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Impact of potassium silicate on biomass yield and organic metabolites in Saltbush (Gtaf) under drought stress

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Abstract

The water deficit effects on growth parameters, protein content, and proline level in the Gtaf (*Atriplex halimus*) plant were investigated using potassium silicate under three drip irrigation regimes (100, 75 and 50% of field capacity). Compared to the control, yield biomass estimated by the dry and fresh weight of the shoot decreased significantly at severe deficit irrigation levels. In contrast, the moderate-level treatment stimulated the growth. The silicate treatments mitigated the adverse effect caused by water deficit but at moderate level. The concentration of protein in leaves decreased by decreasing water, while the reverse effect was observed with the application of potassium silicate. Medium treated with silicate of potassium increased the proline accumulation in leaves, especially at the higher deficit level. Under the potassium silicate treatment, the proline concentration dramatically rose in response to the higher stress level. At low deficit level, there was a slight, but not significant, decrease in this trait. Based on these findings, *Atriplex halimus* as an axero-halophytic shrub could be economical to use as animal feed materials and for the rehabilitation and revegetation of water deficit-affected lands.

Key words: Silicate potassium, water deficit, yield, protein, proline, rehabilitation, animal feed

Introduction

Semi-arid areas are basically dry regions where yearly rainfall isn't enough to support vegetation growth all year round. These regions typically receive 200 to 750 millimetres of rainfall per year, with only 20 to 50% of this amount sufficient to compensate for evaporation and plant water use (Lal *et al*., 2004). Right now, there's a big concern about water scarcity becoming a major problem, particularly for farming and other activities, due to climate change causing more erratic weather patterns (Elkeilsh *et al.*, 2019).

The agricultural utilization of semi-arid and saline areas poses a significant challenge to food security. It necessitates the development of economically and environmentally suitable techniques for reclamation and utilization (Cao *et al.,* 2012). Therefore, an effort to select xerophytic plants is becoming an option to minimize the negative impact of water on food production, which bears remarkable importance for sustainable agriculture. Plants tolerating water deficits is intricate, involving a range of morphological and developmental changes alongside physiological and biochemical processes (Nadeem *et al*., 2019). Water stress primarily inhibits the growth of plants, mainly because it negatively affects photosynthesis and causes cellular disruption and oxidative disintegration under dry conditions (Reddy *et al*., 2017). On the other hand, it is also due to the accumulation of organic metabolites, altered ion relations, and changes in soluble protein synthesis (Hasegawa *et al.*, 2000). The response appears to occur in two distinct phases, with the first being the osmotic phase (Munns, 2002).

Xerohalophytes are unique plants that can grow under low water diponibility (Roy *et al*., 2014). Utilizing these plants for fodder and pasture production on dry soils could offer an economically viable solution for providing animal feed materials (Fahmy *et al*., 2010). *Atriplex* species, commonly known as saltbush, are excellent candidates for establishing plants in dry areas and enhancing biomass productivity in semi-arid or arid regions worldwide. This is due to their remarkable stress tolerance and high productivity. (Squires and El Shaer, 2016).

A. halimus (Chenopodiaceae) is a monoecious C4 perennial shrub indigenous to the Mediterranean basin. It boasts exceptional tolerance to both drought and salinity (Martínez *et al*., 2003). It has been confirmed that *A. halimus* can be recommended for phytoremediation of highly dry and saline soils, making it suitable for rehabilitating such environments (De Souza *et al*., 2014). Hence, these plants have been naturally grown as forage shrubs in marginal lands in Egypt, North and South African countries, Australia, USA and the Middle East (McKell, 1970**;** Squires and El Shaer, 2016). Adding supplemental potassium silicate to irrigation water has been shown to alleviate the negative effects of water stress (Ul-Allah *et al*., 2020). Building on this premise, we hypothesized that applying solutions enriched with potassium silicate could mitigate the adverse impacts of drought stress on plant growth and enhance resistance to water stress. Therefore, the objectives of this study were: 1) to assess whether (K_2SiO_3) could alleviate the detrimental effects of water deficit on shoot biomass yield, and 2) to investigate whether (K_2SiO_3) could influence protein and proline content under drought conditions.

Material and methods

Planting and agricultural practices: *A. halimus* seeds were gathered from the region of El Mesrane in Djelfa province, Algeria, situated within an inland zone at coordinates 3°03'E, 34°36'N, and an altitude of 830 meters. The electrical conductivity of the soil was measured on saturated paste extracts taken at a depth of 20cm using a Mobile-Cassy 524009 conductometer. The average electrical conductivity recorded was 1.03±0.43 mS.cm^{-1}.

