table 2).

For phosphorous rates, the maximum leaf area and leaf dry mass were recorded in 2.6 g P pot-1 of phosphorous (23.5 cm^{-2} and 102.0 mg, respectively). Leaf area and leaf dry masses increased up to 2.6 g P pot-1 of phosphorous rates then declined afterwards. The maximum specific leaf weight was recorded in Jalenie variety (5.2 mg cm^{-2}). For phosphorous rates, the maximum specific leaf weight was recorded in 2.6 g P pot-1 of phosphorous (4.4 mg cm^{-2}). Changes in specific leaf weight had not shown a constant pattern with the different P-rates. Specific leaf weight increment/decrement had not had a constant pattern (Table 2).

Dry Shoot, Dry Root, Total Dry Masses and Relative Biomass

Total dry, dry shoot and root weights were highly significantly (P<0.01) affected by varieties. Dry shoot and root weights, and relative weights of shoots and roots were also significantly (P<0.05) affected by phosphorous rates. Total dry mass was not significantly affected by phosphorous rates. The interaction effect of shoot, root and total dry masses, and relative biomasses was non-significantly affected. The highest total dry weight was recorded in Jalenie variety (314.7 g) and 2.6 g P pot-1 P (306.4 g). The highest shoot dry weight was recorded in Belete variety (207.8 g) and 2.6 g P pot-1 P (225.3 g). The highest root dry weight was recorded in Jalenie variety (103.2 g) and 2.6 g P pot-1 P (108.3 g). There was a significant difference (P<0.05) in relative biomass of shoots in genotypes and P-rates, but not in the interaction. The highest relative biomass of shoots was recorded in the control (1). The highest was recorded in Ater Ababa and Dagim varieties (0.92) and in 0.7 g P pot-1 P (0.97). Dagim variety which is efficient has highest relative shoot and root biomass followed by Ater Ababa variety having high relative root biomass (Table 3). The highest shoot weights (212. 2 g), relative shoot (0.92), root weight (103. 2 g), relative root (0.92) and total dry biomasses (314.7g) were recorded in Jalenie , Gudenie and Dagim, Jalenie , Zengena and Ater Ababa and Jalenie varieties, respectively.

Table1. The mean interaction effect of variety with P-rate on days taken to physiological maturity

Variety	P (g P pot-1)	DM
Dagim	0	113[kl]
Dagim	0.7	117[i]
Dagim	1.3	119[hg]
Dagim	2	120[fg]
Dagim	2.6	122[de]
Dagim	3.3	122.33[d]
Dagim	3.9	127[a]
Belete	0	115[j]
Belete	0.7	119[gh]
Belete	1.3	120[fg]
Belete	2	120.33[f]
Belete	2.6	122[de]
Belete	3.3	123[cd]
Belete	3.9	127[a]
Gudene	0	101[n]
Gudene	0.7	117[i]
Gudene	1.3	118[hi]
Gudene	2	119[gh]
Gudene	2.6	120[fg]
Gudene	3.3	120.67[f]
Gudene	3.9	124[bc]
Jalene	0	113.33[k]
Jalene	0.7	118.33[h]
Jalene	1.3	119[gh]
Jalene	2	120[fg]
Jalene	2.6	121[ef]
Jalene	3.3	122[de]
Jalene	3.9	125[b]
Zengena	0	112[l]
Zengena	0.7	118[hi]
Zengena	1.3	120[fg]
Zengena	2	120[fg]
Zengena	2.6	121[ef]
Zengena	3.3	123[cd]
Zengena	3.9	125[b]
Ater Ababa	0	109[m]
Ater Ababa	0.7	113[kl]
Ater Ababa	1.3	115[j]
Ater Ababa	2	117[i]
Ater Ababa	2.6	117[i]
Ater Ababa	3.3	118[hi]
Ater Ababa	3.9	122[de]
Mean		118.93
LSD		1.09
CV (%)		5.6

DM = days taken to physiological maturity. Means followed by different letters per column differ significantly.

