Do potassium supply, soil water and genotype influence concentrations of potassium in barley tissues?

Khaled Shaheen

The Libya academy for postgraduate studies – Janzour

Khaled.shaheen @academy.edu.ly

Introduction

The area suitable for cultivation globally is limited and much of it needs large quantities of irrigation water to sustain crop production. However, at least 99 % of the World's water is not suitable for use in agriculture because it is either saline or frozen (Peterson, 1971). Many other areas of cultivated land are prone to water shortages. Drought has one of the largest negative effects on global food production. This was attributed to the effect of drought on numerous physiological, morphological and developmental processes (Saki nejad *et al.* 2002). For example, extremely drought conditions could lead to reduced cell turgor which causing closure of stomata and decreasing in cell expansion, thus reducing the surface of leaf area and photosynthesis process (Syed and Rehana, 2007; Kramer, 1983).

In addition to water requirements, nutrients are necessary for plant growth and these are obtained from soil or added as fertilisers. There are 16 essential elements for plant growth, potassium (K^+) is one of these essential nutrients, and is needed by the plant in large quantities, interactive effects of soil K^+ supply and water availability supply on plant K^+ concentrations are investigated.

By measuring the concentrations of nutrients in plants we can determine the relationship between nutritional status and growth (Bates, 1971). In most studies, tissue concentrations of nutrients are expressed as a percentage of dry matter (Bates, 1971**;** Jones, 1982). For K^+, however, some researchers have suggested that K^+ in plants should be expressed as amounts per unit of tissue water instead of percentage of dry matter (Ahmed and Wyn Jones, 1982; Cassidy, 1970; Leigh and Johnston 1983a). This is because the physiological and biochemical processes in which K^+ is involved occur largely in the cytosol and because K^+ inside cells occurs only as the K^+ ion in solution (Wyn Jones *et al*., 1979). The evidence suggests that the K^+ concentration in tissue water is a more accurate and dependable indicator of the status of potassium in plants than is % K in dry matter

Of the main environmental factors that influence plant K^+ uptake, the most important are the availabilities of K^+ and of water. Soil K^+ availability depends on sorption properties of the soil, and on how these are estimated. K^+ supply to roots depends also on the diffusive movement of K^+ ions through the soil's liquid-filled pore network (Nye & Tinker, 1977).

There is a positive relationship between K^+ concentrations in plant and drought resistance due to the stimulation of absorption of water by lowering the osmotic pressure in root

cells and xylem. In addition to this, the role of potassium in the opening and closing of stomata to regulate water status at the whole-plant level is vital (Marschner, 1995). K^+ acts as an osmoticum in plant vacuoles, maintaining high tissue water potential in the plant even under moderate drought (Marschner, 1995).

As well as, cereal crops maintain K^+ concentration in their tissues at about 200 mmol kg^{-1} tissue water, until maturity is reached when water loss causes dramatic increases in K^+ concentration (Leigh and Johnston, 1983b). These researchers found that if K^+ concentration in barley dropped below 200 mmol kg^{-1} it can be concluded that barley is suffering from potassium deficiency. Also, Jensen and Tophaj (1985) observed that concentrations of potassium in barley tissue ranged from 176-200 mmol kg^{-1}. The concentration of potassium in the plant is most likely to be controlled by water content in plant tissues (Leigh and Johnston 1983a and b).Increased K application in barley crops caused a significant increase in tissue watercontent from 4.7 to 5.7 g H_2O g^{-1} dry matter which was associated with maintenance of total cation concentration in tissue water and, consequently, of osmotic potential (Jensen,1982). Jensen and Tophoj (1985) found significant increases in the water content of leaves, from 3.1 to 4.1 g H_2O g^{-1} dry matter when K fertiliser was applied, resulting in similar leaf osmotic potentials at all levels of potassium before the beginning of water stress. When K^+ is in short supply, other cations such as Ca^{2+} becomes important in maintaining cell osmotic potential (Jensen and Tophoj 1985). As yet there have been no detailed studies of the responses in terms of the maintenance of tissue K^+ concentrations in different genotypes to K^+ availability and of interactions with water supplies.For that reason, this experiment aimed to:

Test the influence of K^+ fertilisation levels on $\mathbf{K^+}$ concentrations in both dry matter and tissue water of different parts (leaves, stems and reproductive spikes) of barley plants.

