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Impact of conditioners added to soil of different bulk density on saturated water content and water holding capacity over a six-day manipulative experiment

Ondřej Špulák*, Dušan Kacálek, Jan Bartoš, Jan Leugner, Zdeněk Ráček

Forestry and Game Management Research Institute, Research Station at Opočno, Na Olivě 550, CZ-517 73 Opočno, Czech Republic

Abstract

Artificial superabsorbents specifically influence the water absorption capacity of soils. The article compares four commercially available synthetic superabsorbents mixed with soil of different bulk density. Soils at each of nine study sites were sampled at five spots minimally to get site-representative soil samples. The soils were mixed with hydrophilic substances such as acrylamide, polyacrylic acid, cross-linked polymers and potassium polyacrylate. Both amended and non-amended soil was then put into sampling rings, which open bottoms were exposed to water through a filter paper to be soaked via capillary action to the saturated water content of the soil (θ_S). Then the samples were drained by passive capillary drainage through another piece of 4-layer filter paper. Periodical weighing of the samples enabled us to determine and calculate water-holding attributes. Following the 114 hours of the experiment, the samples were oven-dried at 105 °C to determine their bulk density. The passive capillary drainage showed higher loss of water from the amended treatments though they kept a larger volume of water than the control treatments over the period of experiment. Keeping recommended concentrations of the substances by the producers led to different efficiencies especially in soils with higher bulk densities.

Key words: forest soil; water retention; superabsorbents/hydrogels; water loss

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1. Introduction

One of methods how to increase a temporary soilwater availability, thus amending growing conditions of plants during critical stages, is an addition of soil conditioners – superabsorbents (Landis & Haase 2012; Adjuik et al. 2022). Their principal function is to retain more water in the soil (Montesano et al. 2015; Takahashi et al. 2023). This is related to the content of either artificial or natural ingredients capable of holding water; particularly those ones with expected biodegradability (e.g., Wilske et al. 2014; Guilherme et al. 2015; Montesano et al. 2015; Čechmánková et al. 2021; Durpekova et al. 2021; Kaur et al. 2023; Piccoli et al. 2024). The superabsorbents applied in forestry are expected to ameliorate substrates of containerized seedlings or improve soil properties in planting pits (Landis & Haase 2012; Crous 2017; Tubert et al. 2018). When used in agriculture, more plant-available water means less irrigation i.e. protection from drought (Kaur et al. 2023) or an expected greater production (Womack et al. 2022; Wu et al. 2024). This would be a measure compensating for the amendment costs (Grabowska-Polanowska et al. 2021). There are many commercial amendments, which are supposed to help plantations cope with drought periods. Both synthetic and natural substances can effectively retain water when applied at concentrations as low as 0.1% to 1% of the volume of the amended soil or substrate (Adjuik et al. 2022). The effectiveness of the substances is influenced by their chemical composition, particle size and used dosage. Dosage recommended by the producer can be expected to represent an optimal ratio of costs and benefits. However, mutual comparison of the different products mixed with soil samples of varying physical properties was expected help choosing the best solutions in specific soil conditions.

The objective of the study is to compare how four commercially available synthetic superabsorbents mixed with soil of different bulk density influence water retention. The results can focus producers as well as practitioners on the most effective compositions of the additives regarding positive impact to soil and consequently to plants.

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*Corresponding author. Ondřej Špulák, e-mail: spulak@vulhmop.cz

2. Material and methods

2.1. Experimental material

The used superabsorbents' contents differ in accordance with producer's formulas; three of these are active synthetic substances only and product of TerraCottem Arbor (CLP) is a mixture of synthetic and natural substance (Table 1). The four commercially available superabsorbents were tested because they were expected to hold water efficiently when mixed with the soils. In addition, no dangerous products of their decomposition were known. Besides the four treatments with amendments, control treatments with no superabsorbent added were established.

2.2. Experimental design

Topsoil mineral soil was sampled on seven temporary clear-cut study sites and on two forest-nursery bed sites (Fig. 1, Table 2). To represent each site, the samples taken from minimally five spots were mixed. In the lab, these representative soils were separated into sub-samples for Control treatments (with no amendment) and four parts were then mixed with superabsorbents applied in doses recommended by producers. The exception was the PP-C treatment, which was a whole capsule containing the amendment put to the soil within the 100 ml volume of metal sampling ring, which made its concentration ten times higher than the recommended one (Table 1). The capability of the soil treatments to hold/lose water over time was monitored using a method of absorptiveness (Valla et al. 1983; Zoubková 2014).

Soil-sampling rings had the same volume of 100 ml and accurately known weight. They were filled manually with both treated soils and control soils. The soil of each treatment including Control was compacted to emulate backfill soil properties within planting holes. The filling and firming of the soil samples to the rings were proceeded by one laboratory technician, the pressure put on the soil was relatively constant as can be approved by low variability of sample bulk densities. Each combination of site-specific soil and applied superabsorbent was ten times replicated; a total of 440 samples were subjected to controlled saturation and drying (see Valla et al. 1983). The procedure is outlined as follows:

1. The sample saturation was risen by capillary action. Distilled water was poured into a shallow tray. The sample rings, covered with Petri-dish lids, were laid down on pads covered with 4-layer round filter paper so as to sample bottoms and the centers of the paper below them were placed above the water level whereas the margines of the paper extended to the water. Then, the soil was soaked through the water-saturated paper for at least 12 hours (Fig. 2).

Table 1. The list of tested products (substances) and treatments.

Treatment	Hydrophilic substance	Dosage ($g\ l^{-1}$)	100 ml sample content
Control	—		soil
AA	acrylamide	2.50	soil + 0.25 g of akrylamide
PAA	polyakrylic acid	3.00	soil + 0.30 g of polyakrylic acid
CLP	cross-linked polymers	1.50	soil + 0.15 g of cross-linked polymers mixed with fertilizers and volcanic rock
PP-C	potassium polyacrylate	11.6*	soil + 1 capsule of potassium polyacrylate

Notes: *The dosage was ten-times higher than recommended by the producer, because the whole capsule was put to soil sample in 100-ml sampling rings. Brand (producer): AA – Agrisorb Mikro (Stockhausen); PAA – Hydrogel (Degussa AG); CLP – TerraCottem Arbor (TerraCottem); PP-C – Wasserkapsel (Flügel GmbH).

Table 2. The site attributes, soil bulk densities and soil density groups (SDGs).

