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EFFECTS OF THE APPLICATION OF A HYDROGEL IN DIFFERENT SOILS

SUMMARY

The application of hydrogels aids efficient management of water in agricultural production by improving water conservation and the physical properties of the soil.

The objective of this paper was to determine the influence of an applied polymer (hydrogel) on the physical properties of different soils (sand, peat and chernozem), on the water consumption of oats and on relative changes in aboveground biomass production.

The application of potassium polyacrylate in a concentration of 0.5% led to a change in some water and physical properties of sand. The amount of available water and water retention in the soil at different pressures (0–1.5 MPa) increased, whereas the bulk density decreased. Significant water savings may be achieved if hydrogels are applied to sand. The hydrogel application did not change the irrigation water needs of organic soils with a higher content of clay, and the aboveground biomass production remained unchanged.

Keywords: hydrogel, chernozem, peat, oats

INTRODUCTION

Climatic changes have led to increased needs for water in agricultural production, making the development of various models for preserving soil moisture and reducing water consumption in agriculture very important. The World Meteorological Organization (Alcamo et al., 2007) estimated that South Europe, which includes the Republic of Serbia, would in the future experience, in addition to a continued upward trend in air temperatures, a further reduction in precipitation, followed by reduced runoff, soil humidity and availability of water resources. The issue of the rational use of water is of great importance because water is increasingly becoming a resource of strategic importance (Bates et al., 2008).

Water conservation in agriculture can be achieved by the application of various substances (polymers), which change the water–air properties and the physical composition of the soil. The ultimate goal of such substances, which began to be used as early as the 1950s, is to improve the water regime of the soil. The first preparations sold under the brand name Krylium were relatively quickly

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withdrawn from the market due to their high price, complicated application method and poor dissemination in the soil.

In general, two polymer groups are applied in agricultural practice: water soluble and water-insoluble polymers. Water-soluble polymers were first applied to stabilise the soil, prevent soil erosion and improve soil infiltration. These polymers have a linear structure chain, and they include polyethylene glycol, polyacrylates and polyacrylamides. Most of these compounds occur as derivatives of the oil industry; the most common water-soluble polymer used is polyacrylamide (PAM). The application of PAM increases aggregate stability and reduces soil compaction, as well as reducing erosion and increasing infiltration by 2.5 times (Wallace and Walas, 1986).

Water-insoluble polymers (hydrogels) were introduced into agricultural practice in the 1980s. These polymers do not have linear structure chains; instead, the hydrophilic polymer chains are cross-linked, creating a three-dimensional network. Depending on synthesising conditions, types and covalent bond densities, they can absorb up to 1,000 times of their weight. Sodium polyacrylate, which is derived from the polymerisation of acrylic acid blended with sodium hydroxide ($(C_3H_3NaO_2)n$), is the most widely used hydrogel today. Other commonly used hydrogels are poly(acryl-amide) copolymer, poly(vinyl-alcohol) copolymer (PVAL), cross-linked poly(ethylene-oxide) and cross-linked carboxymethylcellulose.

The application of hydrogels to soil increases the quantity of available water and reduces plant stress. Soil conditioners also influence seed germination, growth and the yields of plants such as tomato, lettuce, corn and sugar beet (Wallace and Walas, 1986a). The authors attributed these benefits to the ability of the conditioner to improve soil aeration, increase microbiological activity, enhance the effect of fertilisers and increase the absorption of some nutrients.

El-Hady et al. (2009) stated that the application of the polyacrylamide copolymer also results in an increase in the content of organic carbon, total nitrogen and accessible forms of nitrogen, phosphorous and potassium. Hydrogels also affect the production of CO_2, cellulose disintegration and enzyme activity and may be used as environmentally friendly materials for water conservation (Sarapatka, 2004).

Hydrogels also increase the efficiency of water use and reduce the frequency of irrigation (Johnson, 1984, Sivapalan, 2006). In addition, they enhance the efficiency of fertiliser use (El-Hady and Wanas, 2006). Previous studies have investigated the possibility of using hydrogels in organic and conventional plant production systems in the cultivation of buckwheat, oats and hull-less barley in Serbia (Oljača et al., 2009, 2010).

