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Effect of partial root zone drying and deficit irrigation on nitrogen and phosphorus uptake in potato

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ABSTRACT

Better understanding of the effects of deficit irrigation regimes on phosphorus (P) and nitrogen (N) uptake dynamics is necessary for sustainable water, P and N management. The effects of full (FI), deficit (DI) and partial root-zone drying (PRD) irrigation on potato P and N uptake with P fertilization (P1) or without (P0) were investigated in two split-root pot experiments in a soil with low plant available P. Under FI, the plants were irrigated to pot water holding capacity while under DI and PRD, 70% of the water amount of FI was applied on either both or one side of the pots, respectively. During potato growth, plant P uptake increased while P concentration decreased at P1 and was almost constant at P0. PRD and DI reduced plants P uptake to a same extent, ca. 22% compared to FI at P1, while at P0, plants P uptake was similar for the three irrigation treatments. Soil P transport to the root surface by diffusion was similar under DI and PRD. DI treatments had higher soil microbial biomass P, water soluble P, root biomass and leaf water potential than PRD treatments, while PRD treatments had higher plant N:P ratios than DI treatments and higher root secretion of acid phosphatases that may have compensated for the lower level of water soluble P. N was immobilized in soil in all the treatments. Plant N uptake under PRD was higher than DI at both P levels, which could be explained by the higher microbial biomass and N-immobilization under DI. In conclusion, when same amount of water was used, PRD was superior to DI in terms of N uptake, but not P uptake. Challenges remain how to maintain crop yield and P uptake under reduced irrigation regimes. Utilization of water and N fertilizer was low when the soil was deficient in P.

1. Introduction

The increasing worldwide competition for fresh water resources requires better management of irrigation to improve water use efficiency (WUE). Deficit irrigation (DI) and alternate partial root-zone drying irrigation (PRD) are two water saving irrigation regimes, which can increase WUE of potatoes (Wang et al., 2009) even without reducing yield (Shahnazari et al., 2007). Under DI, the crop receives irrigation water amounts slightly less than actual evapotranspiration but the resulting mild stress has minimal effects on yield (English and Raja, 1996). PRD is a special form of DI where only half of the root zone is irrigated while the second half is exposed to soil drying to a predetermined level before switching the irrigation to this second half. To maximize potato yield, not only sufficient P but also sufficient water need to be available (White et al., 2005a). Since DI and PRD reduce the soil moisture content, the tortuosity of the diffusion pathway for nutrients increase (Gahoonia et al., 1994) and the transport of P from soil to root is reduced (McBeath et al., 2012). Compared with DI, PRD increases the nitrogen (N) availability by allegedly inducing greater microbial activity and mineralization of organic N, which resulted in improved N uptake in tomato (Wang et al., 2010a,b, 2012, 2013) and potato (Shahnazari et al., 2008; Wang et al., 2009).

Potato is the fourth most important global crop by volume (FAO, 2007). Potato has a shallow root system (Vos and Haverkort, 2007), is generally drought sensitive (Yuan et al., 2003), and has a high phosphorus (P) requirement (Westermann, 2005). P is an essential element for all plants and rock phosphate from which P fertilizers are derived is a vital non-renewable resource, which may be depleted in a relatively short time span (Elser and Bennett, 2011). However, plant P uptake of freshly applied fertilizer P is normally

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Abbreviations: P, phosphorus; N, nitrogen; FI, full irrigation; DI, deficit irrigation; PRD, partial root-zone drying irrigation; WUE, water use efficiency; WSP, water soluble phosphorus; P1, treatments with phosphorus fertilizer; P0, treatments without phosphorus fertilizer; MBP, microbial biomass P; ΔSN_{min}, soil mineral N balance; APM, soil acid phosphomonoesterase activity.