Study sites	GPS	Bedrock*	Ecosite	Altitude (m)	Aspect	Soil type (FAO)	Soil density group**
Br1	50.1133325N, 16.1166436E	Sand, gravel	nutrient-poor pine-oak	280	flat land	Cambic Arenosol	1
Br2	50.1118600N, 16.1136717E	Sand, gravel	nutrient-poor pine-oak	280	flat land	Cambic Arenosol	1
Bst	50.3273100N, 16.2485547E	Phyllite	nutrient-medium beech	510	NW	Dystric Cambisol	4
Dst	50.2808783N, 16.3695706E	Gneiss	nutrient-medium spruce-beech	720	SE	Dystric Cambisol	2
Hrl	49.2431294N, 15.6975150E	Paragneiss	nutrient-medium spruce-fir	630	SE	Dystric Cambisol	1
Nvp	50.3072392N, 15.9397572E	Sand, gravel	nutrient-medium birch-oak	260	flat land	Albic Luvisol	2
Pls	50.3170914N, 16.3084539E	Phyllite	acidic fir-beech	680	E	Dystric Cambisol	4
Bd1 Bd2***	50.2680817N, 16.1078836E	soil mixed with peat from the forest nursery beds				Anthroposol	3 3

Notes: *Source: https://mapy.geology.cz/geo/; **1 – highest soil density soils to 4 – lowest soil density soils; ***no CLP treatment.
The soil sampling sites within the municipality district: Br1 – Borohrádek 1, Br2 – Borohrádek 2, Bst – Bystré, Dst – Deštné, Hrl – Heraltice, Nvp – Nový Ples, Pls – Plasnice; Bd1 and Bd2 – Opočno.

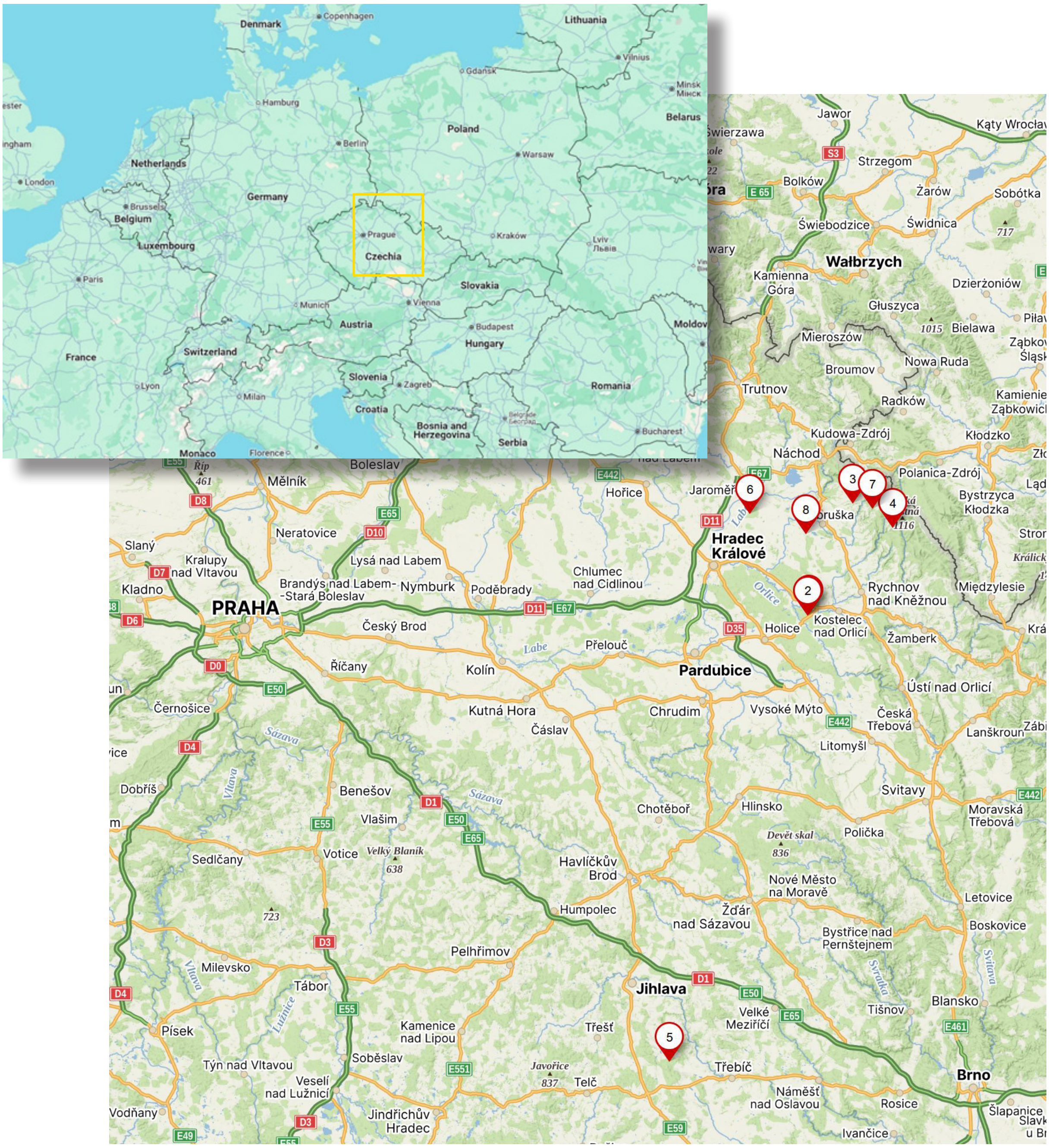


Fig. 1. Location of the sampling sites. 1 and 2 (overlapped) – Br1 and Br2; 3 – Bst; 4 – Dst; 5 – Hrl; 6 – Nvp; 7 – Pls; 8 - Bd1 and Bd2. For more information see Table 2. (Source: Mapy.cz).

2. After saturation, the ring with the sample was weighed to determine the saturated water content in the sample (θ_S; capillary saturated sample, see Table 3).
3. Being still covered with the glass lids, the rings were laid down on dry 4-layer filter papers thus initiating the passive capillary drainage of excess water.
4. After 30-minute drainage, the rings were weighed to determine θ_{30}.
5. The samples were laid down on new pieces of 4-layer filter paper (ditto at each further step). After totally 2-hours of drainage, the rings were weighed to determine maximum capillary water-holding capacity (θ_{CWH}; Novák 1954).
6. After 24-hour drainage, the rings were weighed to determine soil-water retention capacity (θ_{SWR}).
7. After 48-, 72- and 144-hour drainage, the rings were weighed to determine θ_{48}, θ_{72} and θ_{144}, respectively.
8. Then, the soil samples, still in sampling rings, were dried out at 105 °C in an oven for 24 hours until its weight became constant, then the bulk density (BD) of dry soil was determined.

