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The combined effects of phosphorus and zinc on evapotranspiration, leaf water potential, water use efficiency and tuber attributes of potato under water deficit conditions

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ABSTRACT

This study was conducted for evaluating the combined effect of soil moisture, phosphorus (P) and zinc (Zn) levels on crop evapotranspiration (ET), leaf water potential (LWP), water use efficiency (WUE) and various tuber attributes of potato (*Solanum tuberosum* L. cv. Agria) under greenhouse conditions. This investigation was conducted as a factorial experiment based on randomized complete blocks design with Zn at three levels (0, 10 and 20 mg Zn per kg dry soil as $ZnSO_4{\cdot}7H_2O$), P at three levels (0, 30 and 60 mg P per kg dry soil as $Ca(H_2PO_4)_2{\cdot}H_2O$) and soil moisture at three levels (0.5 FC–0.6 FC, 0.7 FC–0.8 FC and 0.9 FC–FC) using three replications. The various attributes of potato tubers including tuber numbers, dry matter content (DM), yield, WUE and indicators of water deficit stress intensity (ET and LWP) were measured routinely during the crop growth period. The results showed that the water deficit stress resulted in a significant decrease in ET, tuber numbers, yield and WUE. Application of P significantly increased the ET, tuber numbers and yield and Zn application significantly affected the tuber numbers. The P × soil moisture interaction effect was significant for ET, LWP, tuber numbers and yield. While the Zn × soil moisture interaction was significant only for yield. The results showed that the two way interactions of Zn, P and soil moisture were mainly synergistic on the most of above mentioned attributes. In general, to achieve the optimum yield of potato tubers in similar soils, application of 10 mg Zn and 30 mg P per kg of dry soil could be recommended under full-irrigated conditions. The regression analysis showed that the yield of potato was increased by application of P under water deficit conditions.

1. Introduction

In natural environments, plants are subjected to many stresses that can have negative effect on growth, metabolism, and yield. Biotic (insects, bacteria, fungi, and viruses) and abiotic (light, temperature, water availability, nutrients, and soil structure) factors affect the growth of higher plants. Among these, water deficit is a major abiotic factor that limits crop production (Reddy et al., 2004). Potato production is ranked fourth (based on production) in the world after rice, wheat, and maize with the production of 321 million tons from 19.6 million hectares (FAOSTAT, 2007). In Iran this important crop is ranked third after wheat and tomatoes with the production of 4.05 million tons (FAOSTAT, 2010). Potato is a temperate crop, growing and yielding well in cool and humid climates or seasons, but it is also cultivated in tropical to sub-polar climatic regions, and represents a major food crop in many countries (Shalhevet et al., 1983; Ierna and Mauromicale, 2012). Water supply is a major limiting factor in the production and quality of potato. It is known to be sensitive to water deficit (Fabeiro et al., 2001; Ierna and Mauromicale, 2012) due to its sparse and shallow root system, and tuber yield might be reduced considerably in response to soil moisture deficit (Deblonde and Ledent, 2001; Ahmadi et al., 2010). Water deficit stress influences the development and growth of potato shoot, root and tubers. For example, leaf area index, stem height and ground coverage of potato are reduced under water deficit stress conditions (Deblonde and Ledent, 2001; Yuan et al., 2003; Fleisher et al., 2008). The impact of water deficit on plants depends on time (Fleisher et al., 2012b), duration and severity of stress (Jefferies, 1995). At all growth stages, water deficit stress reduces photosynthetic efficiency, but water deficit stress has the most drastic effect on the tuber yield during the tuber initiation and

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Abbreviations: ABA, abscisic acid; ANOVA, analysis of variance; CCE, calcium carbonate equivalent; DM, dry matter content; ET, crop evapotranspiration; FC, field capacity; IAA, indoleacetic acid; LWP, leaf water potential; P, phosphorous; ROS, reactive oxygen species; SOD, superoxide dismutase; WUE, water use efficiency; Zn, zinc.

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bulking stages (Önder et al., 2005). Fleisher et al. (2012a) showed that potato dry matter reduced proportionately by drought cycles at both vegetative and post tuber initiation periods comparing with control.

The nutrients such as K, Zn and P perform important role in protecting plant from water deficit stress damage. Zn has been found to be a vitally important micronutrient in crop production and its deficiency has been shown to be more widespread throughout the world than those of any other micronutrient (Alloway, 2008). Zn has an important role in improvement of water deficit stress effects in plants. Zn has functional role in maintaining the structural integrity and controlling permeability of biomembranes (Cakmak, 2000). In Zn deficiency conditions, plant cells loss their membrane integrity that results in higher membrane permeability to inorganic ions (Welch et al., 1982). Apart from its role as a structural component in membranes, Zn also plays a key role in controlling the generation and detoxicification of reactive oxygen species (ROS), which can damage membrane lipids and sulphydryl groups (Alloway, 2008). Zn exerts an inhibitory action on membrane damage catalyzed by ROS (Cakmak, 2000). In general, it would appear that the major role of Zn in membranes is to protect membrane lipids and proteins from peroxidation caused by the ROS (Alloway, 2008). The level of Zn nutrition may also affect plant water relations and alter stomatal conductance (SC). Sharma et al. (1984) reported that Zn deficiency in cabbage decreased osmotic potential and relative water content compared to plants grown with an adequate supply of Zn. Transpiration rate, SC, and WUE also declined under Zn deficiency conditions (Khan et al., 2004). Although, Zn is required directly for superoxide dismutase (SOD) enzyme activity and indirectly for high activity of the enzymes involved in H_2O_2 detoxification such as catalase, ascorbate peroxidase and glutathione reductase (Cakmak, 2000).

