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ALLEVIATING ADVERSE EFFECTS OF WATER STRESS ON YIELD OF SORGHUM, MUSTARD AND GROUNDNUT BY POTASSIUM APPLICATION

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Abstract

The amount of soil moisture available to plants in arid and semi-arid regions is a major limiting factor for crop yield. Under such conditions, potassium fertilization proved helpful in mitigating the adverse effects of water stress. The interaction of plant K status and water stress on yield and water relations of mustard, sorghum and groundnut was studied. Plants were subjected to increased soil water stress conditions, tissue K concentrations analysed at peak growth stage (flowering) and relationships worked out between tissue K concentrations, yield parameters and relative water content. The water content of the leaf tissue was significantly increased by K application and the highest increase in RWC was 14.7 %, 17.4 % and 22.8 % under normal conditions, and by 8.7 %, 19.9 % and 17.7 % under water stress conditions in mustard, sorghum and groundnut, respectively. Water stress caused grain yield reductions and K application could enhance yield to a great extent. Production of above ground biomass, grain yield and RWC were highly correlated with the tissue K concentration, showing that concentration of K^+ in leaves played a vital role in increasing water stress resistance and stabilizing yield in the crops studied.

Keywords: water stress, potassium, relative water content, yield, harvest index

Introduction

Availability of water is one of the limiting factors determining plant distribution and survival in natural ecosystem. The crop, soil and water management could be improved by increasing root penetration and improving water use efficiency or photosynthetic capacity (Athar & Ashraf, 2005). Generally, water use efficiency in plants tends to be high as an adaptation under stress conditions. This adaptation remains effective until stress conditions are severe or prolonged (Saxena, 1985; Umar & Moinuddin, 2002). Status of mineral-nutrient in plants plays a critical role in increasing plant resistance to drought stress (Marschner, 1995). Of the mineral nutrients, potassium (K) is reported to be valuable in ameliorating the ill-effects of soil water stress for the survival of crop plants. Potassium nutrition to plants stimulates root growth and hence, efficient exploration of soil water (Saxena, 1985). Further, it decreases the loss of soil moisture by reducing the transpiration and increasing the retention of water in plants (Umar & Moinuddin, 2002). Keeping these facts in view, feasibility of K nutrition in augmenting the performance of the crops namely, mustard, sorghum and groundnut was tested under water stress conditions.

Under water-deficit conditions, K nutrition increases crop tolerance to water stress by utilizing the soil moisture more efficiently than in K-deficient plants. The positive effects of K on water stress tolerance may be through promotion of root growth accompanied by a greater uptake of nutrients and water by plants (Rama Rao, 1986) and

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through the reduction of transpirational water loss (Beringer & Trolldenier, 1978). Also, K maintains the osmotic potential and turgor of the cells (Hsio, 1973; Lindhauer, 1995) and regulates the stomatal functioning under water stress conditions (Umar *et al*., 1993; Nandwal, 1998; Kant & Kafkafi, 2002), which is reflected in improved crop yield in drought conditions (Umar & Bansal, 1997; Umar & Moinuddin, 2002). Besides, it takes part in many essential processes in plants (Marschner, 1995) and enhances photosynthetic rate, plant growth and yield under stress conditions (Egila *et al*., 2001; Sharma *et al*., 1996; Tiwari *et al*., 1998; Umar & Moinuddin, 2002). The protective role of K in plants suffering from drought stress has been attributed to the maintenance of a high pH in stroma and against the photo-oxidative damage to chloroplasts (Cakmak, 1997). The present paper discusses results of experiments with some important crop plants using varying levels of potassium under field and greenhouse conditions.

Materials and Methods

Three sets of experiment were conducted using mustard, sorghum and groundnut as the experimental materials. In the first set of experiment, mustard (*Brassica juncea* Czern & Coss cv. Pusa bold) was grown in enamel pots containing 8 kg of soil under greenhouse conditions during rabi season. The second and third sets of experiment were conducted during kharif season using sorghum and groundnut under greenhouse and field conditions, respectively. The soil used for pot studies (mustard and sorghum) was K-deficient, belonging to Lukhi soil series of Gurgaon district. The experimental soil for groundnut was highly calcareous (Vertic Ustocrept soil) and the crop experienced erratic rainfall conditions during the growth period (June to September). Potassium was applied in pots @ 0, 30, 60 and 120 mg kg^{-1} soil and in field @ 0, 25, 50 and 75 kg ha^{-1}. These treatments (0, 30, 60 and 120 mg kg^{-1} soil) may be considered as T_1, T_2, T_3 and T_4 for pot culture experiments. For field experiment, K treatments @ 0, 25, 50 and 75 kg ha^{-1} may be considered as T_1, T_2, T_3 and T_4.

