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EFFECT OF THE SILICON AND PHOSPHORUS-CONTAINING FERTILIZER ON GERANIUM (*Pelargonium hortorum* L.H. Bailey) RESPONSE TO WATER STRESS

Karolina Mieszkalska, Aleksandra Łukaszewska
Warsaw University of Life Sciences (SGGW)

Abstract. Geraniums are popular bedding plants used in urban public space and private gardens. Although well adapted to drought they often suffer from water stress, especially when planted into containers. In this trial, a response to periodical soil water shortage was tested on potted geraniums fertilized with a fertilizer containing 36% silicon and 20% phosphorus. During five weeks of culture under the experimental conditions, half of the greenhouse-grown plants were subjected to two 7 and 10-day periods without irrigation, separated by the periods of standard watering (7 and 10 days, respectively) (stressed plants) while the other half were irrigated (control plants). Half of the plants in each watering regime were planted into a growing medium enriched with the Si+P fertilizer. The parameters of growth and flowering were evaluated on the 35th day and the leaves were analyzed for RWC, chlorophyll a+b and free proline contents. Water stress had little effect on plant height but decreased by one third the fresh weight of the above-soil plant parts. The number of flowers remained unaffected but the number of flower buds developed under the experimental conditions fell to 30% in plants subjected to stress as compared to the watered control. The application of the fertilizer enhanced plant growth regardless the watering regime but decreased flower numbers in both groups. However, this treatment positively affected development of new flower buds, especially in stressed geraniums, where the increase in bud number was nearly 8-fold relative to the non fertilized plants. The relative leaf water contents remained unaffected by the watering regime while the fertilizer increased RWC in both plant groups. Total chlorophyll contents doubled under stress, and were further increased by the fertilizer in both plant groups. Water deficit increased the free proline content in leaves by a third. However, in the non-stressed and fertilized plants it increased by 48% and remained unchanged in stressed fertilized plants. The experiment demonstrates that Si+P fertilization may mitigate the undesirable effects of water-stress in potted geraniums.

Key words: bedding plants, drought, growth, flowering, RWC, free proline, chlorophyll a+b

Corresponding author – Adres do korespondencji: Karolina Mieszkalska, Department of Ornamental Plants, Warsaw University of Life Sciences (SGGW), Nowoursynowska str. 166, 20-787 Warszawa, Poland, e-mail: kro@sggw.pl

INTRODUCTION

Bedding plants are an important part of the urban public spaces and private gardens. However, they are not always properly watered and suffer from drought stress, especially when grown in limited-volume containers. Numerous experiments dealt with the effects of abiotic stresses on agricultural plants such as alfalfa [Wang et al. 2011], wheat [Siddique et al. 2000; Pei et al. 2010], soybean [Jin et al. 2006; Shen et al. 2010] and many others. Until recently, ornamental plants have not been frequent objects of such studies even though these plants constitute a major part of horticultural production and play an important role in everyday humane life [Chyliński and Łukaszewska 2008]. Geraniums belong to the most popular seasonal plants widely used both in private and public green areas, often planted into containers. Our earlier trials have shown that geraniums are more resistant to drought than several other popular bedding plants [Chyliński and Łukaszewska 2008].

Drought, similarly to other abiotic stresses, leads to a series of physiological, biochemical and molecular changes [Wang et al. 2003], including chlorophyll degradation. Chlorophylls are essential pigments of the higher plant assimilatory tissues, responsible for light absorption and proper functioning of the photosynthetic apparatus. Reduced photosynthesis can negatively affect floral development thus lowering the ornamental value of plants. Likewise, adequate levels of chlorophylls also affect the ornamental value as chlorotic, yellowing plants lose their aesthetic appeal. According to Ueda et al. [2003] the chlorophyll a+b content in the leaves can be indicative of stressful conditions, such as water or salt stress.

Our earlier trials have shown that treatments with calcium chloride [Chyliński and Dziedzic 2005] or benzyladenine [Łukaszewska et al. 2008] can alleviate the negative effects of soil water deficit in geraniums. Also silicon is known to exert an alleviative effect on plants subjected to various abiotic stresses [Ma 2004] and its positive effects on bedding plants threatened with periodic soil water deficit were confirmed [Chyliński 2008]. The aim of this study was to compare responses of potted geraniums supplemented with a fertilizer containing 36% silicon and 20% phosphorus to periodical water withdrawal. Application of this fertilizer might be more efficient than watering plants with an aqueous silicon solution as it also provides phosphorus, a macro element known to improve tolerance to drought stresses in many plants [Nelson and Safir 1982; Hu and Schmidhalter 2005; Jin et al. 2006].