In experiments on loamy sand and sandy loam, Owczarzak et al. (2006) showed that hydrogel applied to soil in quantities of 0.033, 0.066, 0.132 and 0.264 % compared with dry matter resulted in a reduction in the bulk density and in the aggregate porosity of the soil, whereas the content of aggregates larger than 0.25 mm increased by 5–7%, depending on the hydrogel dose applied. The highest retention growth (pF value) reported to influence gravitational water retention and even create unfavourable conditions for plants ranged from 0–2.2 (Leciejewski, 2009). Data on the effects of the hydrogel on water retention at various pressures yield a different picture. For example, Sivapalan (2006) stated that applying 0.03 and 0.07% of polyacrylamide increased the water capacity of soil in the pressure of 0.01 MPa by 23 and 95%, respectively, whereas no pronounced changes were observed at higher pressures (1.5 MPa). On the other hand, some authors (El-Hady and Abo-Sedera, 2006, Djurovic et al., 2011) reported that the application of a hydrogel improved the aggregate composition of the soil, increased the amount of available water and increased the water retention in the soil at pressures ranging from 0–1.5 MPa.

However, most of the research carried out so far has focused on results obtained following the application of hydrogels to sandy soils or soils with a lighter mechanical composition. The effect of hydrogels on sandy soils can be expected to be particularly obvious due to their low productive humidity capacity. The objective of this paper was to determine using a pot trial the influence of polymers (hydrogels) on the physical properties of various soils and their effect on water consumption by plants.

MATERIALS AND METHODS

The trial was carried out in plastic pots containing three different soil types: sand, peat and chernozem (clay loam). The soil samples were collected in the vicinity of Belgrade, Boljevci. Considering that the substrate type could not have been a factor (i.e. independent changeable) in the trial, various types of soils were used to observe the relative changes in the soil (substrate) following the application of the hydrogel, as well as relative changes in the biomass of oats grown in various soil types with and without hydrogel application. The pots contained 2 kg of homogenised air-dry soil, with three repetitions. The hydrogel (potassium polyacrylate) was applied to half of the pots in the amount of 5 g kg^{-1} of sand.

The oats were sown in each of the pots. Following germination, they were thinned to 10 plants per pot. Oats were selected for this study because the plant consumes a higher quantity of water compared with other small grain crops throughout the growing period. The increased water consumption is due to its high transpiration coefficient and large leaf mass (Todorović, 2008).

The total vegetation period lasted 68 days. During the experiment, the pots were rotated on a daily basis to expose them equally to light. Fertiliser was added to the pots with the sand in an amount equal to N 90 kg ha^{-1} and P and K 75 kg ha^{-1}.

After removing the plants from the pots, the part above the ground was dried at 60–65 °C until a constant weight was reached. The quantity of dry aboveground biomass was then determined. The dry biomass was expressed in grams per pot.

To determine the water properties of the soil, the samples were taken undisturbed from the pots, and a tensiometric curve was determined. The field water capacity (FWC) was determined by exposing the soil samples to a pressure of 33 KPa, and the wilting point (WP) was determined by exposure to a pressure of 1.5 MPa (Richards, 1948).

The interval between two irrigations was five days. During watering, the pots were filled up to the desired weight, which corresponded to the water content at the level of the FWC. Water was added from a graduated cylinder along the rim of the pot on the soil surface. The plant weight was not taken into account during measuring and watering because the accumulation of biomass was negligibly small compared to the weight of the pots with the soil.

RESULTS AND DISCUSSION

The soil water capacity data showed that the application of potassium polyacrylate in the amount of 0.5% to the sand resulted in significant changes in the water properties of the soil. Higher water retention was observed at all pressures ranging from 0–1.5 Mpa. The maximum water capacity (MWC) increased by 81%, while the FWC increased by 4.12 times. The application of the hydrogel also resulted in significant changes in water retention at a pressure of 1.5 MPa, (wilting point, WP). Compared with the control, the amount of available water increased by 3.38 times (3.39 and 11.48, respectively, Table 1). This result unequivocally shows that the application of the hydrogel to sand resulted in significant changes in the water–air properties of the sand and that the application can significantly improve these properties, particularly in terms of increasing the total quantity of available water. Following the application of the hydrogel, the bulk density of the sand was reduced by 27%, while the substrate became far more suitable for plant rooting.

