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Phosphorous use efficiency of Ethiopian potato (*Solanum tuberosum L.*) varieties

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Abstract: **This proposal was initiated to assess the response of different potato varieties (Dagim, Belete, Gudene, Jalene, Zengena, and Ater Ababa) to phosphorus application and nutrient use efficiency under screen house with plastic pots. There were seven phosphorous levels per variety including the control. The experiment was conducted in completely randomized design (CRD) with three replications with a total of 42 treatments. The result showed that most parameters studied significantly changed with varieties and P-rates. Belete variety and 2 g phosphorous pot^{-} showed the highest values in soil available phosphorous (52.6 mg/kg and 49.53 mg/kg, respectively,) and Belete variety and 3.9 g phosphorous pot^{1}showed highest values in plants phosphorous (3.48 mg/g and 3.98 mg/g, respectively). The highest phosphorous uptake (14.81 mg/plant) was recorded in Belete variety. The highest phosphorous uptake efficiency (92.35 and 78.67 kg/kg) and phosphorous use efficiency (33.63 and 37.58 mg/g) were recorded in Dagim and Ater Ababa varieties, respectively. Though the lowest marketable tuber yield was recorded in the Ater Ababa variety followed by Dagim variety, they had the highest PUE and PAE. Evaluation of the existing varieties of potato for their phosphorous use and uptake efficiency could also potentially increase the future potato yield without excess P application.**

Keywords: **Potato, available soil phosphorous, phosphorous in plants, phosphorous use and uptake efficiency (PUE and PAE), P-uptake.**

1. 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. 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).

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).

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. 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 in Ethiopia. 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.

2. MATERIALS AND METHODS

2.1. 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 660 mm, 34°C and 24°C, respectively (North Western Meteorological station, 2018).

2.2. Experimental materials, planting and management practices

Widely grown potato varieties in the NW Amhara (Dagim, Belete, Gudene, Jalene, 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 11.783 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 top 30 cm profile. The soil around Adet Agricultural Research Center is Nitosol. 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/pot), 125% recommended (3.3 g/pot), recommended (2.6 g/pot), 75% of the recommended (2.0 g/pot), 50% of the recommended (1.3 g/pot), 25% of the recommended (0.7 g/pot) 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) 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.

2.3. Data collection and analysis

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

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

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

$$\text{RB} = \frac{\text{DMt}}{\text{DMck}}$$

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)

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

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

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

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

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

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

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 at 5% were separated using the LSD procedure. Simple linear correlations between parameters were computed.

3. RESULTS AND DISCUSSIONS

3.1. 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 in the control (125 days) and the shortest was from the highest P-rate (Table2). This may be due to the role of phosphorous in hastening physiological maturity of potato as reported by Birtukan (2016).

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/pot phosphorous application (127 days) (Table1). Highly significant interaction effects of varieties and P-rates on days taken to physiological maturity were reported by Wacker-Fester *et al*. (2019) and Sandaña (2016). 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.

3.2. 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) (Table1). These specific parameters were totally dependent on the efficiency of a genotype for the applied phosphorous (Tesfaye, 2009). Adhikari (2009) reported that different varieties have different morphological growth habits. As a result, their leaf dry masses and leaf area greatly vary.

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Table 1: The mean interaction effect of variety with P-rate on days taken to physiological maturity

Variety	P (g/pot)	DM	Variety	P (g/pot)	DM
Dagim	0	113^{kl}	Jalene	0	113.33^{k}
Dagim	0.7	117^{i}	Jalene	0.7	118.33^{h}
Dagim	1.3	119^{hg}	Jalene	1.3	119^{gh}
Dagim	2	120^{fg}	Jalene	2	120^{fg}
Dagim	2.6	122^{de}	Jalene	2.6	121^{ef}
Dagim	3.3	122.33^{d}	Jalene	3.3	122^{de}
Dagim	3.9	127^{a}	Jalene	3.9	125^{b}
Belete	0	115^{j}	Zengena	0	112^{l}
Belete	0.7	119^{gh}	Zengena	0.7	118^{hi}
Belete	1.3	120^{fg}	Zengena	1.3	120^{fg}
Belete	2	120.33^{f}	Zengena	2	120^{fg}
Belete	2.6	122^{de}	Zengena	2.6	121^{ef}
Belete	3.3	123^{cd}	Zengena	3.3	123^{cd}
Belete	3.9	127^{a}	Zengena	3.9	125^{b}
Gudene	0	101^{n}	Ater Ababa	0	109^{m}
Gudene	0.7	117^{i}	Ater Ababa	0.7	113^{kl}
Gudene	1.3	118^{hi}	Ater Ababa	1.3	115^{j}
Gudene	2	119^{gh}	Ater Ababa	2	117^{i}
Gudene	2.6	120^{fg}	Ater Ababa	2.6	117^{i}
Gudene	3.3	120.67^{f}	Ater Ababa	3.3	118^{hi}
Gudene	3.9	124^{bc}	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.

