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Phosphorus uptake and utilization efficiency in response to potato genotype and phosphorus availability

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ABSTRACT

Increased phosphorus (P) use efficiency (PUE) of potato production systems through P uptake and P utilization efficiency (PUPE and PUTE, respectively) is one of the main challenges for potato breeding and crop management programs. The aim of this study was to assess PUE, PUPE, PUTE and related traits in different potato genotypes (*Solanum tuberosum* L.) in response to P availability. Three field experiments were carried out in southern Chile in Andisol soils. In each experiment treatments were the factorial combination of (i) 22 genotypes of potatoes and (ii) two P fertilization rates (0 and 130 kg P ha^{-1}, −P and +P, respectively). On average, biomass, P concentrations and P uptakes were reduced ($P < 0.05$) 32, 13 and 41% by −P, respectively. Conversely, −P increased PUTE (1.2-fold), PUPE (7-fold) and consequently PUE (8.3-fold). All traits were consistently affected ($P < 0.01$) by genotype (G), and the coefficient of variation (up to 47%) for each trait reflects the genotypic variability under both +P and −P. In all experiments, PUE and its main components were affected ($P < 0.01$) by P × G interaction. PUE was highly correlated with tuber yield, total biomass, P uptake and PUPE ($P < 0.01$; $r = 0.74 – 0.99$) but not to PUTE. In addition, PUPE was well correlated to yield and highly correlated with total P uptake ($P < 0.01$; $r = 0.94–0.99$). By contrast, PUTE was strongly negatively correlated ($P < 0.01$; $r = –0.85 – 0.89$) with P concentration in tubers. Genotypes from native (1 and 4), national cultivar (Puren-INIA, Yagana-INIA and Patagonia-INIA) and advanced line (R 89063 and RD 36–35) groups were among the best regarding PUE under −P. The PUPE was found to be more important than PUTE in determining PUE across a broad range of genotypes. Moreover, there is important genotypic variability in these traits with the potential to be used to improve PUE in potato crops through breeding and crop management programs.

1. Introduction

Phosphorus (P) has been considered a major factor limiting crop productivity. Despite P being quite abundant in many soils, it is largely unavailable for plant uptake because P forms insoluble complexes with cations under acid and alkaline conditions (Vance et al., 2003; Lynch, 2007; Ramaekers et al., 2010; Manschadi et al., 2014). As a result, a large amount of phosphate fertilizers have been applied since the Green Revolution to sustain production of agricultural systems (Tilman et al., 2001, 2002). In second place, P fertilization contributes to greenhouse gases (Haverkort and Hillier, 2011; Haverkort et al., 2014; Sandaña and Kalazich, 2015a) and has a direct negative impact on surface waters that influence the functioning of ecosystems (Tilman et al., 2001; Ruark et al., 2014). This creates a challenge for the goal of increasing crop production while using inputs in such a way as to avoid environmental problems (Gregory and George, 2011).

Among crops, potato is particularly sensitive to P-deficient soils, indicating a low P uptake efficiency (Westermann, 2005; Hopkins et al., 2014; Thornton et al., 2014; Sandaña and Kalazich, 2015b). This is most likely due to its small root system in relation to other crops such as cereals and legumes (Iwama, 2008). However, there are some trends likely to drive the effort to improve P use efficiency (PUE) in this crop, since i) phosphate rock will be much less available in the next 50 to 100 years (Cordell et al., 2009), ii) P prices are likely to increase as it becomes more difficult to extract from phosphate rock (Elser and Bennett, 2011), and iii) the environmental concern regarding the effect of P fertilization will increase environmental regulations designed to reduce its impact on water resources (Thornton et al., 2014). It is thus important to improve the PUE of crop production systems through breeding and/or crop management to increase productivity with a lower input of P fertilizers (Batten, 1992; Lynch, 2007; Ramaekers et al., 2010; Thornton et al., 2014).

