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WATER ABSORBING GEOCOMPOSITE: A NOVEL METHOD IMPROVING WATER AND FERTILIZER EFFICIENCY IN *Brunnera macrophylla* CULTIVATION. PART I. PLANT GROWTH

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ABSTRACT

Water absorbing geocomposite (GC) consisting of SAP, geotextile and internal skeleton is a novel method of superabsorbent polymer (SAP) and fertilizer application. Roots can overgrow the geotextile and thus obtain access to water. The objective of the experiment was to determine the effect of the geocomposite on the growth of container-grown *Brunnera macrophylla*. The geocomposite was used as a multi-compound fertilizer (Insol® U) carrier and compared with soluble fertilizer (SF) and controlled-release fertilizer (CRF). The doses of fertilizers were calculated to cover the equal N supply: 0.36 and 0.72 g plant^{-1}. The geocomposite positively influenced the plant traits after 8 and 16 weeks of cultivation. The number of leaves increased by 42% and 60% and the biomass of the above-ground parts of plants increased by 260% and 340% in comparison to plants treated with other fertilizers. The effect of the fertilization rate on plants was weakly pronounced, but a positive influence of a higher dose and the GC combined on all the examined traits of Siberian bugloss plants was detected.

Key words: container nursery, superabsorbent polymers, plant development, chlorophyll

INTRODUCTION

One of the methods of reducing the water consumption is the maximization of water retention through the introduction of hydrophilic superabsorbent polymers (SAPs, hydrogels) [Koupai et al. 2008, Ekebafe et al. 2011, Babelewski et al. 2017]. SAPs are a class of three-dimensional hydrophilic polymeric networks that are able to absorb and retain high quantities of water that can be subsequently taken up due to the suction force of roots. The cycle of swelling and shrinking may occur repeatedly. In agricultural production and landscape architecture in arid lands, superabsorbent polymers are usually used to prevent the loss of water from the soil, caused both by leaching and evaporation [Bhat et al. 2009, Dorraji et al. 2010]. Their effect on plants consists in delaying the wilting point, enhancing the drought tolerance and diminishing the water stress responses such as reduced transpiration, decreased chlorophyll content and abscission of leaves [Nazarli and Zardashti 2010].

So far, the application of superabsorbent polymers into the soil has been realized through: spraying in

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the form of solution directly onto the soil surface, polymer injection to a determined depth, hydro-sowing of diluted emulsion with seeds, conditioning the root system prior to planting and mixing with the growing medium or the soil into a determined depth – being the most common methods [Ingram and Burbage 1985]. However, the application of SAP often does not yield expected economic results, when an increase in the productivity of plants does not compensate for high costs of SAP application. This limits its usage to high quality crops such as landscape trees and ornamental plants cultivated in containers. SAP amendment in nursery production results in a decrease in the need for water supply and irrigation frequency as well as a reduced fertilizer use. These facts, together with the induction of faster growth in response to SAP, contribute to an increased efficiency of production [Montesano et al. 2015]. Delayed wilting point and improved establishment and survival after planting extend the range of plant species that can be cultivated in dryer conditions [Agaba et al. 2010]. Although majority of studies confirm the positive influence of SAPs on plant growth, they emphasize that the effectiveness of SAPs depends on numerous factors. Overuse of SAPs, especially by direct application, e.g. by mixing with soil or substrate, leads to a deterioration in physical properties of the growing medium [Hejduk et al. 2012] and a decline in the soil aeration [Khodadadi Dehkordi 2016]. Moreover, low pH of the soil/medium and even small loads cause a significant deterioration in water absorbing capacity of the superabsorbent polymer [Pourjavadi et al. 2010, Sadeghi and Hosseinzadeh 2008]. Another problem is competing with plants for water under severe drought conditions [Zohuriaan-Mehr et al. 2010]. Water absorbing geocomposites that retain water inside, enable the root system to use it as a water reservoir without mixing with soil and may be applied in a wide range of water conditions, from extreme water deficit e.g. in gabion constructions to circumstances when water supply is not limited.

Siberian bugloss *Brunnera macrophylla* (Adams) I.M. Johnst. is a rhizomatous perennial native to Western Asia and the Caucasus, where it grows in oak and spruce forests, often near creeks. It is a frost-resistant plant characterized by high water and nutrient demand, but with relatively good tolerance to drought [Hinova et al. 2016], cultivated for ornamental purposes due to its large, heart-shaped leaves and small, blue flowers in cymes forming lax panicles. Varieties with variegated or silvery leaves are considered particularly attractive.

The objective of the experiment was to determine the effect of water absorbing geocomposite on the growth of *Brunnera macrophylla* cultivated in containers. The geocomposite was used as a multi-compound fertilizer carrier and compared with other fertilizers commonly used in container nursery production.