Fig. 2. Experimental rings filled with soil samples during passive capillary drainage.

The weight changes due to soaking and draining periods were used to calculate attributes describing both recharge and depletion regimes (Table 3).

2.3. Data analysis

The data was processed using R (R Core Team 2024). The soils of the site origins were grouped together to have four soil density groups (SDG1 for the soils with highest BD and SDG4 for the soils with smallest BD; Table 2, Fig. 3). The SDG1 was represented by Dystric Cambisol developed on Paragneiss and Cambic Arenosol on Sand. The SDG2 was represented by Dystric Cambisol on Gneiss and Albic Luvisol on Sand. Antroposoils from forest nursery beds formed the SDG3 and SDG4 included Dystric Cambisol on Phyllite (Table 2). Each SDG was then analyzed separately. To verify data consistency, the attributes (Table 3) were compared using a factor ANOVA test where the amendment was set a fixed factor and substrate (soil) was a blocking factor. Some data describing water content exhibited deviations from homoskedasticity. Boc-Cox transformation did not

Table 3. The water-content attributes of soil samples.

	Attribute	Unit	Description	Calculation
	BD	kg m^{-3}	bulk density of soil	weight of the dried soil samples
	θ_S/BD	%	saturated water content in sample in % of bulk density	θ_S/BD
Volumetric water content	θ_S	%	saturated water content in sample = absorbed at T_0 (the beginning of water loss by passive capillary drainage)	equivalent to weight of water in 100 ml of saturated soil sample (in experimental ring)
	θ_{30}	%	water content after 30 min. of passive capillary drainage (i.e. 30 min. after saturation)	equivalent to weight of water in 100 ml (in experimental ring) of sample after 30 min. of passive capillary drainage
	θ_{CWH}	%	capillary water holding capacity (water loss 2 hours after saturation)	ditto after overall 2 hours of passive capillary drainage
	θ_{SWR}	%	soil water retention capacity (24 hours after saturation)	ditto after 24 hours
	θ_{48}	%	water content 48 hours after saturation	ditto after 48 hours
	θ_{72}	%	water content 72 hours after saturation	ditto after 72 hours
	θ_{144}	%	water content 144 hours after saturation	ditto after 144 hours
Relative water content	SWD_{30}	%	relative Soil Water Depletion due to passive capillary drainage 30 min. after saturation	relative share of water in the sample after 30 min. of drainage (Saturated Water Content (SWC) = 100%)
	SWD_{CWH}	%	water loss relative to θ_{CWH}	ditto at the time of CWH determination
	SWD_{SWR}	%	water loss relative to θ_{SWR}	ditto at SWR
	SWD_{48}	%	water loss relative to θ_{48}	ditto after 48 hours
	SWD_{72}	%	water loss relative to θ_{72}	ditto after 72 hours
	SWD_{144}	%	water loss relative toθ_{144}	ditto after 144 hours