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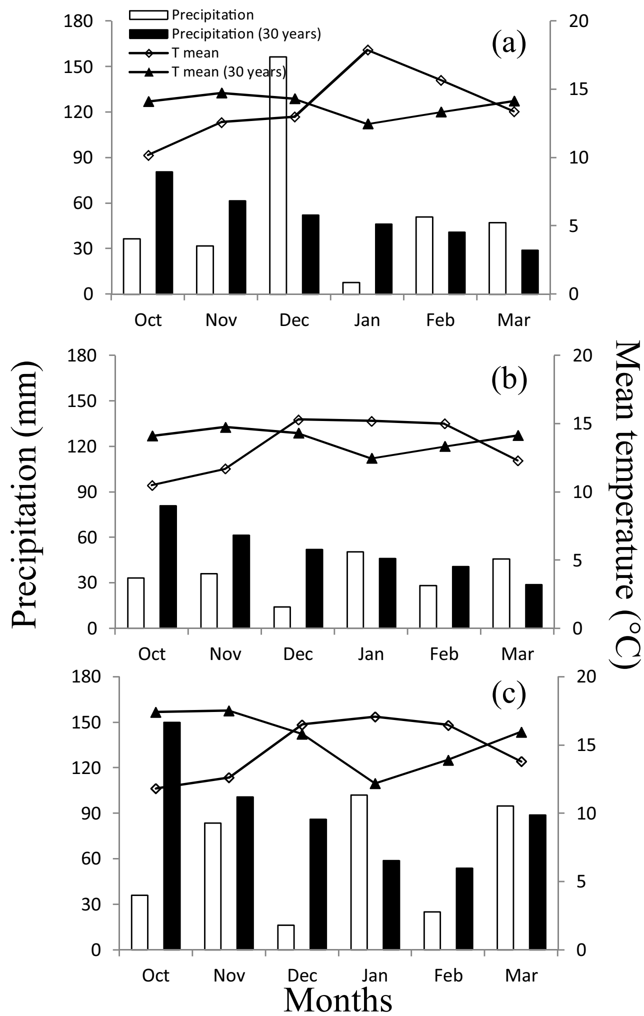

Fig. 1. Averaged monthly mean (open symbols) precipitation and temperature measured during Experiments 1 (a), 2 (b) and 3 (c), and historical averages (closed symbols) for the same climatic variables (1977–2012, Experiments 1 and 2; 1980–2010, Experiment 3).

In terms similar to those defined for nitrogen use efficiency by Moll et al. (1982), PUE (kg yield kg^{-1} P supply (P from soil plus fertilizer)) for crop yield can be defined as the product of P uptake efficiency (PUPE, kg P uptake kg^{-1} P supply) and P utilization efficiency (PUTE, kg yield kg^{-1} P uptake). Improvements in either of the above-mentioned components will increase PUE of crops (Ortiz-Monasterio et al., 2001; Wang et al., 2010; Valle et al., 2011; Sandaña and Pinochet, 2014). PUPE is the ability of crops to absorb P from the soil plus fertilizer, while PUTE represents the ability of crops to convert the absorbed P into yield. Genotypic variation in PUE and its components has been assessed in several crops (wheat: Batten, 1992; Gahoonia et al., 1999; Manske et al., 2000,2001; rice: Inthapanya et al., 2000; Wissuwa and Ae, 2001; maize: Inthapanya et al., 2000; Bayuelo-Jiménez and Ochoa-Cadavid, 2014; sorghum: Leiser et al., 2014; pearl millet: Gemenet et al., 2015). Conversely, there are few studies exploring genotypic variability of potatoes in response to P deficiency (Jenkins and Ali, 1999; Balemi and Schenk, 2009a,b; Fernandes et al., 2014; Soratto et al., 2015) and none assessing PUE under field conditions. The relative importance of PUPE and PUTE in defining PUE varies with crop species and environmental conditions (Manske et al., 2001; Wang et al., 2010). A recent study showed significant genotypic differences regarding yield, capture and use of solar radiation in response to P availability (Sandaña and Kalazich, 2015b). However, to our knowledge, there are no studies exploring PUE and the importance of PUPE and PUTE (in defining PUE) in a broad range of potato genotypes in response to different P availabilities.

PUPE differences among crops and cultivars could be related to differences in root traits such as architecture, length density, specific root length and root hairs and secretion of organic compounds (Gahoonia et al., 1999; Jungk, 2002; Vance et al., 2003; Gahoonia and Nielsen, 2004; Lynch, 2007; Ramaekers et al., 2010). Differences in potato root characteristics such as root weight, root length and root diameter have been reported previously (Stalham and Allen, 2001; Iwama, 2008; Wishart et al., 2013; Fernandes et al., 2014). On the other hand, differences in PUTE among cultivars have been related to differences in P concentrations, biomass and P distribution in the plant (Batten, 1992; Calderini et al., 1995; Manske et al., 2001; Bayuelo-Jiménez and Ochoa-Cadavid, 2014; Leiser et al., 2014; Gemenet et al., 2015). Moreover, differences in the energy cost of biomass synthesis could be behind crop differences in PUTE. Previous studies have shown that cereals have the highest nutrient utilization efficiencies followed by legumes and oilseed crops (N: Del Pozo et al., 2000; Sadras, 2006; P: Sadras, 2006). In potato crops, the associations between morpho-physiological traits and variation in PUPE and PUTE have not been assessed. Such studies will increase our knowledge about PUE variability of potato crops under field conditions in response to genotypes and P supply.

Therefore, the aim of the present study was to (i) assess the genetic variation for PUE and its components, (ii) evaluate the