MATERIAL AND METHODS

The experiment was carried out in the greenhouses of the Faculty of Horticulture and Landscape Architecture, Warsaw University of Life Sciences, in May–June 2009. The plant material consisted of 8-week geranium seedlings (*Pelargonium hortorum* L. 'Pulsar Red') bought in a commercial company. The seedlings were planted into 1 dm^3 pots into a mixture of peat and composted bark (1:1 v/v) enriched with multimineral fertilizer Azofoska (2 $kg \cdot m^{-3}$). Half of the plants received the fertilizer containing 36% silicon and 20% phosphorus (1 $kg \cdot m^{-3}$). The experiment on the effects of periodical water withdrawal was started after 5 weeks of acclimatization. The average temperature in the greenhouse ranged from 21.0+4.0°C (day) to 10.0+4.0°C (night).

Plants were subjected to two watering regimes: 1. standard watering to 80% SWC (control), 2. watering withheld during two cycles (7 and 10 days) with each cycle followed by watering (7 and 10 days, respectively) and there were four treatments altogether: within watered and stressed plants there were those enriched with Si+P fertilizer and those not fertilized. After 4 cycles (on the 35th day of experiment) 10 plants from each treatment were measured and later used for physiological and biochemical determinations.

Measurements and analyses. The height of the above-ground plant parts and the width of plants (an average of two measurements done in perpendicular directions) were measured (cm), the weight of the above-ground soil plant part determined (g) and the numbers of open flowers and flower buds were counted. The results are the means of 10 measurements.

The relative water content (RWC) was measured on 10 leaves (1 mature upper leaf per plant). Leaves were weighed immediately (FW) then floated on distilled water and weighed again when they reached a turgid weight (TW). Leaves were dried in the oven at 105^{o}C for 24 h and their dry weight (DW measured). The RWC was calculated using the Barrs's formula [1968].

For analyses of contents of chlorophyll a+b and free proline the mature leaves collected from 10 plants were finely cut and thoroughly mixed. Three 1-gram samples for each analysis were then weighted. The chlorophyll a+b content was determined according to Lichtenthaler and Wellburn [1983] and expressed in $mg \cdot g^{-1}$ DW. Free proline contents was analyzed according to Bates et al. [1973] and expressed in $\mu moles \cdot g^{-1}$ DW. Dry weight was determined by drying three 1 g samples at 105°C until the constant weight.

The results were tested using ANOVA 2 and means were compared using the Duncan's test at p = 95%. Results of the interaction of both experimental factors (watering/fertilizing) are gathered in the joint table 1.

RESULTS

Plant height. Application of the fertliliser affected plant growth (tab. 1). As compared to the non fertilized plants the height measured after 5 weeks of the experiment increased by 67% and 72% in the watered and stressed geraniums, respectively. Stress as such had no effect on plant height.

Plant width. Water stress limited plant width in the non fertilized geraniums by 20% while application of the fertilizer increased it in both groups: by one third in control watered plants and by 58% in geraniums subjected to the periodical water withdrawal.

Fresh weight of the above-ground plant part. Water stress decreased while fertilizer increased the plant fresh weight. The fertilizer produced an almost 2- and 3-fold increase in fresh weight in watered and stressed plants, respectively. Water-stressed non-fed plants had fresh weights lowered by 1/3 as compared to the normally watered non fertilized plants. Application of the fertilizer counteracted the negative effect of water shortage on plant growth so the fresh weight of plants from both watering regimes did not differ significantly.