The experiment took place in the greenhouse at the Laboratory of Plant Physiology of the Desert Research Center in Egypt. Before removing the fruiting bracts, the surface of the seeds was sterilized by immersing them in 97% ethanol for 30 seconds, followed by treatment with 0.8% formaldehyde for 40 minutes and 5% calcium hypochlorite for 20 minutes. They were then rinsed three times with sterile deionized water. The seeds were sown in a mixture of sand, soil, and organic matter in a ratio of 8:1:1. Throughout the experiment, the plants were watered to maintain field capacity. After reaching a certain developmental stage, water was withheld to induce water deficit, lasting a maximum of 4 months.

The plants were subjected to three different water treatments, representing 100%, 75%, and 50% of the field capacity (FC), with or without applying potassium silicate. Each treatment consisted of four replications. These water treatments corresponded to favorable conditions and moderate and severe water deficits. Throughout the experiment, the diurnal temperature was fixed at 30°C (±2°C), while the nighttime temperature was kept at 15°C (±2°C).

Growth parameters: One month after drought stress application, growth parameters, including fresh and dry biomass weight, were estimated after oven-drying (80°C) samples for 48 h.

Protein content: The Protein content was estimated by the method of Bradford (1976) in fresh material. Absorbance was recorded spectrophotometrically at 595nm (Pharmacia Biotech. Novaspec II, Ontario, Canada)

Proline content: The free proline was quantified from leaf tissues based on Bates *et al*. (1973). The absorbance was read at 520 nm. The proline concentration was assessed. Using a calibration curve and expressed as micromoles per gram of fresh weight (µmol.g^{-1}FW).

Data analysis: The experiment was arranged following a completely randomized design, and the data were subjected to statistical analysis using SPSS 7.5 software package, employing analysis of variance (ANOVA).

Results

The study examined the effect of water stress, both with and without the application of K_2SiO_3, on various growth parameters and organic compounds (Table 1).

Table 1. Effect of water stress (treated and non-treated with K_2SiO_3) on growth and organic compounds

Traits	F values
Dry weight	45.66**
Fresh weight	42.65**
Protein content	32.43*
Proline content	141.45**

The results revealed significant differences across all traits measured. Dry weight exhibited a highly significant difference, as indicated by an F-value of 45.66. Fresh weight similarly showed a highly significant difference with an F-value of 42.65. Protein content also demonstrated a significant difference, reflected by an F-value of 32.43. Notably, proline content displayed the most substantial significant difference, with an F-value of 141.45. These findings underscore the considerable impact of water stress on growth and organic compounds, highlighting the modulatory effect of K_2SiO_3 treatment.

Dry matter content: A significant impact on dry shoot weight was observed for water deficit (P<0, 01). In contrast, increasing the substrate humidity significantly reduced the trait, as indicated in Table 1. However, the effect of drought stress on growth was found to be insignificant at the moderate level, compared to the control plants. Moreover, a marked decline of growth was obtained in plant treated by high level, when the decreased was about 19%, compared to plant control. Application of potassium silicate clearly and significantly improved plant growth. The significant increase occurred under low levels combined with K_2SiO_3.

Fresh weight: When using fresh weight as an indicator of plant growth capacity, the results from the study demonstrate that decreasing soil humidity levels significantly reduced plant growth (P<0.01). This reduction was more pronounced at 50% of field capacity (52%). However, the 70% of field capacity stimulated the growth. Therefore, this level of drought could be regarded as optimal for growth. Supplementary potassium silcate increased this parameter compared to plants stressed when the fresh weight reached the highest increase 34%. Shoot dry weight was significantly less at high deficit level than at the other treatments. This means that growth stimulation was the largest in low-level treated plants (K_2SiO_3), with the greatest increase in fresh weight being about 34%.

Table 2. The mean values of dry and fresh weight under water stress, with and without treatment of K_2SiO_3. Each value represents the mean of four replications for each trait. Values that share a common superscript letter are not significantly different at a significance level of P < 0.05

Treatment	Dry weight (g m^{-2})	Fresh weight (g m^{-2})
Control	236.43±0,98^{d}	2169±32.4^{c}
70%FC	239.58±0,40^{c}	2070±6.02^{c}
50%FC	190.35±1,67^{a}	1026± 7.19^{a}
70% FC+(K_2SiO_3)	232.56±0,93^{cd}	2925± 30.8^{d}
50%FC+(K_2SiO_3)	170.64±0,90^{b}	1035±7.54^{b}

Mean values±ES of each trait that share identical letters are not significantly distinguishable at a significance level of 5%.