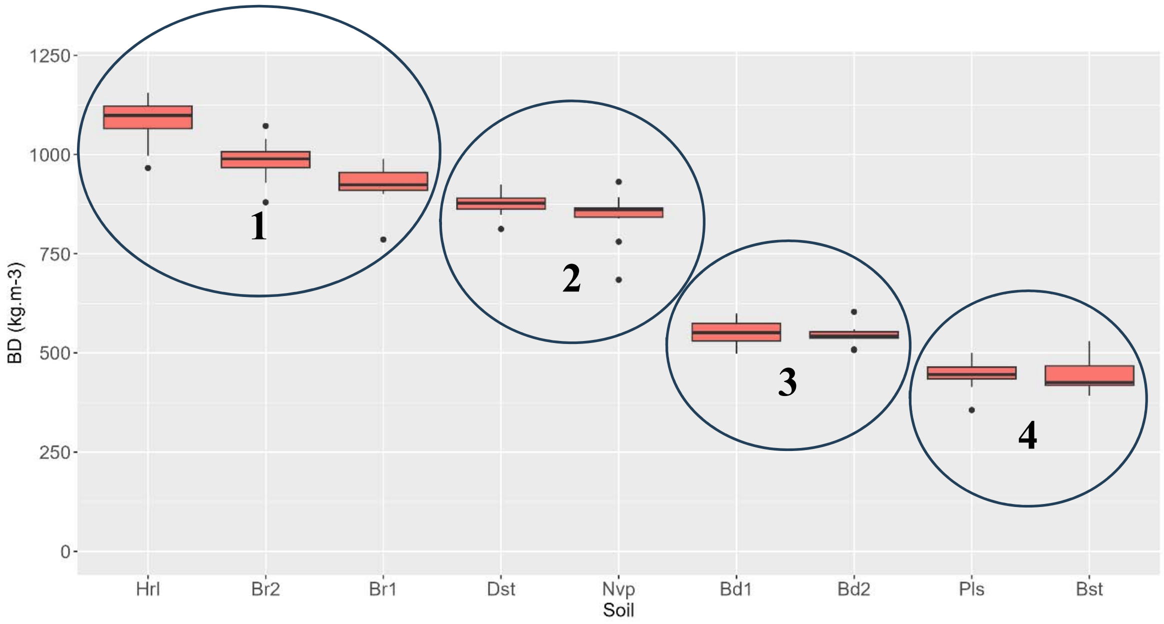


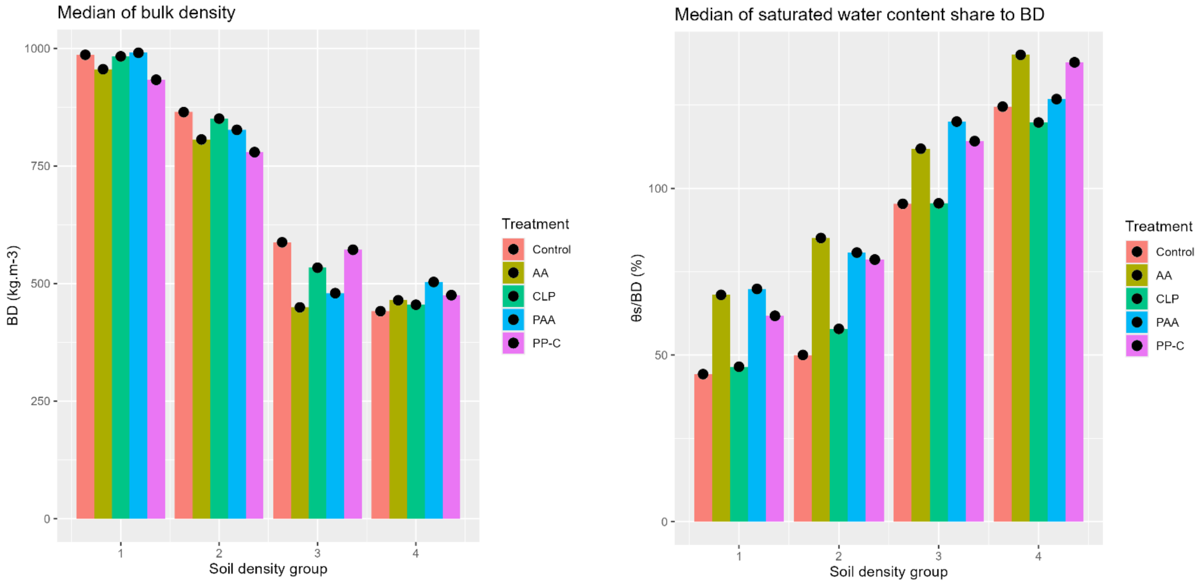
Fig. 3. The blended samples without amendment (i.e. Control) ranked according to emulated backfill soil bulk density (BD): 1 denotes the highest soil density soils and 4 denotes the lowest soil density soils. For more data on soils see Table 2.

turn that deviations, therefore analyses were performed using original data. To increase the reliability of such data analyses, the differences were considered significant if the significance level was lower than 0.001.

The differences among the treatments were analyzed using post-hoc tests based on least-square means (packages agricolae and multcomp) with Tukey's correction of the multiple comparison. The post-hoc tests differences were considered significant if p <= 0.05. Least-square means with standard deviations (SD) were presented. The charts were made using libraries ggplot2, dplyr and tidyr.

3. Results

All four SDGs showed that water contents in soils mixed with hydrophilic polymers with fertilizer and volcanic rock of CLP treatments were close to Control soils without amendments (Fig. 4). SDGs 1 and 2 showed significant θ_S differences as the CLP retained more water than Control not only at T_0, but also over following 48-hour drainage; this did not apply to soils of SDG 3 and 4 (Tables 5–8; Fig. 5). However, also the three most effective amendments AA, PAA and PP-C differed significantly in cer-


Median of bulk density

Median of saturated water content share to BD

Fig. 4. Median bulk density (BD; left) and median saturated content of water in sample in % of bulk density (θ_S/BD; right) of treatments according to soil density groups: 1 denotes the highest soil density soils and 4 denotes the lowest soil density soils.

tain attributes (Tables 5 and 6). The SDG 3 showed significant similarities in water loss not only between the Control and CLP, but also between the Control and AA (Table 7). The latter treatment together with PAA and PP-C treatments had more water frequently compared to Control soils and the CLP treatments; AA, PAA and PP-C treatments showed similar patterns of water loss in lower BD soil (Table 8).

As for the relative soil sample moisture, the SDGs showed a similar pattern to the volumetric water content. Besides the excessive superabsorbent concentration in PP-C treatment, all SDGs showed significantly slower relative water loss in the PAA treatment than in the Control one; SDGs 2 and 4 showed that also in AA (Fig. 6).

Table 5. Soil bulk density (BD), share of saturated water content to BD (θ_S/BD) and volumetric water content attributes (see Table 3) of Soil density group 1. ANOVA.

	BD		θ_S/BD		θ_S		θ_{30}		θ_{CWH}		θ_{SWR}		θ_{48}		θ_{72}		θ_{144}	
	kg/m^3		%		%		%		%		%		%		%		%	
Varianta	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE
p	*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*	
Control	996 a	8.85	42.3 c	1.02	41.8 c	0.96	35.4 c	0.97	32.6 d	0.90	25.3 d	0.92	20.0 d	0.94	15.3 c	0.96	5.8 c	0.91
AA	965 a		65.8 a		63.1 a		55.9 a		51.3 b		43.4 b		36.7 b		30.6 b		16.7 b	
PAA	974 a		67.8 a		65.1 a		58.9 a		56.2 a		49.5 a		42.9 a		37.4 a		22.9 a	
CLP	964 a		48.5 b		46.3 b		40.5 b		36.6 c		30.4 c		24.0 c		18.9 c		8.7 c	
PP-C	929 b		67.7 a		62.2 a		56.1 a		53.9 ab		45.7 b		38.5 b		33.4 b		22.7 a	

Table 6. Soil bulk density (BD), share of saturated water content to BD (θ_S/BD) and volumetric water content attributes (see Table 3) of Soil density group 2. ANOVA.

	BD		θ_S/BD		θ_S		θ_{30}		θ_{CWH}		θ_{SWR}		θ_{48}		θ_{72}		θ_{144}	
	kg/m^3		%		%		%		%		%		%		%		%	
Varianta	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE
p	*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*	
Control	860 a	10.1	50.5 d	1.31	43.6 c	1.26	36.9 c	1.22	33.5 c	1.13	24.3 c	1.06	19.0 c	1.03	14.5 d	1.04	5.0 c	1.02
AA	811 bc		86.2 a		70.0 a		63.4 a		58.9 a		49.5 a		41.7 a		34.8 ab		18.4 b	
PAA	831 ab		79.8 b		66.4 ab		59.8 ab		56.2 ab		47.2 a		39.8 a		33.0 b		16.9 b	
CLP	845 ab		56.3 c		47.4 c		41.0 c		38.2 c		32.3 b		26.4 b		21.2 c		8.6 c	
PP-C	781 c		78.8 b		61.5 b		55.4 b		54.2 b		48.4 a		43.2 a		38.8 a		25.7 a	

Table 7. Soil bulk density (BD), share of saturated water content to BD (θ_S/BD) and volumetric water content attributes (see Table 3) of Soil density group 3. ANOVA.