Hypotheses

1. Droughtiness will affect plants' ability to regulate K^+ concentration in leaf water.
2. K^+ concentration per unit dry matter depends on K fertilisers more than K^+ in terms of tissue water.

Materials and methods

The experiment was done during in a greenhouse with mean day/night temperatures of 15 to 24 ^oC. It was conducted in pots sized 14.5 cm diameter 15 cm deep and arranged in a fully factorial randomized complete block design with five replicates of each treatment, as described below. Each pot contained one kg of moist soil. The soil was a silty clay loam collected from an arable field.

K was applied as potassium sulphate (46 % K_2O) at two levels, K0 (control) and supra optimum level K1 (equivalent to 150 kg ha^{-1}). Other macronutrients (N and P) were applied equally to each pot in all treatments. Phosphorus fertilizer was applied during soil preparation (equivalent to 100 kg P ha^{-1}) as super phosphate (16 % P_2O_5). P (and, in the K1 treatment, K) fertilizers were mixed several times with soil before adding to the pots. N fertilizers were applied in four equal doses (equivalent in total to 150 kg N ha^{-1}) as ammonium sulphate (20 % N): (1) applied during soil preparation; (2) supplied after transplanting seedlings; (3) added one month after planting; (4) applied after two months' growth. The quantities of nitrogen and phosphorus fertilizers (150 and 100 kg

ha^{-1} respectively) are supposed to be optimal for barley requirement, and to avoid deficiency of these nutrients.

All plants were fully irrigated for first two weeks to allow successful seedling establishment. Thereafter, two droughtiness regimes were established by varying irrigation frequency. Irrigated plants were grown in soil maintained at a minimum water content of 40 % (as read by using a Theta probe; Delta-T Instruments, Cambridge, UK), which is close to field capacity for this soil. This moisture content was achieved by irrigating every 7-9 days. Droughted plants watered less frequently such that soil moisture content was maintained around 20-25 %, the interval between irrigations depending on moisture content. Moisture was recorded in all pots every two days using the Theta probe.

Two spring barley (*Hordeum vulgare* L.) genotypes were selected: Westminster, characterized by long and with potentially greater drought tolerance, and Scout, with shorter roots and potentially more drought-susceptible (WB Thomas, personal communication

Seeds were placed on wet filter paper in Petri dishes at room temperature (20-25 °C) to germinate. After one day the seeds which started to germinate were transferred to the pots. Six seeds per pot were planted at 1 cm depth. Seedlings were thinned to three per pot after six days. The experiment contained a total of 200 pots.

The experiment had five harvests, with three weeks between each harvest, the first occurring 35 d after planting. Harvested plants were fractionated into green leaves, dead leaves, stems and spikes and each component weighed. Roots were not harvested. Samples were oven-dried for 48 h at 80 °C and weighed. Dried plant samples ground to a fine powder using a ball mill (Retsch MM 200).

Each tissue subsample (160 in total) in each harvest was digested in 4.5 ml of digest reagent comprising sulphuric acid (112 ml), lithium sulphate (3.6 g) and hydrogen peroxide (93.3 ml). Samples were placed on a digestion block for 2 hours at 360 °C until colourless solutions were obtained.

Data were analysed using analysis of variance (general linear models) in MINITAB. To test for significant differences between means, Tukey tests were used.

Results

K^+ concentration per unit tissue water of green leaves

K^+ concentration in green leaves responded to irrigation frequency more strongly than to K fertiliser. Irrigation had a highly significant effect on K^+ concentration per unit tissue water ($P < 0.001$), whereas the main effect of K fertiliser was non-significant ($P = 0.099$). None of the interactions involving K fertiliser were statistically significant ($P > 0.18$).

However, K^+ concentration in green leaves differed between treatments only after the second harvest, whereas K^+ concentration in plant tissue was similar until the second harvest.. After 55 days of growth, all treatments maintained K^+ ions in their tissue on

average between 7 to 11 mg g^{-1}. However, when water was withheld, K^+ ions slightly increased in concentration at the second harvest. Differences in K^+ concentration between all treatments occurred by the third harvest especially between irrigated and drought treatment, whereas K^+ concentration increased about two-fold in tissue water plants under drought conditions. watered plants maintained K^+ concentration in their tissue consistently less than the concentration in water-deficient plants. For example, K^+ concentration was increased approximately doubled in drought treatments (11.8 - 20 mg g^{-1}) compared with those in the irrigated plants (10 to 12 mg g^{-1}).