Protein content: The present study showed that protein content was significantly (P<0.01) influenced by drought deficit. However, the protein content was stimulated in the presence of a moderate level of irrigation. It induced an increase about 19%, when a relatively low protein content was detected in plants treated with sever levels compared to the other treatments. Supplementary silicate potassium under both examined deficit levels of irrigation ameliorated protein content. The protein levels remained higher than those of the control plants, even when the plants were untreated under stress conditions. The increase was about 25 and 46%, obtained at 70 and 50 %, respectively.

Proline content: Proline accumulation was highly significant (P<0.01) as affected by the drought stress treatments. There was a notable increase in the proline level in response to severe levels untreated with potassium silicate when the plants were recorded the maximum (88.1%). However, it was only slightly

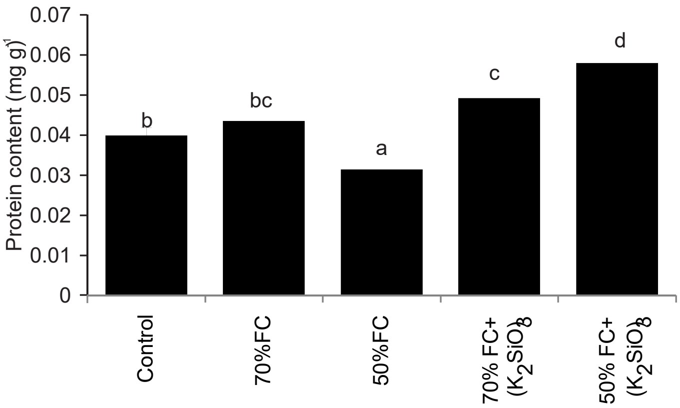

Fig.1. Effect of water stress (treated and non-treated with K_2SiO_3) on protein content. Each trait that share identical letters are not significantly distinguishable at a significance level of 5%.

affected in the leaves of the plant treated by moderate levels of drought stress. There was, however, a strong correlation between the deficit irrigation of plants and the proline concentration in the leaves. In the drought condition treated with K_2SiO_3, the proline concentration rose in response to the elevated stress level. Still, at a lower level, there was a slight, and not significant, decrease in the proline content.

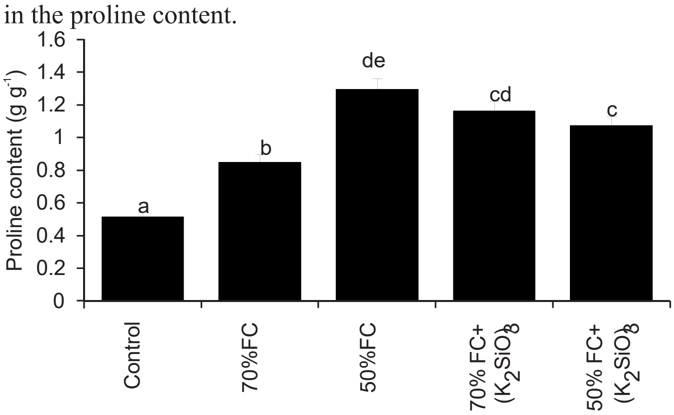

Fig. 2. Effect of water stress (treated and non-treated with K_2SiO_3) on proline content. Each trait that share identical letters are not significantly distinguishable at a significance level of 5%.

Discussion

Drought stress impacts various aspects of plant metabolism, leading to reduced growth and yields (Zahedi *et al.*, 2020). The present research demonstrated that biomass yield, assessed through dry and fresh weights, decreased significantly (Table 1-2) under high-level drought stress (50%) in contrast with the control group. Drought hampers the growth of plants by negatively affecting key biochemical and physiological processes. Water scarcity primarily impacts the roots' and leaves' growth, photosynthesis, stomatal conductance, and dry matter accumulation (Ozgur *et al.*, 2008). The results also indicated a 70% stimulation in growth, affirming the xero-halophytic characteristics of this genus, consistent with previous findings by other researchers (Martinez *et al.*, 2003). The stimulation of growth due to drought and water under moderate application of potassium silicate has been previously documented. Hasanuzzaman *et al.* (2018) reported that Silicon (Si) can improve various aspects of plant physiology, including Seed size, quality, growth, cell division, water relations, photosynthesis, leaf erectness, plant growth, and root architecture.

