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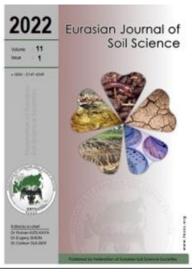

Effects of different polymer hydrogels on moisture capacity of sandy soil

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Abstract

In arid and semi-arid regions, efficient utilization of available water necessitates the adaptation of appropriate water management practices. One such approach is through soil conditioners like polymer hydrogels. The application of polymer hydrogels aids efficient management of water in agricultural production by increasing water holding capacity and improving water conservation of sandy soils. This has led to practical applications of these materials particularly in arid regions and countries, where water is the limiting factor for plant production. Therefore, the ultimate objective of this study was to address the impacts of different polymer hydrogels such as potassium polyacrylate (PH1), starch-acrylonitrile (PH2), starch-acrylic-acid (PH3) and polyacrylic acid (PH4) on the moisture capacity of sandy soils from sand dune. The sandy soils contained >95% sand. Maximum rate of water absorption of polymers (PH1, PH2, PH3 and PH4) were 174, 38.75, 21.7 and 201.1 times their weight respectively. Four polymer hydrogels with three treatments (0.25:0.75, 0.5:0.5 and 0.75:0.25; v/v) were used in the experiment with four replication. With respect to the untreated soil, addition of polymer hydrogels increased significantly full moisture capacity (FMC) and smallest moisture capacity (SMC) for for all polymer: sand mixtures. PH1 recorded highest FMC and SMC than all four polymers. The results suggest that addition of a potassium polyacrylate to sandy soils is more effective polymer hydrogel at increasing moisture capacity in sandy soils.

Keywords: Polymer hydrogel, sandy soil, desert, moisture capacity.

Introduction

Desertification due to wind erosion (deflation process) has touched the semi-desert and desert landscapes of Central Asia and Kazakhstan. The problem of desertification in Central Asia is more serious; 75% of the territory in Kazakhstan, 60% of the territory in Uzbekistan, and 66% of the territory in Turkmenistan are prone to antropogenic desertification (Gulnara et al., 2014). Among the states of Central Asia, Kazakhstan possesses the largest area 'captured' by desertification processes - 179.9 million ha. In fact, about 66% of the country's territory is subject to degradation. The total area of Kazakhstan's non-irrigated arable land is 24 million hectares, of which desert lands make up 10.4 million ha. More than 17 million ha have been withdrawn from the category of arable lands due to loss of humus, salinization, low productivity of land, chemical pollution, and erosion (UNDP, 2004). Degradation is especially pronounced in arid pastures with sandy or sandy loam soils, the area of which in the Kazakhstan is more than 25 million ha, which includes one of the largest sand massifs of the Southern Balkhash region (7.3 million ha). Unsuitable land practices and irrigation use of natural resources and environmental pollution lead to land degradation and desertification in Southern Balkhash region, Kazakhstan. The problem of soil degradation and desertification is the most problem of land agriculture development in this region, Kazakhstan (Almaganbetov and Grigoruk, 2008). Soil

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moisture is an important parameter of the hydrological cycle of terrestrial ecosystems (Bindlish et al., 2003; Song et al., 2007; Schneider et al., 2008), and also is one of the most important ecological factors in sandy ecosystems, where its shows significant variation (Chen et al., 2011; Wagner et al., 2003). Thus, decreasing soil water content is a main driving force in the development of desertification (Berndtsson and Chen, 1994; Yao et al., 2013).

Sandy soils are characterized by low water holding capacity and excessive drainage of rain and irrigation water below the root zone, leading to low water, poor water and fertilizer use efficiency by crops. Therefore, development of non-traditional new technologies to conserve water is becoming important for attaining a sustainable economic growth, especially in agriculture producing countries (Nada and Blumenstein, 2015). Hydrogel is one of the most popular materials, in addition to increasing water holding capacity for agricultural applications having also been used to reduce water runoff and increase infiltration rates in field. The efficiency of the technology is highly suited for farmers growing crops under rained and limited water availability areas (Kumar et al., 2020). Cross-linked Polymer hydrogels with hydrophilic properties have attracted much interest in this area as they can increase water holding capacity of sandy textured soils (Li et al., 2014) and thus increase plant growth (Nada and Blumenstein, 2015). Polymer hydrogels with high molecular weight and high negative charge that absorb a significant amount of water, up to 2000 g water g^{-1}, therefore are considered very suitable for applications in agriculture (Zhang et al., 2006; Yang et al., 2014; Guilherme et al., 2015).