MATERIAL AND METHODS

The experiment was established in Psary (long. 17.00E; lat. 51.05N), at a research station of Wrocław University of Environmental and Life Sciences (WUELS), Poland, from May to August 2010 and 2012. Plants of *Brunnera macrophylla*, propagated *in vitro*, were planted in 1.5 dm^3 containers, in peat substrate containing 1 g dm^{-3} of YaraMila^{TM} fertilizer, pH 6.8 (determined in distilled water, in water to medium ratio 2 : 1, V : V). The two-factorial experiment was established in a completely randomized design, with three replications, 8 plants in each. The first factor was the type of fertilization; the second one was the dose of a fertilizer.

Geocomposite. The cylindrical geocomposite with 5 g of superabsorbent polymer (potassium salt of cross-linked polyacrylic acid) was used for the purposes of the study. A recycled version built with water permeable polyester, non-woven sheath and internal skeleton structure from polyethylene was proposed (Fig. 1). Plant roots could overgrow the geotextile to obtain the access to water absorbed by the SAP [Lejcus et al. 2015, Oksinska et al. 2016]. The geocomposite element (diameter 7 cm, height 5 cm) could expand its size, and therefore absorb 300.0 cm^3 of distilled water.

Experiment conditions. Three types of fertilization were applied: 1. geocomposite (GC) + multi-component fertilizer Insol® U, produced by Fertilizer Research Institute, Puławy, Poland; 2. soluble fertilizer (SF) YaraMila^{TM} Complex by Yara International ASA; 3. control release fertilizer (CRF) Osmocote® Exact® Standard 3-4M by Scotts (Tab. 1). The fertilizers' doses were calculated to cover the equal N supply: 0.36 and 0.72 g plant^{-1}.

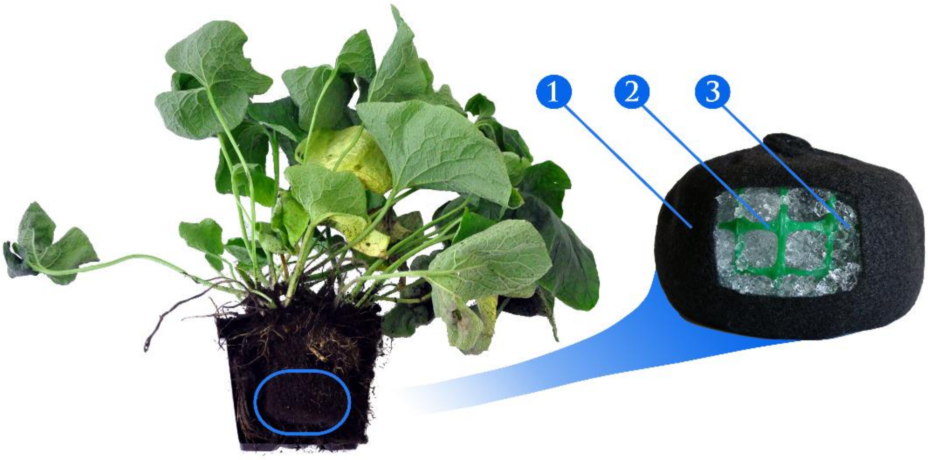

Fig. 1. Longitudinal section of the container with *Brunnera macrophylla* and geocomposite; (1) nonwoven sheath, (2) internal skeleton structure, (3) superabsorbent polymer

Table 1. Composition of fertilizers

Nutrients (% by weight)	Insol® U*	YaraMila™ Complex	Osmocote® Exact®
NO_3^--N	2.0	5.0	7.1
NH_4^+-N	–	7.0	8.9
Urea	10.0	–	–
P_2O_5	4.0	11.0	12.0
K_2O	6.0	18.0	12.0
MgO	–	2.7	2.0
S	–	8.0	–
B	0.01	0.015	0.03
Cu	0.01	–	0.03
Fe	0.02	0.02	0.08
Mn	0.01	0.02	0.06
Mo	0.005	–	0.02
Zn	0.01	0.02	0.015

* density 1.2 g cm^{-3}

To avoid excessive SAP swelling restraint, the GCs were soaked in Insol® U 0.3% and 0.6%, absorbing about 250 cm^3 of solution. After soaking, the GC element was placed on the bottom of each container before plants planting. The lacking nutrients (75 cm^3 of 0.3 and 0.6% solution, respectively), were supplemented in four weekly injections directly into the GCs to provide total dose 2.5 and 5.0 cm^3 Insol® U per plant, respectively. The remaining plants received SF (3.0 g or 6.0 g per plant) applied twice in two equal doses (1.5 g or 3.0 g per each treatment) at a monthly interval onto the surface of substrate or CRF (2.25 g or 4.50 g) mixed with the growing medium before planting. The plants were cultivated in a shaded (59%) plastic tunnel at 0.4 × 0.3 m spacing and irrigated with tap water depending on weather conditions: the plants were watered by sprinklers, 2–7 times a week, receiving 200 cm^3 $plant^{-1}$ per each irrigation.