Table 2. Days taken to physiological maturity, leaf area, leaf dry mass and specific leaf weight of different varieties and rates of phosphorous

Treatments	DM	LA (cm^2)	LDM (mg)	SLW (mg/ cm^2)
Variety				
Dagim	119.76^b	21.7^c	85.3^c	3.8^d
Belete	120.86^a	23.2^a	105^a	3.7^e
Gudenie	118.43^c	22.7^b	89.9^b	3.8^d
Jalenie	119.71^b	19.5^e	84.2^c	5.2^a
Zengena	119.86^b	20.3^d	89.7^b	4.4^b
Ater Ababa	116.0^d	19.7^e	82.2^d	4.3^c
Mean	118.86	21.2	89.1	4.2
LSD (5%)	0.414	0.3	1.97	0.07
P-rate (g P pot-1)				
0	125.00^a	18.9^f	72.7	3.9^e
0.7	121.53^b	19.9^e	81.1	4.0^d
1.3	120.24^c	21.4^d	88.9	4.2^{bc}
2	119.33d	22.6^b	98.9	4.1^c
2.6	119.15^d	23.5^a	102.0	4.4^a
3.3	116.88^e	22.1^c	93.2	4.1^c
3.9	110.50^f	19.9^e	86.5	4.3^{ab}
Mean	118.86	21.2	89.1	4.2
LSD (5%)	0.447	0.36	2.13	0.09
Var*P-rate	**	Ns	Ns	Ns

Where by Var: variety, P-rate: Phosphorous rates, DM: Days taken to physiological maturity, LA: leaf area, LDM: Leaf dry mass and SLW: Specific leaf weight. Means followed by different letters per column differ significantly.

Table 3. Shoot, root and total dry masses, relative biomasses, marketable tuber number and total marketable yield of different varieties and rates of phosphorous

Treatments	SDW (g)	RBs	RDW (g)	RBr	DM(g)	MTN/pot	TMYld (g)/pot
Variety							
Dagim	192.7^c	0.92^a	92.8^{cd}	0.92^a	285.48^d	8.8^{ab}	123.9^{ab}
Belete	207.8^{ab}	0.91ab	91^d	0.88^{bc}	298.76^b	7.7^{bc}	167.5^a
Gudenie	199.9^{bc}	0.92^a	94.1^{cd}	0.85^c	294.1^{bc}	6.0^c	118.5^b
Jalenie	212.4^a	0.89^{ab}	103.2^a	0.91^{ab}	315.67^a	8.4^{abc}	112.3^b
Zengena	199.3^{bc}	0.91^{ab}	98.8^{ab}	0.90^{ab}	298.14^{bc}	6.3^{bc}	109.9^b
Ater Ababa	215.6^a	0.88b	96.7^{bc}	0.92^a	312.33^a	11.1^a	53.5^{cd}
Mean	204.6	0.9	96.1	0.90	300.75	8.1	109.6
LSD (5%)	10.2	0.04	4.6	0.03	13.18	2.76	44.9
P-rate (g P pot-1)							
0	205.8^{bc}	1.0^a	86.1^e	0.88^{cd}	267.72^e	4.5^d	56.4^e
0.7	191.0^{de}	0.96^b	90.3^{de}	0.95^b	281.33^{de}	5.2^d	82.8^{de}
1.3	199.2^{cd}	0.92^{bc}	93.7^{cd}	0.91^c	292.83^{cd}	6.4^{cd}	115.2^{bcd}
2	215.2^{ab}	0.88^d	98.3^{bc}	0.84^e	313.5^b	10.8^{ab}	162.7^b
2.6	225.3^a	0.79^e	108.3^a	0.82^e	333.61^a	11.9^a	217.9^a
3.3	214.2^b	086^d	100.2^b	0.85^{de}	314.44^b	9.1^{abc}	147.4^{bc}
3.9	181.6^e	0.90^{cd}	95.9^{bc}	1.0^a	301.78^{bc}	8.2^{bc}	101.8^{cde}
Mean	204.6	0.90	96.1	0.9	300.75	8.1	126.3
LSD (5%)	10.98	0.04	4.99	0.03	14. 25	2.98	48.5
Var*P-rate	ns	ns	Ns	ns	ns	Ns	ns