The performance of polymer hydrogels depends on the soil and crop types. The addition of polymer in saline soil had positive effects on plant growth, yield, and available moisture content in corn (Dorraji et al., 2010). Likewise, better performance in sandy loam soils over the clay and clay loam soils has been reported (Narjary et al., 2012).

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 different polymer hydrogels such as starch-acrylonitrile, starch-acrylic-acid, polyacrylic acid and potassium polyacrylate on the moisture capacity of sandy soils from sand dune.

Material and Methods

Soils in deserts are very thin; humus content in them is meager. The mean soil types in the Southern Balkhash region, Kazakhstan are sandy desert, gray-brown, takyr-like, and solonchaks. The sandy desert soils dominate in the Southern Pre Balkhash deserts. The research site was conducted in the Southern Pre-Balkhash deserts (Gulnura et al., 2014). Study site is located from a fine-grained dune located 5 km from the village of Bakbakty on the right side of the road towards the district center of Bakanas (N44°33"54', E076°41"12'), Southern Balkhash region. The height of the dune from the base is about 5 m. It was formed on the territory of the parking lot of the peasant farm "Tarshelov", engaged in animal husbandry (Figure 1). The surface of the sand dune is broken and exposed due to the daily cattle run of 135 cattle. The grazed area of the farm is 300 ha.

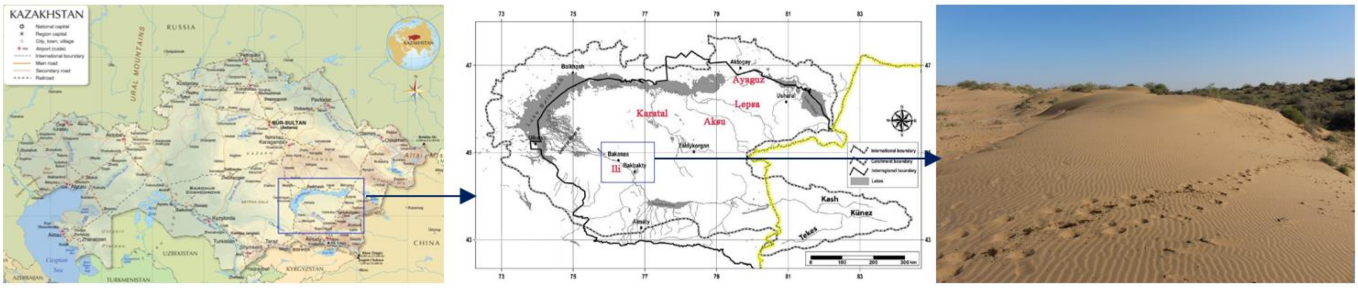


Figure 1. Study area

Climate

The climate of deserts in Kazakhstan, Central Asia, and elsewhere in the world are characterized by high air temperatures and a long dry period during the summer. Climate of the southern Pre-Balkash is continental, arid, characterized by daily and annual variations of air temperature, and high levels of solar radiation. The average mean temperature is about 33°C highs in July and the average mean temperature is −8°C in January. Average precipitation is 175 mm per year (Figure 2).