Seed yield, biomass, harvest index, relative water content (RWC) and leaf K content were estimated using standard protocols (Umar *et al*., 1993; Umar & Bansal, 1995; Umar & Moinuddin, 2002). Data were analyzed statistically using analysis of variance (ANOVA), according to Gomez and Gomez (1984).

Results

Seed yield, biomass and harvest index: Seed yield as well as plant biomass reduced considerably due to water stress in mustard and sorghum. However, these could be increased significantly by increasing K-application rate under normal as well as water stress conditions, the increment in both the growth parameters being higher in the latter case. Seed yield was the highest with K_{120} showing a variation of 70.45 % and 358.3 % in mustard and sorghum (Fig. 1) respectively, over the K_0 in water stress conditions. Similarly, the effect of K application on biomass was most prominent at K_{120} with a variation of 66.3 % and 197.2 % in mustard and sorghum (Fig. 1), respectively under water stress conditions. Effect of water stress as well as K application on harvest index was also significant in these crops. The optimum dose of K for maximum harvest index was K_{120} with a variation of 6.14 % and 8.69 % in mustard and sorghum (Fig. 1), respectively.

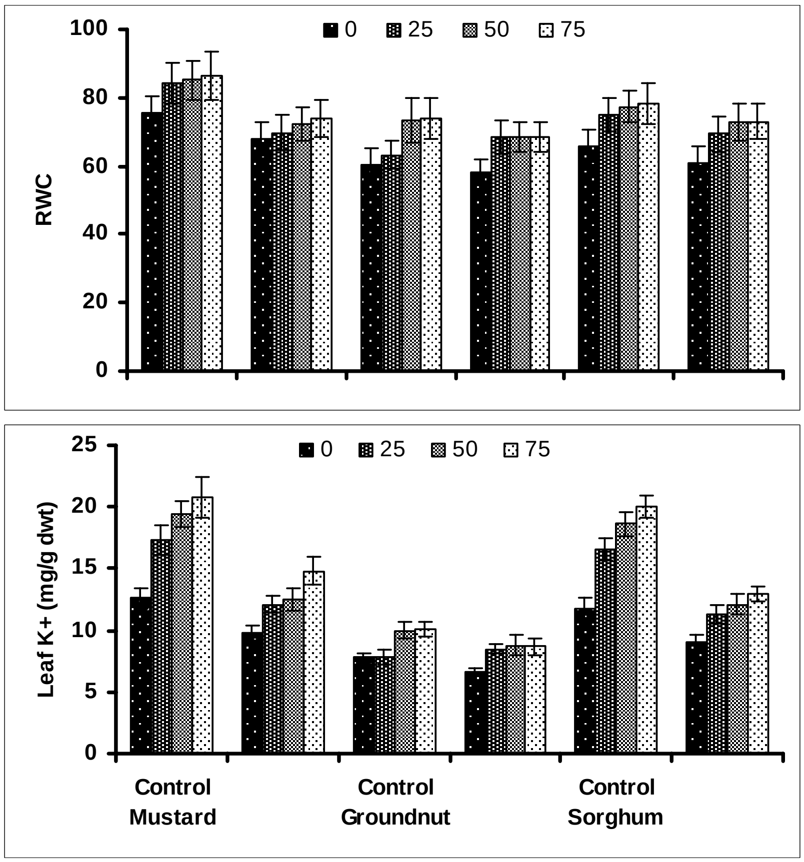

Fig. 1. Leaf K and relative water content (RWC) of three crop species when varying levels of K were applied to non-stressed or water stress plants.

In groundnut also, seed yield, biomass as well as harvest index reduced significantly due to water stress. However, these increased considerably on increasing K-application rate under both normal and water stress conditions, the increase being higher under normal condition. The maximum values were recorded at K_{50} showing values significantly at par with K_{75}. The percent variation in seed yield, biomass and harvest index (Fig. 2) was 44.2 %, 26.3 % and 14.3 % respectively at K_{50} in comparison to K_0 under normal conditions.

Relative water content: In all the crops studied, RWC was significantly lower in water-stressed plants than in plants grown under normal conditions. Application of K improved RWC under both moisture levels in all three crops with the maximum effect figuring at K_{120} in mustard and sorghum, and at K_{75} in groundnut. The highest K application increased RWC by 14.7 %, 17.4 % and 22.8 % under normal conditions, and by 8.7 %, 19.9 % and 17.7 % under water stress conditions in mustard, sorghum and groundnut (Fig. 1), respectively. As evident from these values, the effect of K application was more pronounced under normal condition in mustard and groundnut and under water stress condition in the case of sorghum.