Where by Var: Variety, Prate: Phosphorous rates, SDW: Shoot dry weight, RBs: Relative biomass of shoots, RDW: Root dry weight, RBr: Relative biomass of roots, DM: Total dry weight, MTN/pot: Marketable tuber number/pot and TMYld: Total marketable yield/pot. SDW, RDW, DM and TMRKTYLD are in grams. All measurements were per pot. Means followed by different letters per column differ significantly.

For phosphorous rates, the highest dry shoot (225.39 g P pot-1), relative shoot (0.96), dry root (108.3 g), relative root (1) and total dry biomasses (306.4 g) were recorded in 2.6 g P pot-1, 0.7 g P pot-1, 2.6 g P pot-1, 3.9 g P pot-1 and 2.6 g P pot-1, respectively (Table 3).

Total Number of Marketable Tubers and Marketable Yield

Both total number of marketable tubers and marketable tuber yield were highly significantly ($P<0.01$) affected by varieties and P-rates, but not the interaction. The highest total number of marketable tubers was recorded in Ater Ababa variety (11.1 per pot) and 11.9 per pot in 2.6 g P pot-1 phosphorous. The highest marketable tuber yield was recorded in Belete (167.5 g) followed by Dagim variety (123.9 g) and in 2.6 g P pot-1 phosphorous (217.9 g) (Table 3).

Plant Phosphorous Concentration and Available Phosphorous in The Soil

There was a significant difference ($P<0.05$) in plant phosphorous and available phosphorous in the soil between varieties and P-rates, but the interaction was non-significant. The highest plant phosphorous concentration (3.48 mg g-1) and available soil phosphorous (52.6 mg kg^{-1}) was recorded in Belete variety. The lowest plant and soil phosphorous concentration was recorded in Ater Ababa and Dagim varieties. The highest plant phosphorous concentration (3.98 mg g-1) was recorded from 3.9 g P pot^{-1} and available soil phosphorous (49.53 g kg-1) from 2 g phosphorous/pot (Table 4).

P-Uptake, Use and Acquisition Efficiency

There was a highly significant (P<0.01) difference between different P-rates and varieties in PUE and P-uptake, but not significant in the interaction. The highest PUE (37.58 mg g-1) and P-uptake were recorded by Ater Ababa (14.81 mg/plant) followed by Dagim (33.63 mg/plant) and Belete varieties, respectively. The highest PUE (30.2 mg g-1) and P-uptake (14.51 mg/plant) were recorded from control treatment and 2 g phosphorous/pot, respectively (Table5). The highest PAE was recorded in Belete variety (92.35 kg kg^{-1}) and 3.9 g P pot-1 (87.88 kg kg^{-1}) (Table4).

Discussions

Birtukan (2016) reported phosphorous can hasten physiological maturity of potato. Highly significant interaction effects of varieties and P-rates on days taken to physiological maturity as reported by Wacker-Fester et al. (2019) and Sandaña (2016) was recorded.

Table 4. Phosphorous in plants and available phosphorous in the soil after harvesting of different varieties and Prates