Table 1. Effect of fertilizer (P+Si) on geranium plants determined on 35th day of growth under the experimental conditions (control, normally watered plants *vs* plants subjected to periodical water stress)
Tabela 1. Wpływ nawozu (P+Si) na rośliny pelargonii oznaczony 35 dnia wzrostu w warunkach eksperymentalnych (kontrola, rośliny podlewane normalnie vs rośliny poddane okresowemu stresowi wodnemu)

Parameters measured Określane parametry	Watered Podlewane		Stressed Stresowane	
	- (P+Si)	+ (P+Si)	- (P+Si)	+ (P+Si)
Plant height, cm Wysokość roślin, cm	14.7 a*	24.5 b	13.8 a	23.7 b
Plant width, cm Szerokość roślin, cm	25.4 b	33.9 c	20.3 a	32.1c
Number of flowers Liczba kwiatów	26.5 bc	17.3 a	30.7 c	14.3 a
Number of flower buds Liczba pąków kwiatowych	38.8 b	100.8 c	11.5 a	88.3 c
Weight of plant, g Masa części nadziemnej, g	52.7 b	98.9 c	33.9 a	94.5 c
RWC in leaves RWC w liściach	85.7 a	90.5 b	72.8 a	85.2 b
Chlorophyll a+b, $mg \cdot g^{-1}$ DW Chlorofil a+b, $mg \cdot g^{-1}$ s.m.	2.4 a	9.7 c	4.7 b	10.5 c
Proline, $\mu g \cdot g^{-1}$ s. m. Prolina, $\mu g \cdot g^{-1}$ s. m.	265.9 a	392.9 b	355.8 b	386.4 b

* means in a row followed by the same letter do not differ significantly at $\alpha = 0.05$
* średnie w rzędach oznaczone tą samą literą nie różnią się istotnie przy $\alpha = 0{,}05$

Flower number. Water stress did not significantly affect the flower number which was lowered by the fertilizer – by 35% and 53% in watered and stressed plants, respectively.

Flower bud number. The Si+P fertilizer positively affected the flower bud number in both plant groups and this effect was very pronounced in the stressed group (almost an 8-fold increase as compared to the non fertilized plants). Periodical water withdrawal resulted in a considerable decrease in flower bud number, especially in plants not fed with the fertilizer where it dropped to 30% of the bud number in control watered plants. This dramatic decrease was counteracted by the fertilizer so that the stressed and fertilized plants had only 12% fewer buds than the fertilized plants from the watered control treatment.

Relative water content in leaves. Water stress resulted in a lower RWC in leaves of geraniums but only in plants not fed with fertilizer – by 15% as compared to the watered plants. Feeding the stressed plants with the fertilizer resulted in an elevated RWC – by 17% as compared to the non-fed plants – so that the water contents in both groups of the fertilized geraniums were similar.

Content of chlorophyll a+b in leaves. Both tested factors positively affected the chlorophyll a+b content in leaves. Application of Si+P resulted in 4-fold and over 2-fold increase in pigment level in watered and stressed plants, respectively. In non-fertilized plants grown under the periodical water shortage the chlorophyll content was almost double of that found in control watered geraniums while in the group of plants fed with Si+P no effect of water stress on pigment level was observed.

Content of free proline in leaves. Both factors had an effect on the contents of free proline in leaves of *P. hortorum.* Water shortage caused the 34% increase in the proline content in plants not fed with Si+P while it did not affect it in the fertilized plants. In the watered plants the fertilizer increased the amino acid level by 48% and did not affect it significantly in the stressed plants.

DISCUSSION

Drought frequently affects bedding plants in urban areas causing adverse effects on plant growth and flowering, therefore reducing their aesthetic value. The assessment of plant tolerance of water shortage is usually based on comparison of several growth parameters. In ornamental plants, flowering is usually critical, as it is a decisive trait affecting their commercial value and suitability. Plants subjected to various stresses reduce flowering to save assimilates needed for survival [Augé et al. 2003]. Stresses also lead to a series of physiological, biochemical and molecular changes [Wang et al. 2003]. Measuring selected physiological or biochemical attributes may be another objective and effective approach to evaluate plant drought tolerance or the effectiveness of protective methods aiming to alleviate stress effects [Šircelj et al. 2007]. In our earlier studies we have shown that RWC and chlorophyll a+b contents are parameters which may be used as possible indicators of plant response to drought stress in ornamentals [Chyliński et al. 2007].