On the other hand, in the chernozem and the peat, these differences were much smaller, with the productive humidity increasing by 7.5% in the chernozem (as a result of the WP being somewhat lower in the option with the hydrogel (14.71 and 13.80, respectively). The MWC and the FWC showed little change. The application of the hydrogel resulted in some reduction in the bulk volume, but these changes were much less (10%) than those observed with the sand. Similar findings were observed with the hydrogel application to the peat. In the peat, the available water capacity showed a 32% reduction on weight due to a change in the FWC and little change in the MWC and the WP. Therefore, it could be concluded that the application of the hydrogel increased the water availability to plants in peat and resulted in soils with more favourable water properties for plant development than soils without the application of the hydrogel.

Table 1. Soil water properties (% on weight basis)

	Max water capacity (MWC) %	Field water capacity (FWC) %	Wilting point (WP)%	Productive humidity capacity %	Bulk volume $g \cdot cm^{-3}$
Sand	20.82	5.10	1.71	3.39	1.75
Sand+hydrogel	37.76	21.04	9.56	11.48	1.28
Chernozem	53.68	28.46	14.71	13.75	1.04
Chernozem+hydrogel	53.23	28.58	13.80	14.78	0.94
Peat	63.17	54.56	34.22	20.34	0.68
Peat+hydrogel	62.48	48.94	35.12	13.82	0.62

As noted already, the different substrates were not compared with each other in this study because many properties (different mechanical composition, structure, content of macro- and microelements etc.) of very different substrates influence the consumption of water and the development of plants, which influence the production of biomass and water consumption. The effect of the hydrogel is presented in relative amounts, i.e. changes in certain properties of the soil and particular indictors of plant production were compared in soils treated and untreated with potassium polyacrylate.

The analysis of the effect of potassium polyacrylate on the water properties of the different substrates suggests that the effects of the hydrogel application can be significantly different and that the application is only unequivocally justified with substrates with a light mechanical composition. For the clay loam (chernozem), the ability of the hydrogel to improve the water properties of the soil was much lower. Taking into account the more difficult conditions for equal application, i.e. homogenisation of the soil, which, as a rule, in natural conditions has a higher water content than sandy soils, application in natural conditions would probably be even less justified. The high price of application also needs to be considered. For example, in this trial, the hydrogel was applied at a concentration of 0.5% compared to soil weight. Therefore, a large quantity would need to be applied in field conditions. As noted by Jhurry (1997), in such conditions, when soil is mixed with a hydrogel, a quantity of 0.1% of hydrogel applied compared to soil weight requires an application of 1,000–4000 kg ha^{-1}. Furthermore, we should take into consideration the fact that soils, such as clay loams or soils abundant in organic matter already have significant water available capacity. Therefore, smaller modifications to this capacity could not be considered essentially significant for modification of water properties of such soils.