Treatments	Pplant (mg g-1)	Psoil (mg kg-1)	PAE (kg kg-1)
Variety			
Dagim	2.74[de]	29.53[b]	92.35[a]
Belete	3.48[a]	52.6[a]	66.45[c]
Gudenie	3.04[bc]	47.74[a]	63.68[c]
Jalenie	3.23[b]	51.65[a]	62.63[c]
Zengena	2.96[cd]	42.92[a]	62.72[c]
Ater Ababa	2.58[e]	32.76[b]	78.67[b]
Mean	3.01	42.87	71.09
LSD (5%)	0.51	10.97	7.29
P-rate (g P pot-1)			
0	2.22[d]	40.54[ab]	56.4[g]
0.7	2.07[d]	37.28[b]	60.73[f]
1.3	2.62[c]	46.67[ab]	63.01[e]
2	3.10[b]	49.53[a]	70.15[d]
2.6	3.22[b]	39.54[ab]	76.15[c]
3.3	3.82[a]	39.9[ab]	82.89[b]
3.9	3.98[a]	46.64[ab]	87.88[a]
Mean	3.01	42.87	71.09
LSD (5%)	0.25	10.97	0.01
Var*P-rate	Ns	Ns	Ns

Where Var: Variety, Pplant: total phosphorous in the plant, Psoil: available phosphorous in the soil, and PAE: Phosphorous acquisition efficiency. Means with the same letter are not significantly different.

Table 5. PUE and P-uptake of different varieties and P-rates

Treatments	PUE (g mg-1)	P-uptake (mg/plant)
Variety		
Dagim	33.63[ab]	12.79[c]
Belete	21.57[c]	14.81[a]
Gudenie	26.36[c]	13.94[a]
Jalenie	24.37[c]	14.72[a]
Zengena	27.69[bc]	13.91[ab]
Ater Ababa	37.58[a]	12.99[bc]
Mean	28.53	13.86
LSD (5%)	6.81	0.93
P-rate (g P pot-1)		
0	30.20	13.71
0.7	30.21	13.51
1.3	27.03	14.27
2	26.42	14.51
2.6	28.68	13.61
3.3	29.64	13.65
3.9	27.55	13.77
Mean	28.53	13.86
LSD (5%)	7.35	1.01
Var*P-rate	Ns	Ns

Means with the same letter are not significantly different.

Muthoni et al. (2010) also indicated that not only the variety but also growth environmental conditions and physiology of the seed tubers used have effects on potato maturity periods. Tesfaye (2009) reported leaf area, leaf dry mass and specific leaf weight were totally dependent on the efficiency of a genotype for the applied phosphorous. Adhikari (2009) reported that potato varieties have different morphological growth habits. As a result, their leaf dry masses and leaf area greatly vary. Barker and Pilbeam (2020) reported that phosphorous affects leaf area after emergence. Fleisher et al. (2013) also reported that with low P fertilizer leaf area decreased. But, Ekelöf (2007) reported that leaf area increment observed in P deficient soils for highly efficient genotypes. Leaf area growth was consistent with leaf dry mass patterns. Changes in specific leaf weight had not shown a constant pattern with the different P-rates. This may be due to the fact that growing conditions have a significant effect on vegetative growth as reported by Adhikari (2009). Terry and Rao (1991) reported that plant growth is more affected by P-limitation. On the other hand, Niguse (2016) reported that non significance growth of potato varieties with external P application. The differences in the reported results might be attributed to initial soil nutrient levels, nature of genotypes and the type of growth environment. Specific leaf weight is one of the characteristics of a plant and is closely related to environmental factors. Such environmental factors include varieties and growing media. Nelson and Schweitzer (1988) also reported that leaf photosynthesis has been positively correlated to leaf area and specific leaf weight for several species and the high specific leaf weight can be explained by the greater concentration of the photosynthate accumulation (including nutrients). Zia-ul-Hassan and Arshad (2010) also reported that the negative relation of specific leaf weight with P-rates.

The genotypic and P-rate variability in their total dry mass was reported by Wacker-Fester et al. (2019) and Israel et al. (2016), respectively. Fernandes and Soratto (2012) also reported increasing P levels up to some level can improve dry matter of stems, leaves, shoots, roots and the whole plant. Korkmaz et al. (2009) and Tesfaye (2009) reported relative biomass of P efficient genotypes was less affected by P deficiency unlike the inefficient ones. Lee (2013) reported relative biomass significantly vary within genotypes and P-rates. A relative growth rate was significantly lower at high P than at low P for all genotypes. Victorio et al. (1986) reported that a significant higher biomass in undergrounds in tuber bearing solanum genotypes with external P application. Fernandes and Soratto (2012) reported that dry shoots, dry roots and total dry weights were highly significantly vary up to some level with P application rates in potato varieties.