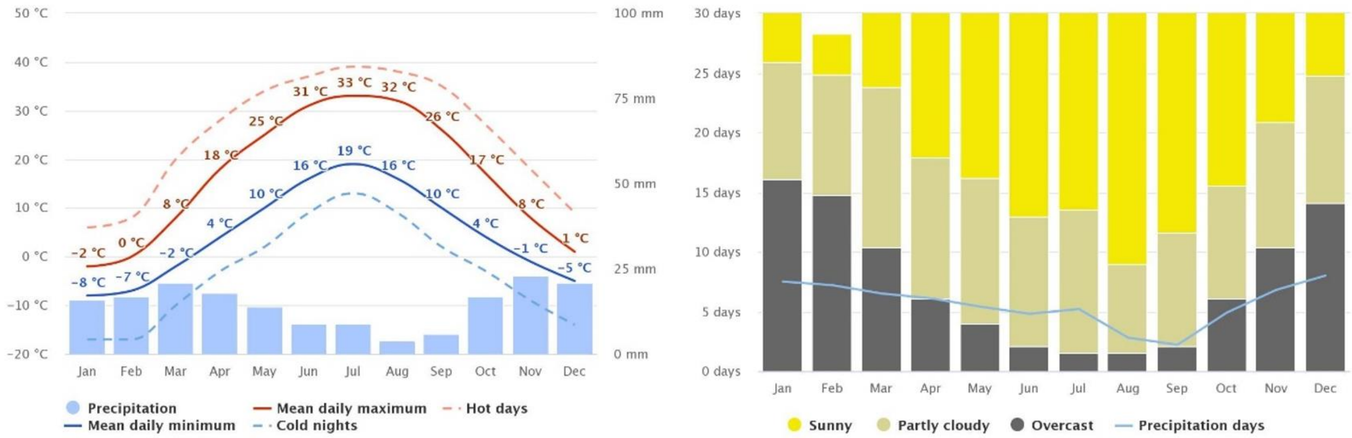


Figure 2. Climate conditions of the study area, Southern Balkhash region, Kazakhstan

Sandy Soil Sampling

Sandy soil samples were collected from 0-20, 20-40, 40-60, 60-80 and 80-100 cm of sand dune. Hygroscopic moisture content of samples determined according to Prakash et al. (2016) and The granulometric composition of samples was determined by the pipette method (Day, 1965). To Seasonal moisture regime of a sand dune, samples were repeatedly taken from the soil depth of 0-20, 20-40 and 40-60 cm to cover the whole spring and summer season of research site (May, June, July, August and September). Two different locations (erosive zone by wind erosion and deposition zone) were selected for sampling. Soil samples were transported to the laboratory and moisture contents of sand samples determined according to Gardner (1965).

Polymer hydrogels

The soil amendments used were four hydrogels. These were “starch-acrylonitrile”, “starch-acrylic-acid” and “polyacrylic acid” synthesized in Kazakh National Agrarian Research University by chemists group. “potassium polyacrylate” is supplied ready to use. Polymer hydrogels degree of swelling and moisture capacity is determined by the difference in weight and volume between dry hydrogel samples and water-soaked samples. To establish the maximum swelling of hydrogels, samples of air-dry polymer hydrogel with a known total weight were taken according to a measurement of mass or a change in mass provides quantitative information about Gravimetric methods after 120 min. (Bassett et al., 1981).

Laboratory experiment

Polymer hydrogels have an amazing ability to absorb and retain exceptionally large quantities of water. When it comes in contact with water it swells to form a gel. Sandy soil samples (0-20, 20-40, 40-60, 60-80 and 80-100 cm) of sand dune was used in the experiment. The sandy soils contained >95% sand. Four polymer hydrogels (starch-acrylonitrile, starch-acrylic-acid, and polyacrylic acid and potassium polyacrylate) with three treatments (0.25:0.75, 0.5:0.5 and 0.75:0.25; v/v) were used in the experiment with four replication. The volumetric weight of the mixture of hydrogel and sand was calculated for a volume of 175 cm^3 dishes, taking into account the degree of swelling of hydrogels in free water space and the volumetric weight of each component of the mixture (sand and hydrogel) was 1.51 and 0.40 g/cm^3, respectively. Then evenly mixed calculated mixtures of hydrogel and sand filled the vessels according to their volume ratio (0.25:0.75, 0.5:0.5 and 0.75:0.25). After that, the mixtures were compacted by gently tapping the bottom of the vessels on the table. Then plastic dishes with a mixture of polymer hydrogel and sand were immersed in a special bath with water so that the water was at the level of the mixture in the vessels. After that, the vessel covers were closed to prevent physical evaporation from the surface of the mixture and left in this form until the next day. Water was transferred through the pores of the paper in the mixture, and its complete saturation took place. Thus, these cylinders were moistened to such a state until all the pores were filled with water. After reaching the specified state, the vessels, after wiping water from their walls, were weighed on electronic scales until its mass was constant.

To determine the SMC (smallest moisture capacity), i.e. the volume of water remaining after the gravity water drained, the vessels with the mixture soaked to PV were pulled out of the bath and left for some time until the water stopped dripping from the bottom of the vessels. Upon reaching the specified state, the cylinders were weighed and the weight of moisture of the corresponding SMC was determined by the difference in mass between the air-dry and the current one.