	BD		θ_S/BD		θ_S		θ_{30}		θ_{CWH}		θ_{SWR}		θ_{48}		θ_{72}		θ_{144}	
	kg/m^3		%		%		%		%		%		%		%		%	
Varianta	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE
p	*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*	
Control	547 ab	10.2	91.9 c	2.8	50.2 c	0.99	42.4 c	0.94	37.6 c	0.91	29.4 c	0.90	22.8 c	0.88	17.2 c	0.83	7.5 c	0.69
AA	449 c		111.3 b		49.9 c		42.2 c		38.3 c		31.5 c		25.5 c		19.8 c		9.2 c	
PAA	481 c		123.2 a		58.8 b		50.6 b		44.8 b		38.7 b		33.6 b		29.3 b		18.4 b	
CLP	542 b		97.0 c		52.5 c		44.1 c		36.9 c		28.8 c		23.8 c		19.8 c		10.6 c	
PP-C	583 a		119.9 ab		69.0 a		61.4 a		57.8 a		49.9 a		42.9 a		37.5 a		27.2 a	

Note: The CLP values come from Bd1 site only.

Table 8. Soil bulk density (BD), share of saturated water content to BD (θ_S/BD) and volumetric water content attributes (see Table 3) of Soil density group 4. ANOVA.

	BD		θ_S/BD		θ_S		θ_{30}		θ_{CWH}		θ_{SWR}		θ_{48}		θ_{72}		θ_{144}	
	kg/m^3		%		%		%		%		%		%		%		%	
Varianta	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE
p	*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*		*<0.001*	
Control	444 b	9.11	124 b	4.57	55.0 b	1.37	48.1 b	1.44	42.7 b	1.37	35.5 b	1.29	29.9 b	1.22	24.4 b	1.17	12.8 c	0.913
AA	466 ab		144 a		63.9 a		59.1 a		54.3 a		47.8 a		41.9 a		36.3 a		22.5 ab	
PAA	496 a		134 ab		63.6 a		56.8 a		52.6 a		45.5 a		39.2 a		33.4 a		19.7 b	
CLP	469 ab		123 b		55.9 b		49.7 b		44.4 b		36.7 b		30.7 b		25.6 b		14.0 c	
PP-C	472 ab		145 a		66.4 a		60.5 a		56.3 a		47.9 a		41.9 a		36.6 a		26.0 a	

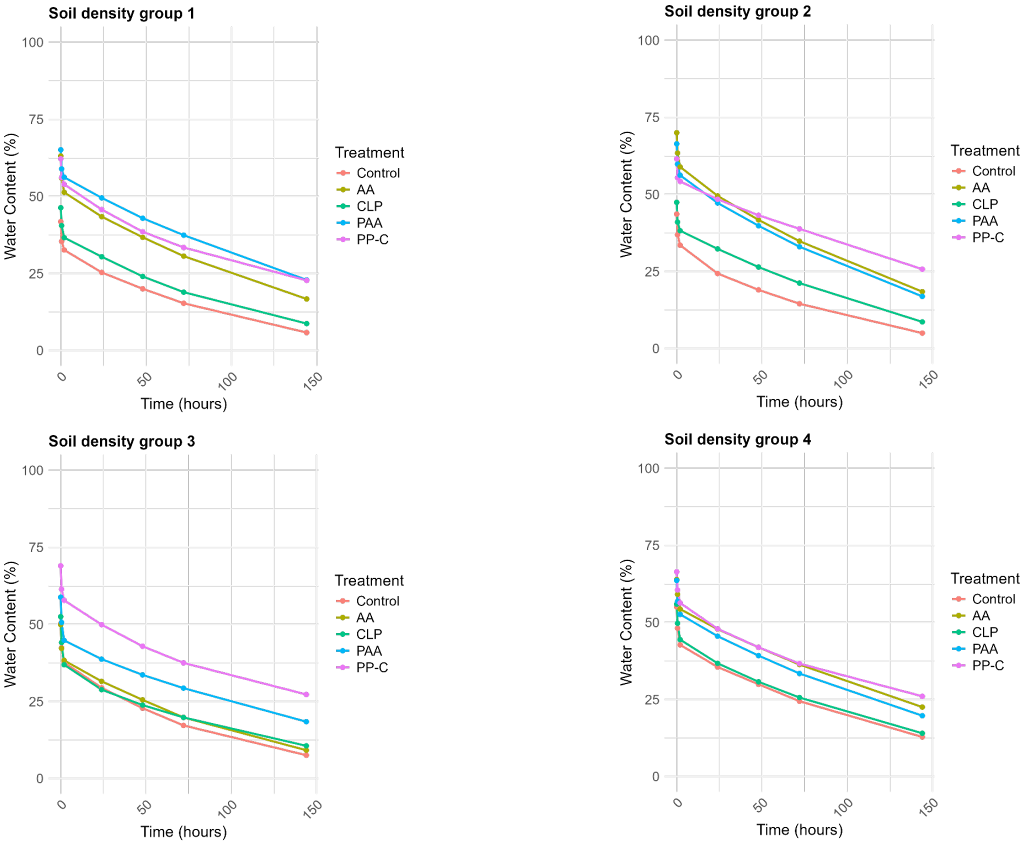


Fig. 5. Water content over time according to Soil density groups and treatments (least-square means).