Genotypic yield difference of potato varieties was reported by White et al. (2018). Fernandes et al. (2014); Vhuthu (2017) and Debaba et al. (2019) reported that externally applied phosphorus is believed to increase tuber yield of potato only when available P in the soil increased. Ekelöf (2007) and Wacker-Fester (2019) reported to a certain level of external P application can increase yields of potato. This might be due to the functionality of phosphorus in plants. In addition to this, morphological growth increment goes to intercept the incoming radiation rather than increased conversion efficiency. Israel et al. (2012) also reported the significance difference of number of marketable tubers with phosphorous rates.

Genotypic variability of plant phosphorous concentration was reported by Sandaña (2016) and Wacker-Fester et al. (2019). Fernandes et al. (2017) reported that different potato varieties with different P application rates have different plant P concentration. Fernandes and Soratto (2012), and Fleisher et al. (2013) also reported that phosphorous fertilizer significantly increased P concentration in the shoots, tubers, and roots of potato plant when compared to the control plants. The non-significant difference of the interaction of variety with P-rate was reported by Wacker-Fetcher et al. (2019) and Fernandes et al. (2017). Plant P contents with different rates of phosphorous varied from 2.75 to 4.19 mg g-1 by Wacker-Fetcher et al. (2019); and 2 to 2.6 g kg-1 by Fernandes et al. (2017) and 0.08-0.16% by Lee (2013). The significant difference in available soil phosphorous after harvesting of potato varieties and P-rates was reported by Fernandes et al. (2017) and Debaba et al. (2019). This may be due to the fact that potato varieties differ in root growth which is responsible to take available soil P. Wacker-Fester et al. (2019) reported high biomass producers have small whole-plant P concentrations. Smaller phosphorous concentrations in plants may not mean smaller amounts of total phosphorous. Besides this, Fernandes et al. (2017) reported highest phosphorous concentrations was recorded with low soil available phosphorous. Unlike the above results, a variety with high biomass had a high available soil phosphorous and whole plant P concentration. This may be due to different environmental growth conditions, treatments applied and different varieties used in the experiment.

Sandaña (2016) reported P-uptake and PUE significantly vary with potato genotypes. Wacker-Fetcher et al. (2019) and Lee (2013) also reported PUE significantly affected by potato cultivars and P-rates. Low P uptake may also come with low biomass production as reported by Ayele et al. (2020). This indicates that P uptake alone does not guarantee P uptake and use efficiency as Tesfaye (2009) reported. But, a non-significant difference of varieties on PUE that ranged from 40.42 to 48.44 g mg-1 is reported by Vhuthu (2017). The declining or increment trend in PUE was like total dry matter and reciprocal trend with plant P concentration. Martins et al. (2018) also reported PUE reduced due to the decrease in DM production and increase in plant P concentration with a supply of higher Prates. Fernandes and Soratto (2012) reported that PUE in potato reduced with increasing P application. Kawakami and Iwama (2012) and Dechassa et al. (2003) reported PUE is strongly influenced by plant characteristics such as root length, diameter and weight. Wang et al. (2010) also reported that most modern crops are selected by root architectural and morphological traits that allow for more P acquisition from the P-rich soil surface zone. Ater Ababa variety which was efficient which had a higher comparable root to shoot ratio as reported by Akhtar et al. (2008) as P efficient genotypes had a higher root to shoot ratio.