Measurements and analyses. Plant growth was assessed in the 8th and 16th week of experiment on the basis of the following measurements: height and diameter of plants, number of leaves, fresh and dry weight of the above-ground parts of plants. After 8 weeks of cultivation, the chlorophyll content of leaves was determined after extraction in 80% acetone [Cirillo et al. 2016]. Absorption was measured with a spectrophotometer (WPA, S106), at 645 and 663 nm, and chlorophyll content (in mg g^{-1} f.m.) was calculated according to the equation: chlorophyll $a + b = 8.02\ (A_{663}) + 20.21\ (A_{645})$.

Experimental results were statistically processed according to the method of variance analysis (ANOVA) for two-factorial experiment. To estimate the significance of differences, the Duncan test was used. Analyses were conducted with the use of the Statistica v. 10 software. The level of significance was set at 0.05.

RESULTS

Plant growth. Our research indicated a positive influence of the geocomposite on all examined biometrical traits of *Brunnera macrophylla* after both periods, 8 and 16 weeks of cultivation. A substantial increase in the number of leaves was documented (Fig. 2). After 8 weeks, it rose by 42% and 60% as compared to the plants fertilized with SF and CRF, respectively. This relation was further improved at the end of the experiment (Tab. 2). It was reflected in a distinct increase in the biomass of the above-ground parts of plants. In comparison to plants fertilized with SF and CRF, an increase by 260% and 340%, respectively, was recorded (Tab. 3). This was also the only trait that differed between the plants fertilized with SF and CRF, with the lowest weight represented by plants cultivated with CRF. There were no other differences between the influence of SF and CRF on any other feature of the plant growth. The influence of the fertilization rate was equivocal and less pronounced. The application of fertilizers in a higher rate led to a decrease in the height of plants after 8 weeks of the experiment, whereas it determined an increase in the number of leaves in the second period of cultivation. At that time, simultaneous influence of both examined factors on plant diameter and leaf number could be noticed – plants cultivated with the geocomposite and higher doses of fertilizer achieved the largest diameter and the highest number of leaves. Neither the form nor the dose of fertilization influenced the dry matter content in *Brunnera* leaves.

Chlorophyll content. Regardless of the fertilizer dose, a significant increase of chlorophyll was stated in leaves of *Brunnera* plants cultivated with the geocomposite (Tab. 3). Also fertilisation in the higher dose positively affected this trait of plants. This resulted in a distinct rise of chlorophyll content in plants cultivated with the GC-0.72 g N per plant.

Fig. 2. *Brunnera macrophylla* plants cultivated with different types of fertilization (abbreviations: see Table 2)

Table 2. Effect of dose and type of fertilization on biometrical traits of *Brunnera macrophylla*

Treatment	Plant height (cm)		Plant diameter (cm)		Leaf number (no plant^{-1})	
	8 weeks	16 weeks	8 weeks	16 weeks	8 weeks	16 weeks
Mean for fertilizer type and dose						
GC-0.36 g N	25.04a	25.67a	37.03a	57.29c	24.50a	24.40b
GC-0.72 g N	21.92a	24.25a	36.81a	49.98b	23.65a	31.56c
SF-0.36 g N	21.87a	20.27a	31.04a	38.95a	15.46a	17.29a
SF-0.72 g N	18.56a	18.18a	30.99a	39.89a	18.54a	17.65a
CRF-0.36 g N	20.63a	20.29a	32.33a	35.67a	13.96a	16.71a
CRF-0.72 g N	21.16a	19.35a	32.58a	38.58a	16.15a	19.17a
Mean for fertilization type						
GC	23.48b	24.96b	36.92b	53.64b	24.08b	27.98b
SF	20.22a	19.23a	31.02a	39.42a	17.00a	17.47a
CRF	20.90a	19.82a	32.46a	37.13a	15.06a	17.94a
Mean for dose						
0.36 g N	22.51 b	22.08a	33.46a	43.97a	17.97a	19.47a
0.72 g N	20.55 a	20.59a	33.46a	42.82a	19.45a	22.79b

Mean values within the columns with the same letters are not significantly different
Means of years 2010 and 2012. GC – Geocomposite + soluble fertilizer Insol® U; SF – soluble fertilizer YaraMila™ Complex; CRF – control release fertilizer Osmocote® Exact®

Table 3. Effect of dose and type of fertilization on *Brunnera macrophylla* and growing medium