In the regions from which the geraniums originated, drought periods are frequent. Plants are compact, with hairy leaves and woody stems what makes them well adapted to drought. The stress conditions imposed on plants during this trial mitigated situations which may occur during their growth in urban spaces. After 2 cycles of water stress, plant height and flowering remained unaffected by the experimental conditions, however, the fresh weight of the above ground plant part was reduced by one third. This could not be related to the diminished water content as RWC in leaves did not dropped due to the soil water deficit. The numbers and surface areas of the developing leaves were also visibly reduced but these parameters were not evaluated here. Earlier observations on geraniums showed that growth and flowering after three 10-days water stress cycles were not seriously affected [Chyliński et al. 2007] but when watering was withheld for 2 weeks, both parameters were significantly reduced [Łukaszewska et al. 2008]. Compared with both earlier experiments the stress conditions used in this trial might have been too mild to seriously harm geraniums.

Silicon has been shown to promote growth and development of plants under different stresses, including water stress [Ma 2004] and our first trials with watering bedding plants with the solutions of water glass were promising [Chyliński 2008]. Therefore, it seemed sensible to test if the application of a Si-containing fertilizer may be a simple method of improving the quality of ornamental plants endangered by drought, especially as the Si fertilizer also contains phosphorus, and phosphorus is known to improve plant resistance to water stress. For example, adequate P nutrition in the onions during soil water stress was a major factor in improved drought tolerance [Nelsen and Safir

1982]. The positive effects of P on the African violets growth under drought have been attributed to an increase in the water use efficiency, stomatal conductance and photosynthesis, to a higher cell membrane stability and to its effects on water relations [Sawwan et al. 2000]. In these experiments, the Si+P fertilization significantly improved geranium growth under both watering regimes, and especially the growth of plants subjected to periodical water stress so that the stressed plants did not significantly differ from the normally watered controls.

Earlier trials on bedding plants [Chyliński et al. 2007] showed that drought did not affect the flower numbers in geranium, however, in those experiments, flower buds developing during stress were not counted at the experiment's end. In this test, a temporary water deficit did not reduce the abundance of flowering but its main impact was on the number of flower buds developing during the experiment itself. Therefore, even a relatively short water stress does negatively impact future plant performance. In the context, addition of Si+P to the growing medium was spectacular: it produced an almost 8-fold increase in the flower bud number in stressed geraniums. A reduction in the number of open flowers was observed in the fertilized (watered and non watered) plants but was probably due to a faster development and fading of flowers initiated and developed before the beginning of the trial. Thus, an application of the fertilizer appears as an easy and efficient treatment ensuring at least adequate bloom for an extended period. Which of the two components of the fertilizer used, Si or P, was not ascertained but Jin et al. [2006] have shown that a P-containing fertilizer mitigates drought stress at the reproductive stage of soybeans by improving its flowering and seed yield. According to Sawwan et al. [2000], P exerts a positive effect on plant water relations under drought. On the other hand, Si improved the water status of drought stressed wheat plants grown in pots [Gong et al. 2005]. Results of Hattori et al. [2005] suggest that Si may be useful to improve the drought tolerance of sorghum due to the enhancement of water uptake We did not measure this variable but water uptake might have been affected as the relative leaf water content (RWC) was elevated in both plant groups fed with the fertilizer. In soybean seedlings, the RWC increased 19% with the Si application under drought stress [Shen et al. 2010] and it was 17% in our stressed and fertilized geraniums.

No harmful effect of water stress on the chlorophyll a+b in geraniums was reported in earlier tests [Chyliński and Dziedzic 2005; Chyliński et al. 2007]. Here, the pigment content was doubled in the stressed plants relative to control watered plants which may confirm a supposition that the stress applied was rather mild and a compensation mechanism was triggered. A good tolerance of geranium to water stress and the absence of a drought-induced damage to the PSII photochemistry in potted geraniums subjected to a severe deficit irrigation was demonstrated by Sanchez Blanco et al. [2009]. An addition of silicon increased the leaf chlorophyll concentration of wheat seedlings under water stress induced by polyethylene glycol [Pei et al. 2010]. Application of the fertilizer considerably increased the chlorophyll levels in geranium plants under both watering regimes therefore it may be advisable to use it routinely on bedding plants as it may improve plant quality under different irrigation regimes.