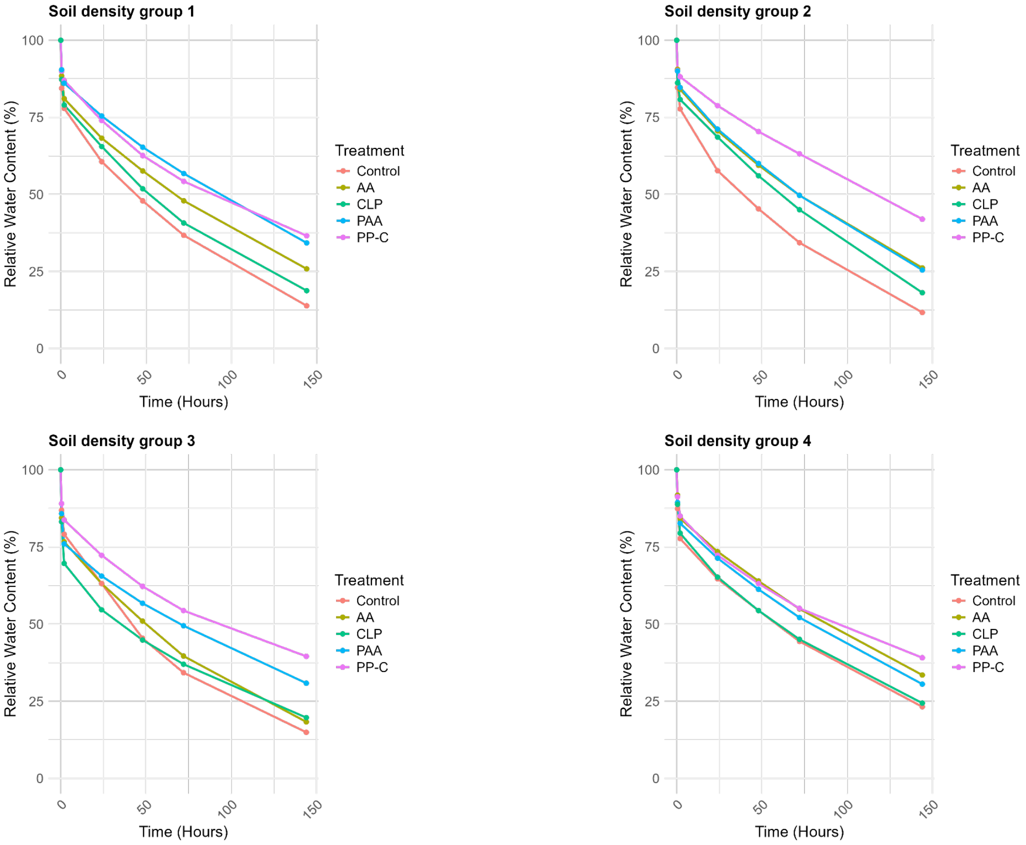


Fig. 6. Relative water content over time according to Soil density groups and treatments (least-square means).

The water content loss during the physical drainage expressed in absolute values (g) differed among the SDGs (Fig. 7). In the SDG 1, more water was lost from the samples of AA compared to Control and later also to CLP. In SDG 2, more water was lost in AA and PAA compared to the other treatments in the end. As for SDG 3, CLP and PAA were losing more water than Control at the beginning, which later was shown in CLP and Control. The differences were small, however significant following 72 hours of passive capillary drainage; in the end, the differences became insignificant. On the other hand, SDG 4 showed a lower drainage rate in AA and exceptionally also in PP-C over 48 hours of the experiment. The differences diminished later. No amendment, therefore, lowered an accessibility of accumulated water.

4. Discussion

4.1. Expected changes due to amendment

Soil texture generally reflects falling values of bulk density ranked in the order sand > loam > silt > clay (USDA 2019). After application of hydroabsorbent, Picolli et al. (2024) reported that treated soils tended to have a lower bulk density compared to control, which corresponds with results in our SDG 1 and 2. Amended soils from the studied sites retained more water than control ones as expected. There can be found many proofs of substances capable of absorbing and holding water in a form of gels, which lowers the loss of moisture via evaporation (Montesano et al. 2015; Crous 2017; Watanabe et al. 2019; Saha et al. 2020; Čechmánková et al. 2021; Durpekova et al. 2021; Adjuik et al. 2022; Womack et al. 2022; Zheng et al. 2022; Takahashi et al. 2023; Piccoli et al. 2024). Our experiment showed a higher total loss of water in SDGs 1 and 2 treated with AA and PAA (Fig. 7). However, even these two treatments held significantly more water than control samples over all study time. Saha et al. (2020) found that amendment using superabsorbents improves soil structure, its water holding capacity, but also content of plant-available water and reduces evaporation and deep percolation through soil.

4.2. Amendment impacts in various conditions

The previously published studies confirm that superabsorbent application is effective particularly in sandy soils (e.g., Landis & Haase 2012; Narjary et al. 2012; Adjuik et al. 2022; Takahashi et al. 2023). In our experiment, two sites Br1 and Br2 had soils developed on sandy gravels; both localities belonged to SDG 1. And both SDG 1 and 2 showed higher mean moisture in amended samples

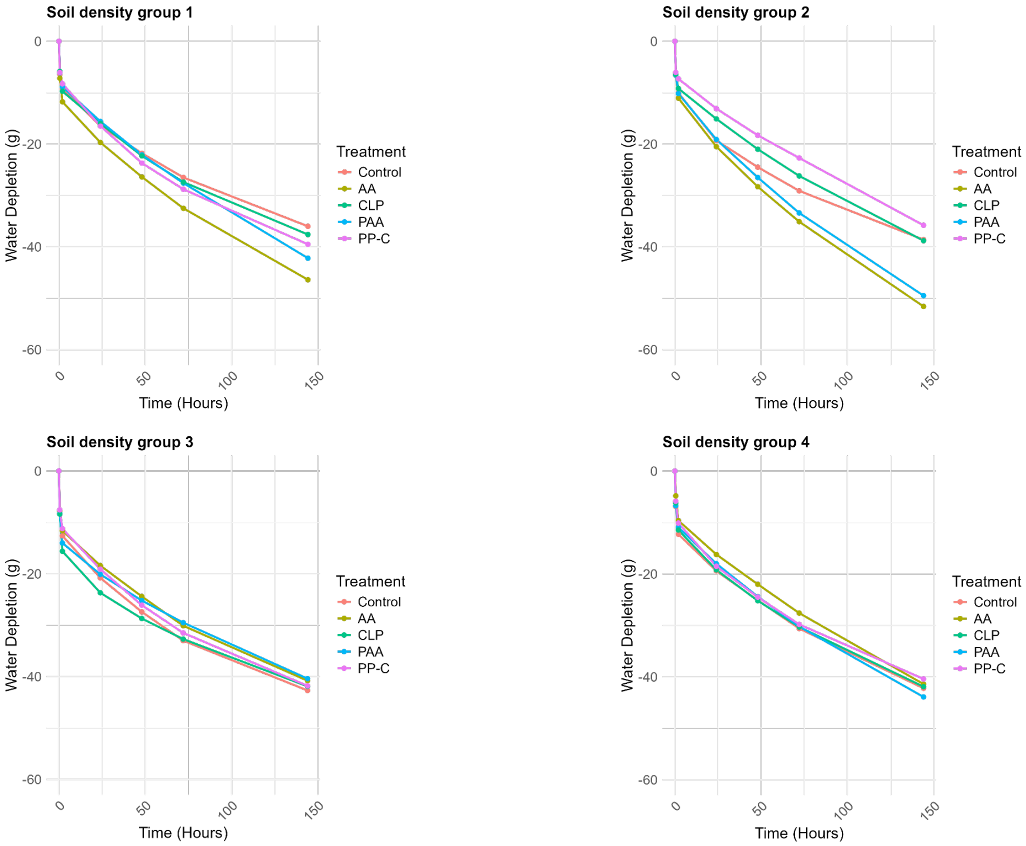


Fig. 7. Water depletion (in grams) according to Soil density groups and treatments (least-square means).

compared to SDGs 3 and 4 (Table 5–8). However, our samples were not sand only, but they were enriched with organic matter of topsoil. Takahashi et al. (2023) showed that the higher application rate (0.1%–0.8% of acrylic acid and/or its mixture with acrylamide added to silica sand), reduces the amount of gravitational water. Nevertheless, it increases plant-available water and total water retained in soil-superabsorbent mixture (Takahashi et al. 2023).