The value of FMC (full moisture capacity) and SMC separately of sand and a mixture consisting of polymer hydrogels of various water characteristics and a sandy substrate was determined as a percentage of absolutely dry sand by the formula (Romashchenko et al., 2019):

$$W_{FMC \text{ and } LMC} = ((d-c+a)/(c-a-b)) \times 100$$

d : the weight of the cup with a mixture of hydrogel and sand, saturated to FMC or LMC, g
c : the weight of the cup with a mixture of hydrogel and sand before moistening, g
a : the amount of water in the sand sample before saturation;
b : the mass of an empty cylindrical plastic vessel and filter paper installed on its bottom, g

Results and Discussion

Partical size distribution of Sand Dune

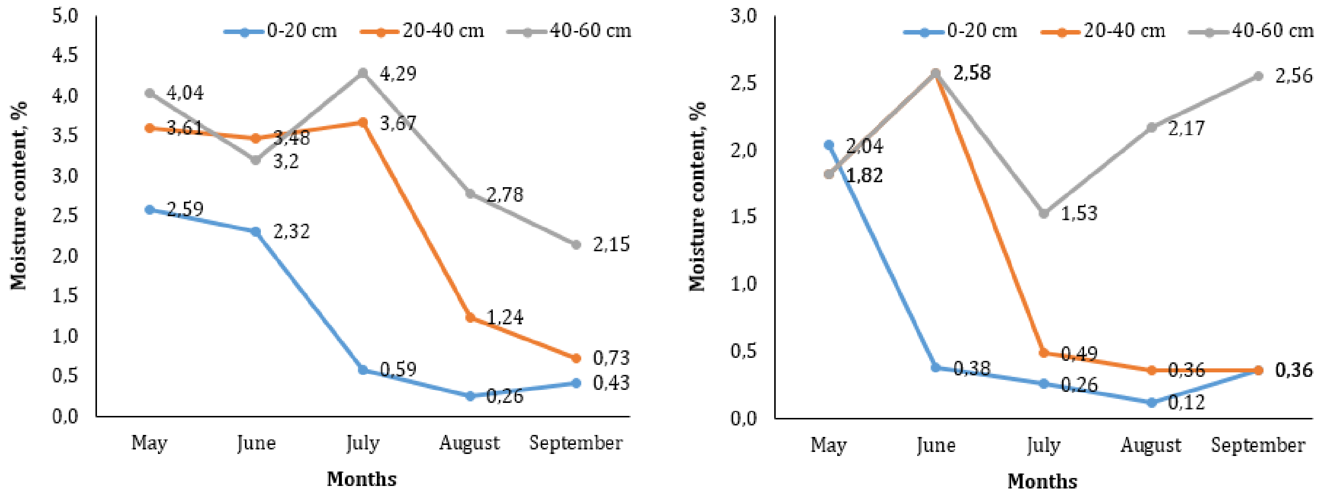
Partical size distribution and hygroscopic moisture for all the different depth from sand dune are given Table 1. The soil was characterized by low organic matter and low water holding capacity. Percentages by weight of medium sand (1,00-0,25mm), fine sand (0,25-0,05mm), coarse silt (0,05-0,01 mm), medium silt (0,01-0,005 mm), fine silt (0,005-0,001 mm) and clay (<0,001 mm) were calculated by weight in accordance to Russian soil partical size classification system. As shown in Table 2, 85,6–89,7% of the sand samples were mainly distributed within the range of 0.25–0.05 mm (fine sand), indicating that only 10.1-14.4% had sizes greater than 0.25 mm and less than 0.05 mm. It can be seen that the trend of particle size distribution and hygroscopic moisture is similar in all depths. This agrees with the findings of Yuan et al. (2008) and You et al. (2022) suggests the predominance of fine sand in the particle composition of the Aeolian sand deposits found in Yulin Area, China.

Table 1. Particle Size distribution and hygroscopic moisture contents of samples

Sampling depth, cm	Hygroscopic moisture, %	Particle Size distribution, mm					
		Sand		Silt			Clay
		1,00-0,25 mm	0,25-0,05 mm	0,05-0,01 mm	0,01-0,005 mm	0,005-0,001 mm	<0,001 mm
0-20	0,32	8,287	85,694	3,612	0,401	0,803	1,204
20-40	0,38	9,155	85,625	2,409	1,205	1,205	0,402
40-60	0,32	8,086	86,697	2,006	1,605	0,803	0,803
60-80	0,28	7,260	87,124	2,407	0,802	1,604	0,802
80-100	0,30	4,514	89,870	2,407	2,006	0,802	0,401

Changes of the moisture contents of the sand dunes

Since the moisture status of the profiles in erosive zone and deposition zone is influenced by the rainfall received during the rainy season, soil moisture contents during the rainless period (August) are particular interest. Sand dune in erosive zone, reasonably high soil moisture encountered within 20-40 and 40-60 cm depth, while sand dune in deposition zone, moisture content below the permanent wilting point may be found (Figure 3).