For phosphorous rates, the maximum leaf area and leaf dry mass were recorded in 2.6 g/pot of phosphorous (23.5 cm^{-2} and 102.0 mg, respectively). Leaf area and leaf dry masses increased up to 2.6 g/pot of phosphorous rates then declined afterwards (Table1). 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 (Tesfaye, 2009). Leaf area growth was consistent with leaf dry mass patterns.

The maximum specific leaf weight was recorded in Jalene variety (5.2 mg cm^{-2}). For phosphorous rates, the maximum specific leaf weight was recorded in 2.6 g/pot of phosphorous (4.4 mg cm^{-2}) (Table1). Changes in specific leaf weight had not shown a constant pattern with the different P-rates. Adhikari (2009) reported that growing conditions have a significant effect on vegetative growth. Terry and Rao (1991) reported that plant growth is more affected by P-limitation. On the other hand, Niguse (2016) reported that no significant effect on growth of potato varieties is observed 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 increment/decrement had not had a constant pattern (Table1). 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). Specific leaf weight increment and leaf area decrement with P deficiency are reported by Poorter *et al.* (2008). These authors also indicate that mechanistic understanding of the genetic and physiological factors determining specific leaf weight is still limited. Zia-ul-Hassan and Arshad (2010) also reported that the negative relation of specific leaf weight with P-rates.

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3.3. 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 Jalene variety (314.7 g) and 2.6 g/pot P (306.4 g). The highest shoot dry weight was recorded in Belete variety (207.8 g) and 2.6 g/pot P (225.3 g). The highest root dry weight was recorded in Jalene variety (103.2 g) and 2.6 g/pot P (108.3 g) (Table3). The genotypic and Prate 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.

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/pot 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 (Table3). Tesfaye (2009) reported relative biomass of P efficient genotypes was less affected by P deficiency unlike the inefficient ones. Lee (2013) stated 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. Low P supply reduced relative growth rates of the P-inefficient genotype (Tesfaye, 2009).

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

Source of variation	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}
Gudene	118.43^{c}	22.7^{b}	89.9^{b}	3.8^{d}
Jalene	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/pot)				
0	125.00^{a}	18.9^{f}	72.7^{ns}	3.9^{e}
0.7	121.53^{b}	19.9^{e}	81.1^{ns}	4.0^{d}
1.3	120.24^{c}	21.4^{d}	88.9^{ns}	4.2^{bc}
2	119.33d	22.6^{b}	98.9^{ns}	4.1^{c}
2.6	119.15^{d}	23.5^{a}	102.0^{ns}	4.4^{a}
3.3	116.88^{e}	22.1^{c}	93.2^{ns}	4.1^{c}
3.9	110.50^{f}	19.9^{e}	86.5^{ns}	4.3^{ab}
Mean	118.86	21.2	89.1	4.2
LSD (5%)	0.447	0.36	2.13	0.09
Interaction	**	ns	ns	ns

Where by Prate: 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.

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 Jalene, Gudene and Dagim, Jalene, Zengena and Ater Ababa and Jalene varieties, respectively. For phosphorous rates, the highest dry shoot (225.39 g/pot), 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/pot, 0.7 g/pot, 2.6 g/pot, 3.9 g/pot and 2.6 g/pot, respectively (Table3). Such types of results were reported by Wacker-Fester (2019). 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 different up to some level with P application rates in different potato varieties.