Mohawesh & Durner (2019) also reported that low dose amounting 0.1% of amendment based on cross-linked polyacrylic acid in sandy soil led to higher water loss than in control soil, whereas 0.25% and 0.50% retained more water than control. Therefore, the values after CLP application rate being close to the Control can be also attributable to its dose of 0.15% (recommended by the producer), which is not only the polymers, but contains also fertilizer and rock. Another disputable treatment seems to be PP-C, which retained water the most; the hydrophilic substance was, however, enclosed in the capsule thus allowing a very concentrated application only, which had both advantages and disadvantages. As for the former, Crous (2017) reported that such applications can mitigate the negative effect of soil cations on water absorption capacity. The disadvantages of the localized applications are the capabilities of pushing plants out of planting pits due to swelling or causing air spaces in soil due to shrinking as water is lost (Crous 2017).

Hydrogels impacted positively on sandy soils, contrary to clay-loam soils with their better structure and capability to hold water, which confirmed Montesano et al. (2015) or Picolli et al. (2024). Crous (2017) described a generally more suitable function of hydrogels in sandy and clay soils whereas effects on loam soils were rather limited. Even more distinctive differences related to soil texture were reported by Agaba et al. (2010), where 0.4% dose of superabsorbent increased plant-available water three times in sand, two times in silt loam and one time in sandy loam, loam and clay soils compared to the controls with no amendment. Also, Abedi-Koupai et al. (2008) reported plant-available water increased 1.8fold in clay and 2 to 3fold in loam and sandy loam compared to controls. In our experiment the water absorption capacity was increased the most in SDG 1 (42% higher in average, with maximum of 56% higher for Hydro treatment) and SDG 2 (41% higher in average, 60% higher for AA treatment); lower impacts were found in SDG 3 (14% higher in average, 37% higher for PP-C treatment) and the least was SDG 4 (14% higher in average, 20% higher for PP-C treatment).

It is evident that hydrogels emulate the function of clay and organic matter in soils being poor in those two soil components (Piccoli et al. 2024). Hüttermann et al. (2009) have called the gels "artificial humus". When added to substrates such as crushed rocks or processed kimberlite, absorbents had a positive effect on retention of water compared to lake sediments where there was only slightly more water retained after amendment (Miller & Naeth 2019). The relative changes in water contents in our treatments showed an interesting development in SDG 3. Relative to saturated soil on nursery bed origin (Bd1 and Bd2), the CLP treatment was losing more water over the first cca 50 hours of passive capillary drainage than other amended treatments but also more than the Control. The CLP showed similar water content as the AA in the end (Fig. 6 and 7). The smallest relative changes in water content were observed in SDG 4, where the similar behavior of the CLP and Control treatments exhibited a smaller relative change in water content compared to the other three SDGs. In terms of changes in gravimetric water content, the differences between the treatments within this SDG 4 group were the smallest (Fig. 7).

4.3. Silvicultural considerations

The results showed that gels in soil samples either increased maximal water absorption capacity or had also a positive influence (particularly the Hydro and the PP-C treatments) on lesser passive capillary drainage during the experiment. Similar effects of hydrogels were reported also by Abedi-Koupai et al. (2008). Despite the evidently more water retained in the amended treatments, those substances have only limited use as insurance against droughts (Crous 2017). Crous (2017) also pointed out that the return of the investment, which is the amelioration, is larger on better-quality sites than on poorer sites, therefore the better sites increase in stocking is larger. The hydrogel impact on plants' performance is related to growing conditions and thus may not be significant (Repáč 2019; Repáč & Belko 2020; Bartoš et al. 2024). The amendment cannot be used as a replacement of proper silviculture (Crous 2017), particularly vigorous planting stock should be in focus (Bartoš et al. 2024). The superabsorbents can be beneficial, for example, if lower planting densities are used (Tubert et al. 2018).

5. Conclusions

Applied superabsorbents increased water absorption capacity of all tested soils. More moisture was held in soil with higher bulk density. Also, controlled passive capillary drainage showed higher loss of water from the amended treatments. Those ones, however, kept a larger volume of water over the whole period of experiment. The applications according to producer-recommended concentrations showed the product based on polyakrylic acid (PAA) and acrylamide (AA) as the most efficient amendments; the one based on cross-linked polymers (CLP) did not differ substantially from the Control soil in water absorption. As for the potassium polyacrylate (PP-C) treatment, the tenfold higher concentration, than the recommended one, absorbed more water than the others, particularly in SDGs 2 and 3. However, its possible benefits are limited due to local application disadvantage (associated with swelling/shrinking effects within the soil) and higher costs.

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References

Abedi-Koupai, J., Sohrab, F., Swarbrick, G., 2008: Evaluation of Hydrogel Application on Soil Water Retention Characteristics. Journal of Plant Nutrition, 31:317–331.

Adjuik, T. A., Nokes, S. E., Montross, M. D., Wendroth, O., 2022: The Impacts of Bio-Based and Synthetic Hydrogels on Soil Hydraulic Properties: A Review. Polymers, 14:4721.

Agaba, H., Orikiriza, L. J. B., Esegu, J. F. O., Obua, J., Kabasa, J. D., Hüttermann, A., 2010: Effects of Hydrogel Amendment to Different Soils on Plant Available Water and Survival of Trees under Drought Conditions. Clean – Soil, Air, Water, 38:328–335.

Bartoš, J., Leugner, J., Kacálek, D., Špulák, O., Hacurová, J., 2024: Indiferentní reakce sazenic borovice lesní a buku lesního ošetřených hydroabsorbenty. Zprávy lesnického výzkumu, 69:216–226. (In Czech).