Erosive zone **Deposition zone**

Figure 3. Changes of the moisture contents of the sand dunes in erosive and deposition zone

Thus sand dune in erosive zone offer better soil moisture condition for plant establishment and growth and also support the usefulness of deep planting in shifting sand dune in research area. Deep planting also provides favorable temperature for root growth during the summer at the early stages of plantation. In this study, moisture regime of the sand dunes showed that in the month of May in its windward part, the moisture content of the sand was relatively in optimal content for normal growth and development of *Psammophytes*. Psammophyte a plant that thrives in shifting sands, primarily in deserts. *Psammophytes* are marked by a number of adaptations that enable them to exist on wind-blown sands. In such an environment, the plants are often covered with sand, or their root system is exposed. *Psammophytes* are encountered not only in deserts but also along seas and large lakes and in sands along rivers (Elymus giganteus, sand fescue, sharp-leaved willow). *Psammophytes* are often used to stabilize sandy soils (For The Great Soviet Encyclopedia, 2021).

Polymer hydrogels

Polymer hydrogels showed rapid initial hydration followed by a progressive decrease in the rate of absorption towards the point of equilibrium. All polymers had a similar pattern in the rate of water absorption. The results of the swelling properties of the polymer hydrogels used in this study are given in Figure 4. The Figure 4 shows that the average absorption of water by potassium polyacrylate (PH1), starch-acrylonitrile (PH2), starch-acrylic-acid (PH3) and polyacrylic acid (PH4) was found to be 174, 38.75, 21.7 and 201.1 times of its weight respectively. The equilibrium swelling tests in distilled water showed that PH4 displayed higher swelling ratios when compared with PH2, PH3 and PH1 (Figure 4). This may be due to its high molecular weight materials that can absorb as much as several hundred times its weight. Chaudhry et al. (1994) revealed that average water absorption by polymer (Aquasorb) after 120 min was 130 times its weight. Hydrogels may absorb water from 10-20% up to thousands of times their dry weight. The character of the water in a hydrogel can determine the overall permeation of nutrients into and cellular products out of the gel. When a dry hydrogel starts absorbing water, the first water molecules entering the matrix will hydrate the polar, hydrophilic groups, leading to primary bound water. As the polar groups are hydrated, the network swells, and hydrophobic groups are exposed, which further interact with water molecules, leading to hydrophobically bound water, or secondary bound water. Primary and secondary bound water are often combined and simply called the total bound water. After the polar and hydrophobic sites have interacted with and bound water molecules, the network will imbibe additional water, due to the osmotic driving force of the network chains towards infinite dilution. This additional swelling is opposed by the covalent or physical crosslink, leading to an elastic network retraction force. Thus, the hydrogel will reach an equilibrium swelling level (Kumar et al., 2020).

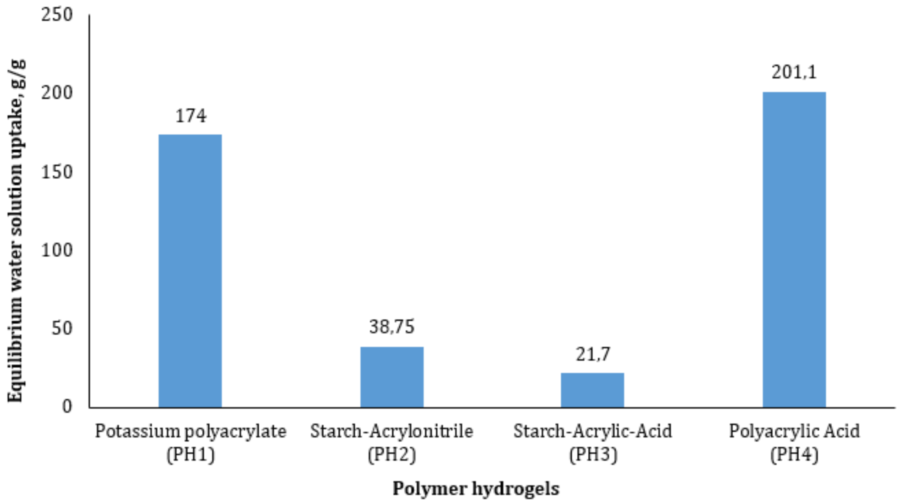


Figure 4. Polymer hydrogels equilibrium swelling properties in distilled water.