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3.4. 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 (Table3). 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/pot phosphorous. The highest marketable tuber yield was recorded in Belete variety (167.5 g) and in 2.6 g/pot phosphorous (217.9 g).

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. This might be due to the functionality of phosphorus in plants. Besides this, the increases in morphological growth go 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. However, Wacker-Fester (2019) and EkelÖf (2007) reported that lowering P fertilizers might not reduce tuber yields and tuber numbers.

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

Source of variation Variety	SDW (g)	RBs	RDW (g)	RBr	DM(g)	MTN/pot	TMYld (g)/pot
Dagim	192.7c	0.92a	92.8cd	0.92a	283.1d	8.8ab	96.5bc
Belete	207.8ab	0.91ab	91d	0.88bc	299.7abc	7.7bc	167.5a
Gudene	199.9bc	0.92a	94.1cd	0.85c	294cd	6.0c	118.5b
Jalene	212.4a	0.89ab	103.2a	0.91ab	314.7a	8.4abc	112.3b
Zengena	199.3bc	0.91ab	98.8ab	0.90ab	296.3bcd	6.3bc	109.9b
Ater Ababa	215.6a	0.88b	96.7bc	0.92a	311.7ab	11.1a	53.5cd
Mean	204.6	0.9	96.1	0.90	299.9	8.1	109.6
LSD (5%)	10.2	0.04	4.6	0.03	15.6	2.76	44.9
P-rate (g/pot)							
0	205.8bc	1.0a	86.1e	0.88cd	297.5	4.5d	56.4e
0.7	191.0de	0.96b	90.3de	0.95b	303.8	5.2d	82.8de
1.3	199.2cd	0.92bc	93.7cd	0.91c	298.4	6.4cd	115.2bcd
2	215.2ab	0.88d	98.3bc	0.84e	300.7	10.8ab	162.7b
2.6	225.3a	0.79e	108.3a	0.82e	306.4	11.9a	217.9a
3.3	214.2b	086d	100.2b	0.85de	296.7	9.1abc	147.4bc
3.9	181.6e	0.90cd	95.9bc	1.0a	295.7	8.2bc	101.8cde
Mean	204.6	0.90	96.1	0.9	299.9	8.1	126.3
LSD (5%)	10.98	0.04	4.99	0.03	16.9	2.98	48.5
Interaction	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.

3.5. 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) and available soil phosphorous (52.6 g/kg) was recorded in Belete variety. The lowest plant and soil phosphorous concentration was recorded in Ater Ababa and Dagim varieties (Table4). Such genotypic variability of plant phosphorous concentration was reported by Sandaña (2016) and Wacker-Fester *et al.* (2019).

The highest plant phosphorous concentration (3.98 mg/g) was recorded from 3.9 g phosphorous/pot and available soil phosphorous (49.53 g/kg) from 2 g phosphorous/pot (Table4). 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,

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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 (Wacker-Fetcher *et al.*, 2019); and 2 to 2.6 g/kg (Fernandes *et al.*, 2017) and 0.08-0.16% (Lee, 2013). The significant difference in available soil phosphorous after harvesting of different potato varieties and P-rates was reported by Fernandes *et al.* (2017). Debaba *et al.* (2019) also reported that available soil phosphorous significantly varied between different P-rates.

Wacker-Fester *et al.* (2019) reported that 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 arguments, 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.

3.6. 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) 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) and P-uptake (14.51 mg/plant) were recorded from control treatment and 2 g phosphorous/pot, respectively (Table5). 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 (Tesfaye, 2009). Sandaña (2016) reported P-uptake and PUE significantly vary with different potato genotypes. Wacker-Fetcher *et al.* (2019) and Lee (2013) also reported PUE significantly affected by potato cultivars and P-rates. A non-significant effect of varieties on PUE that ranged from 40.42 to 48.44 g/mg is reported by Vhuthu (2017).

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

Source of variation	Pplant (mg/g)	Psoil (mg/kg)	PAE (kg/kg)
Variety			
Dagim	2.74^{de}	29.53^{b}	92.35^{a}
Belete	3.48^{a}	52.6^{a}	66.45^{c}
Gudene	3.04^{bc}	47.74^{a}	63.68^{c}
Jalene	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
Prate (g/pot)			
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
Interaction	ns	ns	ns

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.