Treatment	Leaf fresh weight (g plant^{-1})	Dry matter content (%)	Chlorophyll *a + b* (mg g^{-1} f.w.)
Mean for fertilizer type and dose			
GC-0.36 g N	367.8d	21.1a	0.58a
GC-0.72 g N	431.9e	20.0a	0.79b
SF-0.36 g N	132.4b	20.9a	0.54a
SF-0.72 g N	171.8c	21.4a	0.60a
CRF-0.36 N	92.3a	20.6a	0.63a
CRF-0.72 N	140.3b	19.8a	0.59a
Mean for fertilizer type			
GC	399.9c	20.6a	0.69b
SF	152.1b	21.2a	0.57a
CRF	116.3a	20.2a	0.61a
Mean for dose			
0.36 g N	197.5a	20.9a	0.58a
0.72 g N	248.0b	20.4a	0.66b

Mean values within the columns with the same letters are not significantly different
Means of years 2010 and 2012. GC – Geocomposite + soluble fertilizer Insol® U; SF – soluble fertilizer YaraMila™ Complex; CRF – control release fertilizer Osmocote® Exact®

DISCUSSION

The main aim of SAP utilization in horticultural production is to improve the water relations in the soil and plants, especially those exposed to water stress. In light soils or in conditions of drought stress, a moderate application of SAPs improves the soil structure (increased aggregation), water retention, and infiltration, decreases water and nutrient losses and increases the water available to plants. An important aspect of SAP application is also an improved microbial activity and abundance in the soil [Li et al. 2014]. All of this leads to an improved efficiency of water and nutrient use, prolongs the periods of plant survival between irrigations, improves the establishment of plants after replanting and plant performance under drought stress conditions [Khodadadi Dehkordi 2016].

Apart from preventing the drought-induced inhibition of plant growth, SAPs are involved in numerous metabolic plant responses. Among those, leaf and xylem water potential, elevated values of the total soluble protein content in leaves, diminished oxidation stress through increased activity of antioxidant enzymes and increased net photosynthesis are mentioned [Islam et al. 2011]. The stimulation of plant development due to SAP application was also documented under unlimited water supply [Orikiriza et al. 2009, Rostampour et al. 2012], although it can be less pronounced [Boatright et al. 1997]. Most frequently, plants less tolerant to drought benefit more from the SAP incorporation [Dorraji et al. 2010] in such conditions. For example, an increased number of leaves, shoots and flowers, leaf area and flower size as well as number and length of roots were observed in Chrysanthemum [Ghasemi and Khushkhui 2007]. In case of petunia [Boatright et al. 1997] and *Eupatorium purpureum* [Wroblewska et al. 2012], a substantial increase of growth under adequate water conditions was also observed. High water requirements may be one of the explanations of strong stimulatory influence of the geocomposite on *Brunnera macrophylla* not subjected to drought, demonstrated in our research. Regardless of the dose of N fertilization, *Brunnera* plants grown with the geocomposite reached a greater height and leaf number after 8 weeks than the others after a twice longer period of cultivation. An intensified growth resulted in a substantial increase in the above-ground biomass of plants. It was also accompanied by an elevated chlorophyll content. A higher chlorophyll concentration is often connected with the use of SAPs under water deficit [Khadem et al. 2010, Razban and Pirzad 2012], but was rarely reported under sufficient water supply [Sheikhmoradi et al. 2011]. An increased chlorophyll content suggests intensified photosynthesis. An improved stomatal exchange and CO_2 as a response to SAP amendment may also play a part in the stimulation of this process [Nazarli and Zardashti 2010]. An increase in plant biomass under the non-stress conditions is also explained by enhanced utilization of photosynthates and efficiency of water consumption in the photosynthesis process leading to an increased water uptake efficiency [Orikiriza et al. 2009]. The improved uptake of water exceeds the enhanced transpiration water loss of faster growing plants [Jobin et al. 2004]. The increased water content in substrate, connected with the geocomposite application, supports this thesis [Wroblewska et al. 2018]. It is noteworthy that the rise in substrate water content took place without any direct contact between SAP and the growing medium. The effect of the fertilization dose on plants was not so well pronounced, leading to 17% increase in leaf number and 25% in fresh weight after fertilizing with a higher dose at the end of the experiment. This phenomenon was observed despite of the impairment in water retention capacity by higher concentration of salts. A similar response to saline soils was observed by Huttermann et al. [2009]. Despite these circumstances, water retention capacity and plant growth in saline soils are still significantly higher than in the same soils with no SAP applied.

CONCLUSION

The water absorbing geocomposite positively influenced the growth of *Brunnera macrophylla* plants. A significant increase in the biomass of the above-ground part of plants (up to 340%) and in the number of leaves (up to 60%) compared to the plants fertilized with other fertilizers was noted. The enhanced biomass of plants cultivated with the geocomposite at the same level of water and fertilization supply indicates improved efficiency of water and nutrient uptake in container production of *Brunnera macrophylla*.

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