Statistically, K application and genotype did not cause any significant changes in K^+ concentration in plant tissue water ($P > 0.05$). But high accumulations of K^+ in plant tissue of both varieties were recorded in plants which received 150 kg ha^{-1} especially at the fourth harvest (17.2 in Scout and 16.1 mg g^{-1} in Westminster under frequent watering while they were 18.2 and 20.9 mg g^{-1} under water stress, respectively.

Potassium concentration per unit dry matter

There were strong influences of droughtiness, genotype and K level on K^+ concentration in dry matter ($P < 0.001$). Moreover, there were significant interactions between K level * time and droughtiness * time. There were also significant genotype * K level. However, the genotype * droughtiness interaction had no significant effects on K^+ concentration in dry matter.

Mean K^+ concentration per unit dry matter was raised by increasing K supply. For example, plants supplied with 150 kg K ha^{-1} maintained a higher K^+ concentration in their dry matter than did plants that had received no K fertiliser. Whereas in the Scout treatments the highest K^+ concentration was recorded at the third harvest when plants received 150 kg ha^{-1} K (83 mg g^{-1}), whilst the Westminster was recorded at the fourth harvest (89 mg g^{-1} dry matter). Also, the same effect was recorded in fertilised and fully watered treatments at the fifth harvest where it was 31.6 mg g^{-1} in Scout and 43.5 mg g^{-1} in Westminster.

Droughtiness had also a high significant impact on K^+ concentration in dry matter. Droughted plants maintained higher K^+ concentration per unit dry matter more than in fully watered plants. Under all experimental conditions K^+ in dry matter in both genotypes was almost identical at the first harvest and decreased at the second harvest, and then increased for all plants as well as decreasing at the fifth harvest.

Genotypes differed in the response of K^+ concentration per unit dry weight to treatments. For example, Westminster maintained K^+ concentration in dry matter more than Scout especially in irrigated plants that received 150 kg K ha^{-1}

3.5 Discussion

The results of this experiment showed that watering frequency influenced K^+ concentration in leaf water, supporting the first hypothesis that K^+ supply would influence the regulation of K^+ concentration. The second hypothesis, that K^+ concentration per unit dry matter depends on K fertilisers more than K^+ in terms of tissue water, was also supported. There are no differences in the regulation of tissue K^+

concentration between barley genotypes. Differences in K^+ concentrations per unit tissue water between genotypes were found when concentrations were expressed in terms of amounts of K^+ per unit dry matter. But, in contrast, this experiment showed that genotype had no effect on K^+ concentration in green leaves when expressed per unit of tissue water.

1- Effects on K^+ concentrations per unit tissue water (green leaves and whole plant)

K supply and droughtiness had influential effects on the K^+ concentration per unit tissue water in green leaves and whole plant. Potassium concentration in the plant tissue water in all treatments during the experiment increased with time except at the last harvest when crops switched from vegetative to reproductive growth and were heading towards maturity.

After the second harvest, water stressed plants maintained K^+ concentration in their tissue two-fold higher compared with plants in well-watered treatments. This could be attributed to drought causing decreases in growth which in turn caused accumulation of K^+ in plant shoots. The concentration of potassium in the tissues of plants subjected to drought is usually much higher than in fully watered plants for this reason (Ashraf *et al.*, 2002). Shirin *et al.* (2010) stated that under drought conditions, the rate of K^+ uptake is increased by 2-3 times more than the quantity required to support immediate demands in order to encourage physiological resistance to drought. Increased concentrations of potassium in the root and other organs help to ameliorate adverse effects of drought by preserving favorable osmotic potentials between root cells and soil.

The highest K^+ concentration in the whole plant fraction was during the third and the fourth harvests (about 77 days old) this is because the grains start to get milky and complete accumulation of potassium prior to grain formation (Shirin *et al*., 2010).

The highest increases for K^+ tissue water in whole plant occurred at the third and the fourth harvest in treatments which were subjected to drought. The highest response of potassium supply was recorded when water stress was given at milky stage in both genotypes. This increase occurred in crops exposed to drought or given nitrogen or manure.