The declining or increment trend in PUE was like total dry matter and reciprocal trend with plant P concentration. Martins *et al.* (2018) also discussed 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) discussed that PUE in potato reduced with increasing P application. 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.

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The main difference between efficient and inefficient cultivars is the ability to modulate root system morphology under P stress (Parentoni *et al.*, 2005). Dechassa *et al.* (2003) reported that potato PUE is dependent on varieties root morphological characteristics as root exudates of a cultivar such as long root hairs play a role in solubilization and uptake of P. Wang *et al.* (2010) 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. Parentoni *et al.* (2005) reported 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 early in growth periods. 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.

Torres-Dorante *et al.* (2006) reported P-uptake varied with cultivar, climate, soil type, P sources and rates. Westermann and Kleinkop (1983) reported that P-uptake was influenced by plant age, plant parts used for analysis, availability of micronutrients like Zn, Fe and Mn and by soil pH (Hopkins, 2013). Goldstein *et al.* (1988) reported that P-uptake depends on P availability in the soil. Fernandes and Soratto (2012) also reported that P-uptake was strongly influenced by P inputs. Like this experiment Fernandes and Soratto (2012) reported that with increasing P application, P uptake increases to some level, but PUE decreases. They found P-uptake of 2.0-2.6 g/kg with different potato varieties and Prates. Fernandes *et al.* (2017) reported P-uptake of 7-10 kg/ha in different potato varieties. Soratto *et al.* (2015) also reported that total P-uptake per plant values between 22.6 mg/plant and 31.4 mg/plant under low P and between 41.1 mg/plant and 54.3 mg/plant under high levels of P applications. 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), it can be well responded to P fertilization and could be considered as responsive cultivar which performs best under P amendment.

There was highly significant difference observed in P-acquisition efficiency (PAE) between different varieties and P-rates, but not significant in the interaction. The highest PAE was observed in Dagim variety (92.35 kg/kg) followed by Ater Ababa (78.67 kg/kg) (Table-4). Wang *et al.* (2010); Daoui *et al.* (2014) and Hopkins (2013) reported PAE is mostly associated with genotypic variation. Such genotypes have different morphological and physiological root characteristics to explore the soil available P. P acquisition efficiency is highly associated with P uptake (Sandaña, 2016). The taken P should be utilized efficiently to have high PAE. Sandaña (2016) and Wang *et al.* (2010) reported also PAE become increasing with increasing P-rate. Adequate P management improves root growth which can increase P uptake efficiency (Soratto *et al.*, 2015).

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

Source of variation	PUE (g/mg)	P-uptake (mg/plant)
Variety		
Dagim	33.63^{ab}	12.79^{c}
Belete	21.57^{c}	14.81^{a}
Gudene	26.36^{c}	13.94^{a}
Jalene	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/pot)		
0	30.20^{ns}	13.71^{ns}
0.7	30.21^{ns}	13.51^{ns}
1.3	27.03^{ns}	14.27^{ns}
2	26.42^{ns}	14.51^{ns}
2.6	28.68^{ns}	13.61^{ns}
3.3	29.64^{ns}	13.65^{ns}
3.9	27.55^{ns}	13.77^{ns}
Mean	28.53	13.86
LSD (5%)	7.35	1.01
Interaction	ns	ns

Means with the same letter are not significantly different.

4. CONCLUSIONS

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. The result showed that all parameters studied were significantly affected by varieties and P-rates except in total dry masses, available 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. Different seed size, condition and non-uniform physiological stages of seed tubers at planting might be the possible reason for the significant effect of days taken to physiological maturity. Though the lowest marketable tuber yield was recorded in the Ater Ababa variety followed by Dagim variety, they 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 different 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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5. Conflict of Interest

The authors declare that they have no conflict of interest.

6. Declarations

Declarations are not applicable for this article!

7. Data availability

All data used to support the findings of this study are included within the article.

8. Ethics statements

This research is the authors' own original work not published anywhere. The paper reflects the authors' analysis in truthful and complete manner.

9. CRediT author statement

All authors have made a substantial contribution to the design of the article, acquisition, analysis, or interpretation of data for the article. They all drafted the article critically for important intellectual content and approved the manuscript for publication.

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