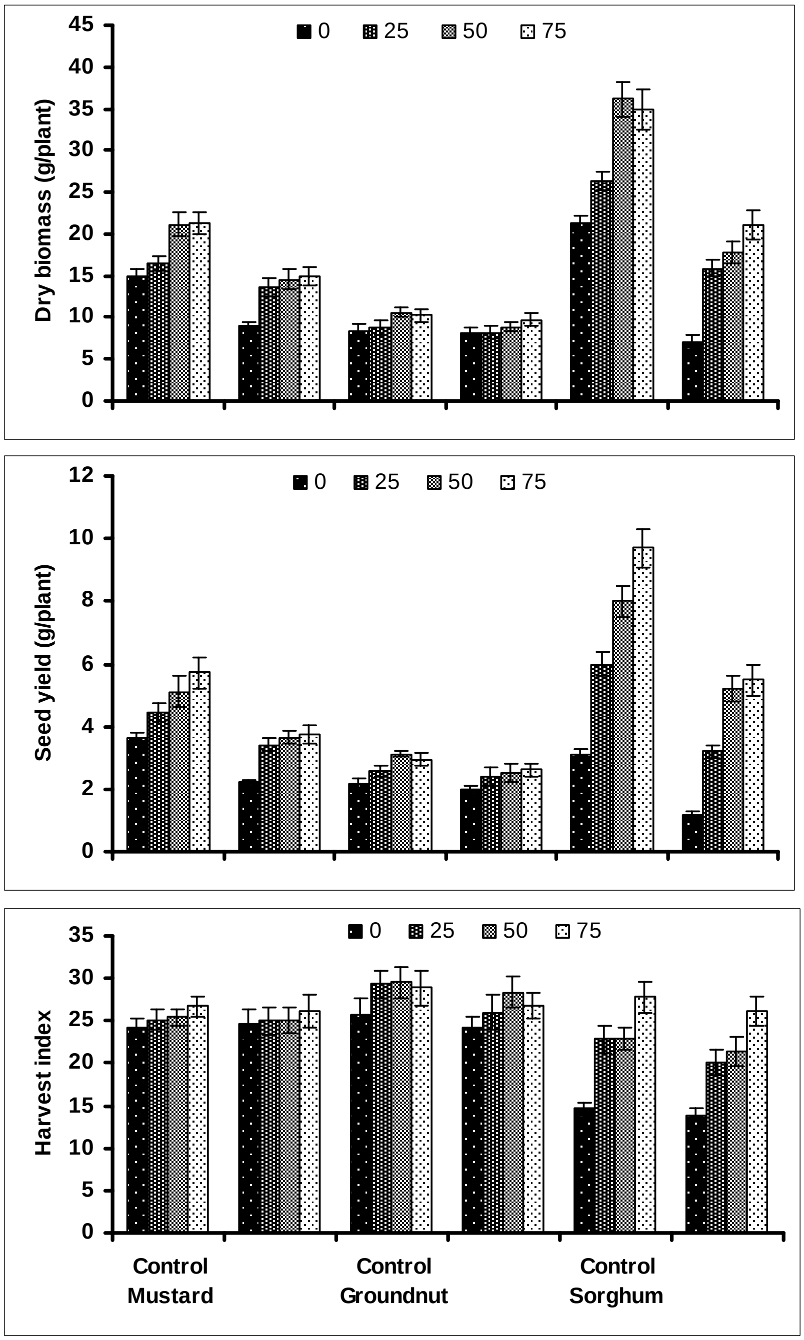

Fig. 2. Growth and yield of three crop species when varying levels of K were applied to non-stressed or water stress plants.

Leaf-K content: Leaf-K content decrease significantly on imposing water stress in the crops. However, the present study shows that K uptake by leaves improves due to elevated soil-K level both under irrigated and stressed conditions. The maximum increase in leaf-K content was observed with the highest K dose. It was 65 %, 69 % and 29 % in mustard, sorghum and groundnut (Fig. 1), respectively, over K_0 under normal conditions. Under water stress, the enhancement in leaf-K content on K application at the rate mentioned was 51 %, 43.3 % and 33.3 % in mustard, sorghum and groundnut, respectively. It is noteworthy that mustard and sorghum plants responded better to K application under normal water conditions, whereas groundnut showed a better response under water deficit conditions. In terms of leaf-K content, sorghum was most significantly affected in comparison to mustard and groundnut. The leaf-K content was found to bear significant positive relationships with seed yield, biomass and RWC (r = 0.971; 0.949 and 0.958) in all the crops studied.