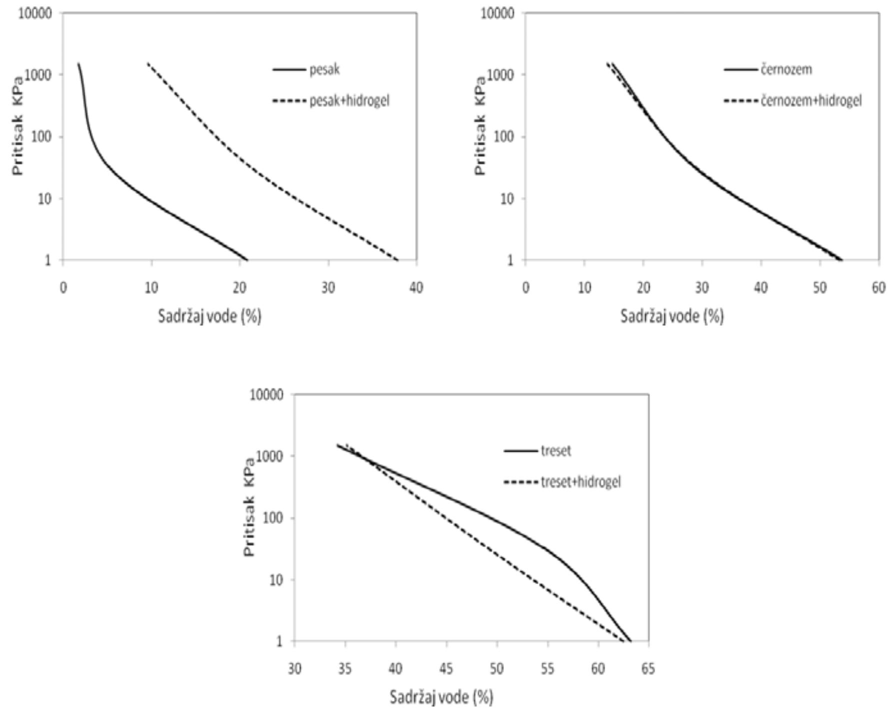

Figure 1. Soil water release curve

During the experiment, differences in water consumption were established. The hydrogel applied to sand had a significant influence on the water consumption during the trial period (Table 2). The water quantity used in the pure sand was higher (26.8%) compared with the water quantity used in the trials with the hydrogel. At the same time, the production of aboveground biomass in the hydrogel trial increased by 27.6%, which shows a significant saving of water and greater efficiency of water use compared with the option without the hydrogel.

Table 2. Amount of water applied to a pot and the aboveground biomass

Quantity of K acrylate g/kg	Substrate	Water quantity added per pot l/pot	Aboveground biomass g/pot
5	Sand	0.56	1.57
0	Sand	0.71	1.23
5	Chernozem	1.26	3.61
0	Chernozem	1.23	3.55
5	Peat	2.38	3.75
0	Peat	2.45	3.71

In contrast, the differences between water consumption in the chernozem-only trial without the application of the hydrogel were not pronounced (1.26 and 1.23, respectively). There was also no pronounced difference in the biomass yield (3.61 and 3.55, respectively). The differences were also small in peat. These findings are in line with previous conclusions about the effects of hydrogels on the water properties of a substrate. On the basis of our findings, we can conclude that the effect of the hydrogel application is much more pronounced in soils with a light mechanical composition and that such application is justifiable on such soils. When drawing a conclusion about the effects of the hydrogel on various substrates on savings in water consumption, it should be taken into account that during this trial, the irrigation interval was equal (five days) and that the quantities of water added during a single watering were significantly different. Although the average water quantity added during a single watering was significantly higher for the peat and the chernozem than the sand, the soil moisture decreased during the five-day interval. Therefore, even at the moment of watering, the available water content was quite high and never below 50–60% of productive humidity capacity. However, in the sand-only trial, the water content during the five-day period was occasionally close to the content corresponding to the WP. Further research with heavier soils and soils rich in organic matter that have been dried to a level where water is not so readily available would show whether in such threshold soil moisture values a hydrogel might have a stronger influence on the reduction in water consumption.

CONCLUSION

Potassium polyacrylate applied in a concentration of 0.5% caused a change in certain water–physical properties of sand. The quantity of available water increased, as did the water retention in soils at different pressures (0–1.5 MPa), whereas the bulk density was reduced. The application of the hydrogel to sand can result in significant savings in water used for irrigation and increase water efficiency. The findings showed that in soils with a higher content of clay and organic matter, the hydrogel did not significantly change the quantities of water required for irrigation or the oat biomass yield. Thus, in terms of water savings, the application of hydrogels does not appear to be justified.

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REFERENCES

Alcamo, J., Moreno, J.M., Novaky, B., Bindi, M., Corobov, R., Devoy, R.J.N., Giannakopoulos, C., Martin, E., Olesen, J.E., Shvidenko, A. (2007): Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, (Ed.), 541-580, Cambridge University Press, Cambridge, UK.

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P. (2008): Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, 210, IPCC Secretariat, Geneva

Djurovic. N, Stricevic, R., Pivic,R., Petkovic, S., Gregoric, E. (2011): Influence of hydrogel on water Conservation and N uptake by barley Irrigated with saline water: a pot study. ICID 21st International Congress on Irrigation and Drainage, Tehran, p. 415-421.

El-Hady, O.A., Abo-Sedera, S.A., (2006): Conditioning Effect of Composts and Acrylamide Hydrogels on a Sandy Calcareous Soil. II-Physico-bio-chemical Properties of the Soil. International Journal of Agriculture & Biology, 8, 6: 876–884.