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modest since P tends to bind strongly to soil constituents e.g. in Oxisols (Shamshuddin and Anda, 2012); with time, the immediate availability of added P fertilizer declines due to a combination of abiotic and biotic processes (Park et al., 2004; Frossard et al., 2000). Due to low P concentration in the soil solution, movement of P in soil is dominated by diffusion, and a large P concentration gradient occurs across the rhizosphere between the bulk soil and the root surface (Tinker and Nye, 2000). At low soil P availability plant adaptations to enhance P uptake are induced, including increased secretion of phosphatase (Bargaz et al., 2012), exudation of organic acids (Liao et al., 2006), greater root and root hair growth (Balemi and Schenk, 2009; Lynch and Brown, 2001) and enhanced expression of P transporters (Liu et al., 2010).

There is some evidence that irrigation management can also influence the use of organic P and the uptake of P (Wang and Zhang, 2008, 2010, 2012; Wang et al., 2012). P interacts positively with N uptake and plant growth (Fageria, 2001), so an improved N uptake might be accompanied by an improved P uptake under PRD. Although several studies on P uptake in potato (Alvarez et al., 2001) and tomato (Wang et al., 2012) have been conducted, a thorough study of how PRD and DI affect P availability and dynamic P uptake in situations with scarce water and P resources is lacking. The main objective of this study was therefore to investigate the effect of FI, DI and PRD irrigation on P and N uptake in situations with or without P fertilization.

2. Materials and methods

2.1. Experimental materials and design

Two pot experiments were carried out in a climate-controlled greenhouse at Aarhus University Research Centre Foulum, Denmark using cylindrical pots with a volume of 10 L (16 cm outer diameter and 50 cm deep), divided into two vertical compartments by a diametric plastic sheet. A 5 cm wide and 10 cm high piece was cut and removed from the middle of the sheet at the top where the seed tuber was going to be planted. Thus water exchange between the two compartments was prevented. The bottom of the pots was covered by 1.5 mm nylon mesh.

For the first experiment (Exp1), the soil was collected from the experimental farm of Foulumgaard also at Research Centre Foulum, and was sandy loam, with 68% sand, 24.3% silt and 7.7% clay, total C 16.3 g Kg^{-1}, total N 1.5 g Kg^{-1}, Olsen P 22 mg kg^{-1}, water soluble phosphorus (P) (WSP) 6.3 mg kg^{-1}, mineral N:(NH_4^+ and NO_3^-) 7.4 mg kg^{-1}, pH 5.4. The field capacity and wilting point of the soil at pF = 2.0 and pF = 4.2 were 25.3% (Vol.) and 6.7% (Vol.), respectively. The water retention curve for the soil is shown in Fig. 1. The soil was dried under a roof to a water content of ca. 12% (v/v) and sieved through a 1 cm mesh sized sieve. Each pot was filled to a dry bulk density of 1.3 g cm^{-3} corresponding to a total of 11.17 kg dry soil. The soil was divided into a subsoil layer with a depth of 24 cm that was unfertilized and a topsoil layer with depth of 20 cm that was mixed with fertilizer before packing. In the second experiment (Exp2), the sandy loam soil was collected from the same site as Exp1 with Olsen P 22 mg kg^{-1}, WSP 8.7 mg kg^{-1}, pH 6.2. The soil was air dried and sieved (1 cm mesh) and heated in an oven two times for 24 h at 85 °C with an interval of 48 h at room temperature to eliminate living microorganisms. Sterilized soil had Olsen P 26 mg kg^{-1}, WSP 12 mg kg^{-1}, pH 6.0. Pots were pre-sterilized by washing with 2% (w/v) NaClO and rinsed with tap water. Each pot was filled with 10.84 kg dry soil to a dry bulk density of 1.3 g cm^{-3} with topsoil and subsoil layer of 22 cm each.