Discussion

Seed yield, biomass and harvest index: The present experiments revealed a decrease in seed yield, biomass as well as harvest index under water stress conditions in comparison to control. This effect of water stress could be ameliorated to some extent by K application. The findings are in consonance with Wyrwa *et al*. (1998) who reported that drought caused reduction in grain yield of triticale by 54% on soils low in K and by only 16% with an adequate K supply. Rama Rao (1986) reported similar response of pearl millet and sorghum to K application in moisture stress conditions simulated in a similar way. In addition, improved seed yield of mustard was reported by Umar & Bansal (1995) in moisture stress conditions on K application. The increase in seed yield with K application under water stress conditions is presumably due to the improved water status of K-treated plants as evident by a comparatively higher RWC that could improve various physiological processes. In fact, K application is known to improve such physiological characteristics as stomatal resistance, RWC, NRA, chlorophyll and proline contents which might improve the overall plant water status and metabolism (Beringer 1982, Umar *et al*., 1990). El Hadi *et al*. (1997) found remarkable yield increases for a wide range of annual crops by applying K when water supply was restricted. These results suggest that improvement of K status of plants is important for sustaining a high yield under rain-fed conditions.

Relative water content: Application of potassium improves RWC of plants under normal as well as water stress conditions. The maintenance of plant water economy by K application in terms of a high RWC level under water stress condition could be ascribed to the supposed role of K in stomatal resistance, water use efficiency and lowered transpiration rate (Umar & Moinuddin, 2002). This is indicative of a positive role of potassium in hydration and organization of cell protoplasm and, thereby, in maintenance of turgor and growth of the plant in water stress condition (Sinclair & Ludlow, 1989; Khanna-Chopra *et al*., 1994). It also helps in maintaining a balance between osmotic potential of the plant and its surroundings.

RWC may indicate a relationship between physiological traits and level of drought tolerance because RWC is a stable yet dynamic property that tends to integrate the water balance of plant tissue over days or may be weeks (Sinclair & Ludlow, 1985) and has a positive and significant correlation with applied K under all moisture stress levels (Umar & Bansal, 1995). Plants have evolved hydraulic stomatal optimization mechanism to ensure that water loss does not exceed its uptake by the roots. It is the concentration of potassium ions moving through the xylem that influence the hydraulic conductivity of the transport pathway, perhaps by affecting the nature of pit membranes within xylem vessels, such that a root-sourced chemical signal can influence the properties of the water-transport pathways through the root and therefore, influence the hydraulic signaling between the root and shoot.

It has been found that when plants are grown under low supply of K, drought-induced ROS production can be additionally enhanced, at least due to K-deficiency-induced disturbances in stomatal opening, water relations and photosynthesis (Marschner, 1995; Mengel & Kirkby, 2001). In addition, under drought conditions chloroplasts lose high amounts of K to further depress photosynthesis (Sen Gupta & Berkowitz, 1987) and induce further ROS formation. These results strongly support the idea that increases in severity of drought stress result in a corresponding increase in K demand to maintain photosynthesis and protect chloroplasts from oxidative damage. The experiments on wheat also suggest that decreases in photosynthesis caused by drought stress are particularly high in plants supplied with low K, and are minimal when K is sufficient (Sen Gupta *et al.*, 1989). Alleviation of detrimental effects of drought stress, especially on photosynthesis, by sufficient K supply has been shown in legumes also (Sangakkara *et al.*, 2000).

Leaf-K content: In the present experiment, leaf K content declined under water stress conditions; this could be recovered to some extent by application of high level of potassium. It may be because the nutrient film around the soil particles becomes thin under water deficit, and consequently, the distance for movement of ions increases resulting in their poor diffusion into the plant roots, and causing low potassium content in the plant. A higher K availability under conditions of water deficit in the soil could lead to a decreased path length for the movement of ions resulting in a high K level in plants. Cakmak (2005) has reported several examples emphasizing the role of potassium in alleviating the adverse effects of drought on crop production.

The crops responded positively to supplementing initial K with applied K at sowing. The effect of moisture stress in depressing K uptake can be countered by higher concentration of the nutrient in the soil solution, which in the present study was achieved by a heavy K application. Re-evaluation of these data in the light of rainfall distribution in different years at different geographical locations may help to understand the significance of K application under aberrant weather conditions. Further investigations need to be carried out for developing a universal relationship between tissue K and RWC for predicting the crop yield under different moisture stress levels by using RWC index.

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