Crous, J. W., 2017: Use of hydrogels in the planting of industrial wood plantations. Southern Forests: a Journal of Forest Science, 79:197–213.

Čechmánková, J., Skála, J., Sedlařík, V., Duřpeková, S., Drbohlav, J., Šalaková, A. et al., 2021: The Synergic Effect of Whey-Based Hydrogel Amendment on Soil Water Holding capacity and Availability of Nutrients for More Efficient Valorization of Dairy By-Products. Sustainability, 13:10701.

Durpekova, S., Di Martino, A., Dusankova, M., Drohsler, P., Sedlarik, V., 2021: Biopolymer Hydrogel Based on Acid Whey and Cellulose Derivatives for Enhancement Water Retention Capacity of Soil and Slow Release of Fertilizers. Polymers, 13:3274.

Grabowska-Polanowska, B., Garbowski, T., Bar-Michalczyk, D., Kowalczyk, A., 2021: The benefits of synthetic or natural hydrogels application in agriculture: An overview article. Journal of Water and Land Development, 51:208–224.

Guilherme, M. R, Aouada, F. A., Fajardo, A. R., Martins, A. F., Paulino, A. T., Davi, M. F. T. et al., 2015: Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. European Polymer Journal, 72:365–385.

Hüttermann, A., Orikiriza, L. J. B., Agaba, H., 2009: Application of Superabsorbent Polymers for Improving the Ecological Chemistry of Degraded or Polluted Lands. Clean – Soil, Air, Water, 37:517–526.

Kaur, P., Agrawal, R., Pfeffer, F. M., Williams, R., Bohidar, H. B., 2023: Hydrogels in agriculture: prospects and challenges. Journal of Polymers and the Environment, 31:3701–3718.

Landis, T. C., Haase, D. L., 2012: Applications of hydrogels in the nursery and during outplanting. In: Haase, D. L. et al. (eds.): National Proceedings: Forest and Conservation Nursery Associations – 2011. Fort Collins (CO), USDA Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-68, p. 53–58.

Miller, V. S., Naeth, M. A., 2019: Hydrogel and organic amendments to increase water retention in anthroposols for land reclamation. Applied and Environmental Soil Science, ID:476809.

Mohawesh, O., Durner, W., 2019: Effects of Bentonite, Hydrogel and Biochar Amendments on Soil Hydraulic Properties from Saturation to Oven Dryness. Pedosphere, 29:598–607.

Montesano, F. F., Parente, A., Santamaria, P., Sannino, A., Serio, F., 2015: Biodegradable Superabsorbent Hydrogel IncreasesWater Retention Properties of Growing Media and Plant Growth. Agriculture and Agricultural Science Procedia, 4:451–458.

Narjary, B., Aggarwal, P., Singh, A., Chakraborty, D., Singh, R., 2012: Water availability in different soils in relation to hydrogel application. Geoderma, 187–188:94–101.

Novák, V., 1954: Voda v půdě – vodní režim půdní. In: Klika, J., V. Novák, V., Gregor, A. (eds.): Praktikum fytocenologie, ekologie, klimatologie a půdoznalství. Praha, Nakladatelství ČSAV, p. 440–484. (In Czech).

Piccoli, I., Camarotto, C., Squartini, A., Longo, M., Gross, S., Maggini, M. et al., 2024: Hydrogels for agronomical application: from soil characteristics to crop growth: a review. Agronomy for Sustainable Development, 44:22.

Repáč, I., 2019: Hodnotenie vývoja lesnej kultúry buka lesného a smreka obyčajného päť rokov po aplikácii mykorizných a hydroabsorpčných prípravkov pri výsadbe. Zprávy lesnického výzkumu, 64:57–64. (In Slovak).

Repáč, I., Belko, M., 2020: Development of Norway spruce and European beech plantations treated with fertilizer and hydrogel on windthrow area in the Javorie Mts., central Slovakia. Zprávy lesnického výzkumu, 65:232–241. (In Slovak).

Saha, A., Sreedeep, S., Manna, U., 2020: Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. Soil and Tillage Research, 204:104736.

Takahashi, M., Kosaka, I., Ohta, S., 2023: Water Retention Characteristics of Superabsorbent Polymers (SAPs) Used as Soil Amendments. Soil Systems, 7:58.

Tubert, E., Vitali, V. A., Alvarez, M. S., Tubert, F. A., Baroli, I., Amodeo, G., 2018: Synthesis and evaluation of a superabsorbent-fertilizer composite for maximizing the nutrient and water use efficiency in forestry plantations. Journal of Environmental Management, 210:239e254.

Valla, M., Kozák, J., Drbal, J., 1983: Cvičení z půdoznalectví II. Praha, SPN, 280 p. (In Czech).

Watanabe, K., Saensupo, S., Na-iam, Y., Klomsa-ard, P., Sriroth, K., 2019: Effects of Superabsorbent Polymer on Soil Water Content and Sugarcane Germination and Early Growth in Sandy Soil Conditions. Sugar Tech, 21:444–450.

Wilske, B., Bai, M., Lindenstruth, B., Bach, M., Rezaie, Z., Frede, H.-G. et al., 2014: Biodegradability of a polyacrylate superabsorbent in agricultural soil. Environmental Science and Pollution Research, 21:9453–9460.

Womack, N. C., Piccoli, I., Camarotto, C., Squartini, A., Guerrini, G., Gross, S. et al., 2022: Hydrogel application for improving soil pore network in agroecosystems. Preliminary results on three different soils. Catena, 208:105759.

Wu, Y., Li, S., Chen, G., 2024: Hydrogels as water and nutrient reservoirs in agricultural soil: a comprehensive review of classification, performance, and economic advantages. Environment, Development and Sustainability, 26:24653–24685.

Zheng, W., Wang, L.-P., Kuang, X., Jin, Y., Shen, C., 2022: Opposing surfactant and gel effects of soil borne-hydrogels on soil water retention. Water Resources Research, 58:e2022WR032845.

Zoubková, L., 2014: Návody k laboratorním cvičením z pedologie. UJEP, Ústí nad Labem, 75 p. (In Czech).

Other sources

R Core Team. 2024: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/.

USDA, 2019: Soil bulk density / moisture / aeration. USDA, Natural Resources Conservation Service, 11 p. Available at https://www.nrcs.usda.gov/sites/default/files/2022-10/Soil%20Bulk%20Density%20Moisture%20Aeration.pdf.