Seed potatoes (*Solanum tuberosum* L. cv. Folva, size: 55–80 g) were pre-germinated. When sprouts emerged, one seed potato was planted in the middle of each pot with all except one sprout removed from the tuber. In Exp2, potato tubers were surface sterilized with 0.5% (v/v) H_2O_2 for 1 min and rinsed thoroughly with distilled H_2O before the sprouting. Exp1 was conducted from November 2012 to January 2013 in the greenhouse. Exp2 was carried out from August to middle of October 2013 and the pots were initially placed outside under a transparent roof for 20 days and then moved into the greenhouse. The conditions of the greenhouse in both experiments were set as: 20 °C/10 °C ± 2 °C day/night air temperature, 16 h:8 h L:D photoperiod and >500 μmol m^{-2} s^{-1} photosynthetic active radiation (PAR) supplied by sunlight plus metal-halide lamps. Pots were randomized on two tables in the greenhouse.

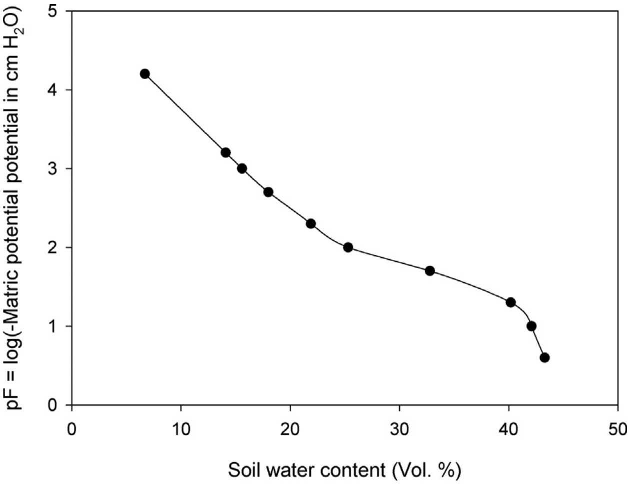

Fig. 1. Soil water retention curve for the experimental soil sampled from Ap-horizon 0–30 cm at Foulumgaard.

In Exp1, two P fertilization levels were created: P1 in which the 20 cm topsoil layer of each pot was supplemented with compound fertilizer consisting of 3.1 g N (47.73% NH_4-N, 52.27% NO_3-N), 2.57 g K, 0.63 g S and 0.8 g P ($CaHPO_4 \cdot 2H_2O$); the control (P0) had the same amounts of N, K, S but no P. The calculation of fertilizer rates per plant was based on an assumed field N application rate of 150 kg N ha^{-1} and P rate of 37 kg P ha^{-1} and further assuming that potatoes are planted at 40,000 plants ha^{-1} (Haverkort, 1982). The packed soil had a water content of 24.4% (v/v) at pot water holding capacity measured in situ after 2 days of drainage of the pots placed on a moist, naturally drained outdoor soil surface and 5.18% (v/v) at permanent wilting point as measured in a pressure plate apparatus (Fig. 1). In Exp2, P1 was supplemented with 2.6 g N, 2.8 g K, 1.8 g S and 0.6 g P mixed into the 22 cm topsoil, while the control (P0) had no P but otherwise the same dressing. Fertilizers used were pure chemicals: NH_4NO_3, KH_2PO_4, K_2SO_4, $MgSO_4 \cdot 7H_2O$. The packed soil had a water content of 23.8% (v/v) at pot water holding capacity.

Soil water content was monitored by a time domain reflectometer (TDR-100, Campbell, UT, USA) with 40 cm probes installed in the middle of each soil compartment. All the plants were kept well-watered to pot holding capacity during the first 44 days. Thereafter, the plants were subjected to: (1) Full irrigation (FI): both soil compartments were watered to pot water holding capacity; (2) Partial root-zone drying irrigation (PRD) treatments: half of the root system was watered to pot water holding capacity while the other half was allowed to dry to around 8% within about seven days before the irrigation was switched between the two soil compartments; (3) Deficit irrigation (DI): the same amount of water used for the PRD treatment was irrigated evenly to the two soil compartments. All the pots were irrigated every second day until the end of the experiment. The water used for irrigation was tap water with negligible concentrations of nutrients.