Additionally, potassium is an essential element for plants, crucial for forming starch and sugar and protein synthesis. Potassium has been observed to stimulate osmoregulation, vegetative growth, and root length, enhancing water status in plants. The rise in dry matter production observed in plants treated with silicate under high deficit irrigation conditions may be attributed to the accumulation of organic solutes and inorganic ions, facilitating osmotic adaptation. Conversely, at the highest deficit water levels, the decline in the dry matter content could result from the inhibition of reserved food source hydrolysis and their translocation to the growing shoots (Alam *et al.*, 2014). However, the decrease was mitigated when silicate was added as shown in Table 1. The application of drought stress in the presence of silicate potassium at a low level facilitates the growth of plants. This advantageous impact of potassium silicate on the growth of numerous species under water-deficient conditions has been previously documented in sweet corn (Ausbie *et al.*, 2019) and tomato (Marodin *et al.*, 2016). Over time, the impacts of water stress became more pronounced for plants at high levels. This level, reduced the dry mass production by 52% for fresh weight and by 27% for dry weight. As indicated in the results, the decrease in biomass production observed at high levels of water deficit could be attributed to disturbances in the photosynthetic process. These disruptions could involve reductions in the photochemical quantum yield, degradation of pigments, and limitations in stomatal conductance (Abdelatif *et al.*, 2020).

Many species of *Atriplex* are highly valued as livestock feed materials, particularly in regions with low herbage availability, such as arid environments and salt-affected areas. This is because of their moderate crude protein contents (El Shaer, 2015), their richness in vitamins such as A, C, and D, and minerals like chromium (McKell, 1989). This study showed that the presence of medium-high drought applied with potassium silicate significantly increased the protein content (25 and 46% when plants treated at 70% and 50% FC, respectively) to that of control.

Fig. 1 illustrates the positive impact of drought conditions on the total protein content of plant shoots. The data suggests a general increase in protein content corresponding to the increase in water deficit, regardless of whether water deficit was applied. However, there was a notable decrease in protein content of plants treated with 50% of the field capacity (FC), as depicted in Figure 1. The responsiveness of this parameter to drought treatment implies that protein biosynthesis was altered. The results obtained were recently supported by Hasanuzzaman *et al.* (2018).

The accumulation of free amino acids, particularly proline and soluble carbohydrates in plant tissues under water deficit conditions represents an adaptive response (Sheela Devi and Sujatha, 2014). Although stress tolerance mechanisms are based on particular stress responses, not all responses are equally pertinent for establishing tolerance. Proline accumulation, for instance, is commonly observed as a general 'response' to abiotic stress across many plant species. However, the extent to which proline contributes to stress tolerance mechanisms can vary depending on the species (Sugenith *et al.*, 2020). This study significantly increased the proline content in plants exposed to higher deficit irrigation levels. Specifically, plants grown in 50% of the field capacity (FC) exhibited the highest proline content. According to Marjanossadat *et al.* (2022), proline accumulation in tissues of plants exposed to drought stress can be attributed the main strategy of plants to avoid the detrimental effects of water stress.

It should be noted that proline concentrations were unusually high in the leaves treated by potassium silicate in both level of stress. Potassium silicate (K silicate) was observed to alleviate drought stress by enhancing proline accumulation in various plant species, such as *Cicorium intybus* L. (Schertl, *et al.*, 2014). Zlatev and Stoyanov (2005) proposed that the accumulation of proline in plants might serve primarily as a potential indicator of drought injury rather than directly influencing stress tolerance mechanisms.

In conclusion, this study demonstrated that growth, protein and proline content of shoot was significantly affected by drought stress. The results indicate that *A. halimus* can grow optimally in the presence of 70% of FC and remains alive when challenged with 50%,. Potassium silicate ameliorated the stress caused by water deficit and the plant produced a reasonable biomass yield. These findings are highly valuable for determining how conditions should be manipulated to ensure the survival and enhance the growth of *Atriplex* plants. The saltbush could be recommended for remediating saline and/or animal feed components. However, further research studies are necessary to improve the nutritional values of *A halimus* as proper livestock feeds under drought conditions.

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