P deficiency in plants is the second most yield limiting nutrient after nitrogen. Its fertilization helps plants overcome or decrease water deficit stress damages. Water deficit and P deficiency stresses may be related because water deficit stress can reduce P concentration in stand biomass by reducing soil organic P mineralization rates (Sardans and Penuelas, 2005) and transforming of P to non-available forms (Sardans et al., 2006; Sardans and Penuelas, 2007). The low availability of P in soil often restricts root growth and reduces access to subsoil moisture (Pathuluri et al., 1986). P deficiency affects the response of a plant to water deficit stress due to effect on stomata behavior and on the resistance to water flow within the plant. P-deficient plants close their stomata at higher LWP (less negative) than those receiving an adequate P supply (Garg et al., 2004).

Limited studies have been conducted on the combined effects of Zn and P on potato production (Soltanpour, 1969; Chaverri and Bornemisza, 1977; Trehan and Grewal, 1983; Sohota, 1985; Trehan and Sharma, 2000; Barben et al., 2010a; Barben et al., 2010b; Oroji and Golchin, 2012), but none of them have been carried out under water deficit conditions. Therefore, the aims of this study were to evaluate (a) effect of soil moisture on tuber yield, yield components, and other measured parameters, (b) combined effect of Zn and P on potato tuber attributes under water deficit conditions, (c) Zn and P fertilizer requirement of potato under different soil water conditions, (d) ability of Zn and P to alleviate water deficit effects on potato tuber yield.

2. Materials and methods

2.1. Greenhouse and soil description

A pot experiment was conducted in a naturally lighted greenhouse at Agricultural Research Station of Tabriz University, Iran during 2012. The maximum and minimum temperature of greenhouse was measured daily and a big hydroelectric cooler was used for controlling greenhouse temperature. The average maximum and minimum of temperature was 32.5 and 11.5 °C during planting period, respectively. Relative humidity of greenhouse was maintained about 65% by periodic moisturizing of the greenhouse floor. At first, a calcareous non-saline soil ($EC = 0.47\ dS\ m^{-1}$) low in available P and Zn (Olsen-$P = 8.7$ and DTPA-Zn = $0.5\ mg\ kg^{-1}$ that were lower than the critical levels) was selected (Alloway, 2008). The soil was taken from Espiran village in northwest of Tabriz (Iran) with the latitude of 38°15′57″ N and longitude of 46°19′53″ E from depth of 0–25 cm. After air drying and sieving (2 mm in diameter), soil properties such as available-P by Olsen method, available-Zn, Mn, Fe and Cu by DTPA-TEA, available-K by 1 N acetate ammonium extraction, pH in a 1:1 soil/water ratio suspension, EC in a 1:1 soil/water solution and soil texture by hydrometric method were measured (Gee and Bauder, 1986; Sparks et al., 1996) and presented in Table 1.

2.2. Treatments and planting description

The experiment was arranged as factorial $3 \times 3 \times 3$ with $n = 3$ based on randomized complete blocks design with three factors including Zn at three levels of 0, 10 and 20 mg Zn per kg of soil as $ZnSO_4 \cdot 7H_2O$, P at three levels of 0, 30 and 60 mg P per kg of soil as $Ca(H_2PO_4)_2 \cdot H_2O$ (monocalcium phosphate), and soil moisture at three levels of 0.5 FC–0.6 FC, 0.7 FC–0.8 FC and 0.9 FC–FC in three replications that all of them planted at same time (04/26/2012) with total 81 pots.

Based on soil testing, 5 mg Fe as Sequestrine-138 (EDDHA-FeNa), 5 mg Mn as $MnSO_4 \cdot H_2O$ and 200 mg of N (one-third at planting and the rest in two split until soil moisture treatments imposing) as urea ($(NH_2)_2CO$) were applied per kg of soil. Then, 10 kg of above mentioned soil by bulk density of 1.1 g per cm^3 of soil was poured into each pot (30 cm diameter and 26 cm height) and two potato tubers (*Solanum tuberosum* L.) cv. Agria with certified seeds and uniform sizes (45–55 mm) were planted in 10 cm depth of pots soil. Two tubers were planted to avoid elimination possibility of a pot because of plant death and need to a large number of leaves for measuring many parameters such as LWP, RWC, enzymes activity and nutrients concentrations that were not presented in this manuscript. The position of the pots within each block was changed once to twice per week to minimize the effects of light and temperature gradients within the greenhouse as well as border effects.

Pots were irrigated equally and uniformly at 0.94 ± 0.05 FC from sowing until flowering (64 days) and then soil moisture levels were imposed three weeks from the flowering (64th day) until harvest (85th day after planting). Throughout the experiment, soil moisture was controlled by pots weighting and watering two times per day. Deionezed water was added by graduated cylinder according to pots weight reduction from the intended soil moisture levels (up to 0.95 FC until flowering and up to 0.6 FC, 0.8 FC and FC during soil moisture imposing period). To compensation of plant weight increasing effect, additional pots were used for each of soil moisture levels. The whole plant fresh weight was determined every two weeks, and the weight correction was done.

2.3. Parameters measurements

Moisture of field capacity (FC) was determined by the pressure plate method at pressure of 300 kPa (Kirkham, 2004) and was 18.5%.

For evaluating the stress intensity, LWP (as a direct indicator of soil water status (Zhu et al., 2004)) and SC were measured on three leaves from each pot by pressure chamber (Model OSK2710, OGAWA Seiki Japan) and leaf porometer AP4 (Delta-T Devices-UK) around midday during the period that water deficit stress was