El-Hady, O.A.,. Wanas, Sh. A. (2006): Water and fertilizer use efficiency by cucumber grown under stres s on sandy soil treated with acrylamide hydrogels. Journal of Applied Science Research, 2(12): 1293-1297

El-Hady, O.A., Abd El-Kader A.A., Shafi, A.M. (2009): Physico-bio-chemical Properties of Sandy Soil Conditioned with Acrylamide Hydrogels after Cucumber Plantation Australian Journal of Basic and Applied Sciences, 3(4): 3145-3151.

Jhurry, D. (1997): Agricultural Polymers, University of Mauritius AMAS 1997. Food and Agricultural Research Council, Réduit, Mauritius 109-113.

Johnson, S.M. (1984): The effects of gel-forming polyacrylamides on moisture storage in sandy soils. Journal of the Science of Food and Agriculture, 35.11: 1096-1200.

Leciejewski, P. (2009): The effect of hydrogel additives on the water retention curve of sandy soil from forest nursery in Julinek. Journal of Water and Land Development, 13a: 239–247.

Oljača, S., Dolijanović, Ž. , Glamočlija, Đ., Đorđević, S., Oljača, J. (2010): Productivity of winter rye in organic vs. conventional cropping system. Journal of Agricultural Sciences, Vol. 55, No. 2: 123-129.

Oljača, S., Dolijanović, Ž. , Glamočlija, Đ., Đorđević, S., Oljača, J. (2009): Produktivnost golozrnog ječma u organskom i konvencionalnom sistemu gajenja, Poljoprivredna tehnika, vol. 34, br. 2: 149-154.

Owczarzak, W., Kaczmarek, Z., Szukala, J. (2006): Influence of Stockosorb hydrogel on selected structure-forming properties of gray-brown podzolic soil and black earth. Journal of Research and Applications in Agricultural Engineering, 51, 3: 55-61.

Sarapatka, B., Rak, L., Bubenikova, I. (2004): Effects of hydroabsorbent used on extremely sandy soils on soil biological and biochemical characteristics. EUROSOIL, September, 04 – 12 Freiburg, Germany, CD-rom

Sivapalan, S. (2006): Benefits of treating a sandy soil with a crosslinked-type polyacrylamide. Austral.J. Experiment. Agricult., 46: 579–584.

Todorović, J., Komljenović, I. (2009): Strne žitarice- (Ratarsko – povrtarski priručnik) – dio četvrti, Ovas. http://www.uns.rs.sr./agric/doc/ovas.pdf, 20.12.2008.

Wallace, A., Wallace, G.A., (1986): Effects of very low rates of synthetic soil conditioners on soils. Soil Science 141 (5) : 324 - 327.

Wallace, A., Wallace, G.A.,(1986a): Effects of soil conditioners on emergence and growth of tomato, cotton and lettuce seedlings. Soil Science 141 (5): 313 - 316.

Nevenka ĐUROVIĆ , Radmila PIVIĆ i Vesna POČUČA

MOGUĆNOSTI PRIMENE HIDROGELA NA RAZLIČITIM ZEMLJIŠTIMA

SAŽETAK

Jedna od metoda za uštedu i racionalnije korišćenje vode u poljoprivredi je primena hidrogela koji utiče na promene vodno-vazdušnih i fizičkih osobina zemljišta, sa krajnjim ciljem poboljšanja njihovog vodnog režima

Cilj ovog rada je da u eksperimentu u sudovima utvrdi uticaj primenjenih polimera (hidrogela) na fizičke osobine različitih zemljišta (peska, treseta i černozema) uticaj na potrošnju vode ovsa kao i relativne promene u produkciji nadzemne biomasi ovsa.

Primenjeni kalijum poliakrilat u koncentraciji 0.5% uticao je na promenu nekih vodno-fizičkih osobina peska. Povećana je količina pristupačne vode, i retencija vode u zemljištu na različitim pritiscima (0 – 1,5MPa) a smanjena zapreminska masa. Korišćenjem hidrogela na pesku mogu se postići znatne uštede vode za navodnjavanje uz povećanje efikasnosti korišćenja vode. Dobijeni rezultati pokazuju da na zemljištima koja imaju veći sadržaj gline i bogatim organskom materijom uticaj hidrogela na promene količine vode za navodnjavanje i prinos biomase ovsa nije izražen pa sa stanovišta uštede vode opravdanost njegove primene nije dokazana.

Ključne riječi: hidrogel, pijesak, černozem, treset, ovas