Parentoni et al. (2005) reported that the main difference between efficient and inefficient cultivars is the ability to modulate root system morphology under P stress. They also reported that PUE in plants can affect P-uptake hence variety selection should consider root system morphology. Wang et al. (2010) also found that PUE depends on the ability of the plant to produce biomass or product of economic yield (e.g. tuber) using the taken up P. Lambers et al. (2013) phosphorus deficiency can also induce the release of root exudates, which can enhance the solubility of the fixed P in the rhizosphere, and increase extractable P concentration within the root zone. Muller et al. (2015) also reported that P-deficiency leads to scavenging of P from P-containing metabolites and reduced protein anabolism. On the contrary, Tesfaye (2009) reported that P efficient genotypes allocated more dry matter to their leaves to capture the incoming light for photosynthesis. Jenkins and Ali (1999) had also reported that varieties with longer growth periods had lower P fertilizer demand than early varieties. Unlike all the above reports, in this experiment the efficient varieties (Ater Ababa and Dagim) were low in shoot and root biomasses and matured earlier than other varieties. There should be other mechanism to be efficient in applied phosphorous. Shen et al, (2011) stated that plants under P deficient soils can facilitate efficient P acquisition by specific microorganisms that can facilitate available soil phosphorous. Hopkins et al. (2014) reported PUE can be increased by making things that can improve root-soil interaction. Jenkins and Ali (2000) also reported late cultivars had lower P fertilizer demand than early ones. Clemens et al. (2015) also reported that root hair density is also very important in absorbing P from the soil.

P uptake varies with potato varieties as reported by Torres-Dorante et al. (2006). Unlike this experiment P uptake varies with P-rates as reported by Torres-Dorante et al. (2006) and Fernandes and Soratto (2012). Even though non-significant difference recorded P uptake increases to some level, but PUE decreases. Fernandes and Soratto (2012) reported P-uptake of 2.0-2.6 g kg^{-1} with different potato varieties and P-rates. Fernandes et al. (2017) reported P-uptake of 7-10 kg ha^{-1} in different potato varieties. Soratto et al. (2015) also reported that total P-uptake per plant values between 22.6 mg $plant^{-1}$ and 31.4 mg $plant^{-1}$ under low P and between 41.1 mg $plant^{-1}$ and 54.3 mg $plant^{-1}$ under high P levels. On the contrary, Vhuthu (2017) and Torres-Dorante et al. (2006) reported significant P-uptake with different external P application rates.

On the other hand, Belete variety was the least in PUE. As a result it may not be able to adapt in low P soils. But, as it has high P-uptake (4.81mg $plant^{-1}$), it can be well responded to P fertilization and could be considered as responsive cultivar which performs best under P amendment.

Highly significant PAE reported with different potato varieties as reported by Wang et al. (2010); Daoui et al. (2014) and Hopkins (2013). Such genotypic difference especially in root characteristics is used to explore the soil available P. Soratto et al. (2015) also reported that to increase root growth, P should be managed. On the other hand, PAE is highly associated with P uptake as reported by Wang et al. (2010) and Sandaña (2016). The taken P should be utilized efficiently to have high PAE.

Conclusions and Recommendations

Assessing potato genotypes for their responsiveness to phosphorus application may be one solution to improve yield without increasing excessively production cost or damaging the environment low rates of phosphorus fertilizer. The result showed that all parameters studied were significantly affected by varieties and P-rates except in total dry masses, available total phosphorus phosphorous in plants and PUE in P-rates. The interaction of variety and phosphorous rates did not significantly affect all growth parameters except days taken to physiological maturity. Ater Ababa and Dagim varieties had the highest PUE and PAE. These two traits are important traits when selecting plants requiring less fertilizer/phosphorous inputs. Belete variety may be considered as responsive cultivar which performs best under external P amendment. This variety had the highest value in soil available P and total P in plants. The results showed presence of genetic variability to phosphorus use among potato varieties. This indicates that choosing P efficient variety may guarantee an improvement of tuber yield with less phosphorus fertilizer demand. Further studies are needed to available genotypes to examine and improve P efficiency!

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