2- Effects on K^+ concentrations per unit dry matter

K^+ concentration in dry matter was almost similar at the first harvest in all treatments because the amount of potassium that already exists in the soil was sufficient, where the mean values of plants did not receive K fertilizer were almost similar to plants did receive K fertiliser. Alternatively, it could be due to the presence of sufficient amounts of moisture in root zone, where soil moisture helped K^+ ions to diffuse from bulk soil to root surfaces. K^+ concentration mg K^+ g^{-1} dry matter initially increased and then declined after the fourth harvest. Potassium concentration decreased in dry matter at the end of the experiment, and this could be attributed to leaves having senesced by that stage. Or this decrease may be due to growth dilution effect. Leigh and Johnston (1983 a) have reported that K^+ in barley dry matter reached a maximum concentration during tillering stage then decreased gradually until the end of growing season. In addition, K^+ concentration in dry

matter significantly decreased by about 14% in all treatments at the second harvest if compared with the first harvest irrespective of droughtiness.

Potassium concentration in the dry matter at third harvest was increased in all treatments regardless of the K level or droughtiness. This increase could be attributed to that plants starting tiller stage and grain formation, which requires to large quantities of the element.

Conclusions

In summary, the main findings of this research are:

1- K^+ concentration in leaf water does not depend on genotype when expressed in terms of tissue water, but it does when in terms of dry matter.

2- K^+ concentration basis on dry matter respond to K supply more than K^+ concentration when expressed in terms of tissue water.

3- K^+ concentration basis on dry matter and was broadly similar to one another in term of their response to droughtiness, K fertilizer and genotype.

Reference

Ahmad N, Wyn Jones RG. 1982. Tissue distribution of glycine-betaine, proline and inorganic ions in barley at different times during the plant growth cycle. Journal of Plant Nutrition **5**:195

Ashraf, M. Ashfaq, M and Ashraf, M. 2002. Effects of increased supply of potassium on growth and nutrient content in pearl millet under water stress. Biologia Plantarum **45**: 141–144

Bates, T.E.1971. Factors affecting critical nutrient concentrations in plant and their evaluation: A review. Soil Science. **112**:116–130

Cassidy, N. 1970. The distribution of potassium in plants. Plant and Soil. 263-267

Jensen C R. 1982. Effects of soil water osmotic potential on growth and water relationships in barley during soil water depletion. Irrigation Science. **3**, 111–121

Jensen, C. R and H. Tophoj. (1985). Potassium Induced Improvement of Yield Response in Barley Exposed to Soil Water Stress Irrigation Science, **6**:117-129

Kramer, P. J. 1983. Water Relations of Plants. Academic Press, Orlando.pp. 342- 389

Leigh RA, Johnston AE. 1983b. The effects of fertilizers and drought on the concentrations of potassium in the dry matter and tissue water of field-grown spring barley. Journal of Agricultural Science **101**:741-748

Leigh RA, Johnston AE. 1983a**.** Concentrations of potassium in the dry matter and tissue water of grown spring barley and their relationships to grain yield. Journal of Agricultural Science, Cambridge **101**: 675-685

Marschner, H., 1995. Mineral nutrition of higher plants. Academic press San Diego, USA.

Nye PH, Tinker PB. 1977. Solute movement in the soil-root system. Oxford: Blackwell Scientific Publication.

Peterson, M, L. 1971. US land and water resource-research needs. *In* Agronomy in a Changing World and Research Needs for the Seventies. Eds. CA Black, GE Van Ripper, WC Barrows and RF Holland. pp 1–65. Spec. Bull. 19. American Society of Agronomy, Madison, Wisconsin.

Saki nejad and colleagues (2002), Study of water stress on the uptake process of nitrogen, phosphorus, potassium and sodium growth in different periods, according to the morphological characteristics corn physiological and climatic conditions Ahvaz, PhD thesis.

Shirin, D N, Tayeb, Shahram L. 2010. Study effect drought stress and different levels potassium fertilizer on K^+ accumulation in corn. Nature and Science. **8**(5): 139-143

Syed Abdul Majid, Rehana Asghar. 2007. Potassium-Calcium interrelationship linked to drought tolerance in wheat (Triticum aestivum L.). Pakistan Journal of Botany Vol: **39** (5) pp: 1609 – 1621

Wyn Jones, R. G., Brady, C.J. & Spiers, J. 1979. Ionic and osmotic regulation in plant cell. In Recent Advances in the biochemistry of cereals (ed. D L. Laidman and R. G. Wyn Jones), pp 63-103. London: Academic Press.