Plants accumulate free proline under drought-stress conditions It is therefore believed that proline acts as osmoprotectant in plants subjected to water stress [Yamada et al. 2005]. Transgenic tobacco synthesized 10–18 times more free proline than the controls and were more tolerant to water stress [Kavi Kishor et al. 1995]. A clear correlation between the survival rate of petunia plants subjected to drought and accumulated proline in transgenic plants was demonstrated by Yamada et al. [2005]. It is difficult to speculate on the significance of this phenomenon in the present study as the increase in the content of free proline was small, and was similarly affected by the water stress and the fertilization, and the two effects were not additive.

Although not all the water stress indicators measured here responded similarly to the earlier reports and the mechanisms of their action are far from having been elucidated the results of this trial seem promising. They suggest that addition of the Si+P fertilizer to the growing medium can be an easy and a cheap method to enhance the resistance of geraniums to water stress, preserving their decorative values for longer.

CONCLUSIONS

1. Application of the Si+P fertilized counteracted the negative effects of water stress on vegetative growth and certain biochemical parameters of potted geranium plants.
2. Number of flower buds was drastically reduced under the stressful conditions and the addition of Si+P almost completely counteracted this damage.
3. Addition of the Si+P fertilizer to a growing medium can be an easy and cheap method to enhance resistance of potted geraniums to water stress.

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WPŁYW NAWOZU FOSFOROWO-KRZEMIANOWEGO NA REAKCJĘ PELARGONII (*Pelargonium hortorum* H.L. Bailey) ROSNĄCEJ W WARUNKACH STRESU WODNEGO

Streszczenie. Pelargonie należą do popularnych roślin rabatowych stosowanych w miejskich terenach zieleni i w ogrodach prywatnych. Są dobrze przystosowane do znoszenia suszy, często jednak podlegają stresowi wodnemu, szczególnie, gdy rosną w pojemnikach. W pracy określono reakcję pelargonii rabatowych posadzonych do doniczek z podłożem wzbogaconym nawozem krzemianowo-fosforowym zawierającym 36% Si i 20% P na okresowe niedobory wody w podłożu. Połowę z uprawianych w szklarni roślin poddano dwóm cyklom bez podlewania (7 i 10 dni) na przemian z 2 cyklami ze standardowym podlewaniem (rośliny stresowane), druga połowa roślin była podlewania w trakcie całego doświadczenia (rośliny kontrolne). W każdej grupie połowa roślin została posadzona w podłoże wzbogacone w/w nawozem. Parametry wzrostu i kwitnienia określono 35. dnia doświadczenia, kiedy to również zmierzono w liściach RWC i pobrano materiał do oznaczeń zawartości wolnej proliny i chlorofilu a+b. Stres wodny w niewielkim stopniu wpłynął na wysokość roślin, ale zmniejszył o 1/3 świeżą masę części nadziemnej. Liczba kwiatów nie uległa zmianie pod wpływem stresu, ale liczba pąków kwiatowych rozwijających się w trakcie doświadczenia spadła u roślin stresowanych do 30% w porównaniu z kontrolą. Zastosowanie nawozu stymulowało wzrost roślin, ale obniżyło liczbę kwiatów w obu grupach roślin. Nawożenie wpłynęło natomiast pozytywnie na liczbę pąków kwiatowych, szczególnie u roślin stresowanych, zwiększając tę wartość prawie 8-krotnie w stosunku do roślin nietraktowanych nawozem. Zawartość wody w liściach (RWC) nie zmieniła się pod wpływem zróżnicowanego podlewania, natomiast nawóz zwiększył ten parametr w obu grupach roślin. Nawóz wpłynął na wzrost zawartości chlorofilu a+b w liściach, która wzrosła istotnie również pod wpływem stresu. O 1/3 wzrósł poziom wolnej proliny pod wpływem okresowego niedoboru wody, ale większy jego wzrost nastąpił pod wpływem nawożenia – o 48% w stosunku do kontrolnych, stale podlewanych roślin. Wyniki doświadczenia dowodzą, że zastosowanie nawozu zawierającego krzem i fosfor może stanowić łatwą i tanią metodę łagodzenia niepożądanych efektów stresu wodnego u pelargonii rabatowej.

Słowa kluczowe: rośliny rabatowe, susza, wzrost, kwitnienie, RWC, wolna prolina, chlorofil a+b

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