Moisture Capacity

The moisture content of treated sand samples was studied. Generally, the full and smallest moisture capacity of the sand samples increased with increasing amounts of polymer hydrogels in the samples. However, the water holding capacity of the samples did not increase linearly with increasing amounts of polymers in the samples. This increase in water retention can reduce the amount of water otherwise lost by deep percolation. FMC is the maximum possible amount of gravitational water that can be contained by the soil while filling all the voids. SMC is the amount of capillary-hanged water retained by the soil after the expiration of excess liquid water (Romashchenko et al., 2019).

Mixing the sandy soil with the polymer hydrogels showed high pronounced effect on its values of FMC, SMC and FMC-SMC (Figure 5). The values of these parameters in the polymer hydrogels amended soils relative to the non-amended control were shown in Figure 5. With respect to the untreated soil, addition of polymer hydrogels increased significantly FMC, SMC and FMC-SMC for all polymer: sand mixtures. PH1 recorded highest FMC and SMC than all four polymers. FMC was 38.54, 59.10 and 119.12 respectively and the SMC was 35.20, 54.03 and 105.24 at 0.25:0.75, 0.5:0.5 and 0.75:0.25 (v/v) polymer: sand mixtures. While, untreated soil observed with the lowest values of FMC and SMC. These results are in agreement with those obtained by Akhter et al. (2004), Dorraji et al. (2010) and Nada and Blumenstein (2015).

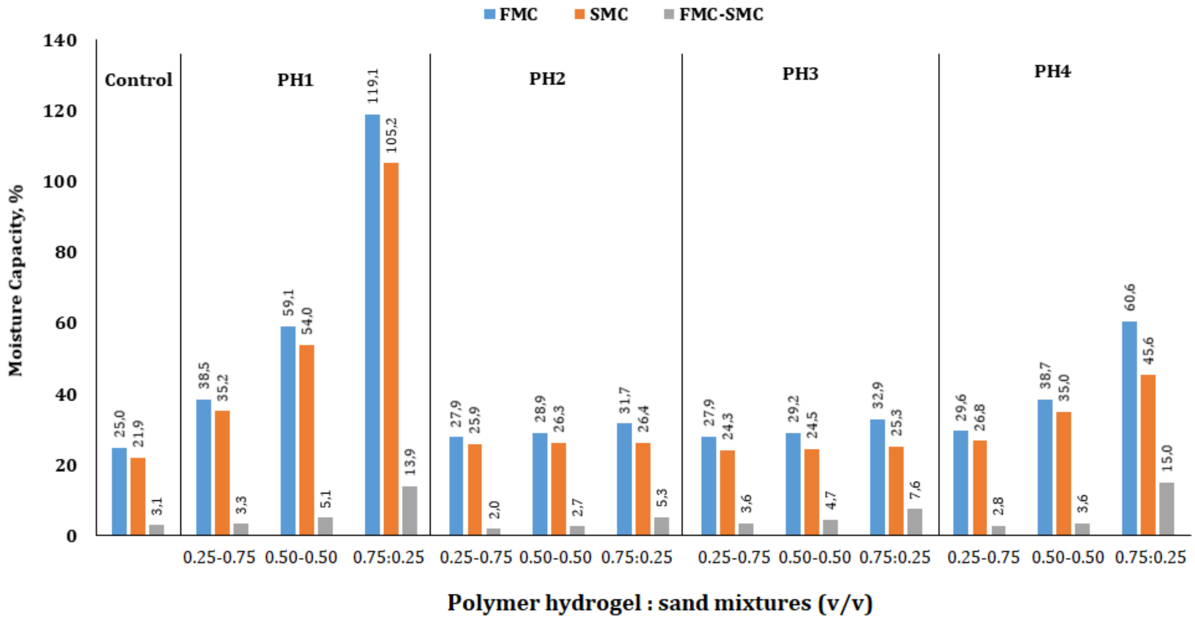


Figure 5. Different polymer hydrogel:sand mixtures (v/v) on moisture capacity

Conclusion

Desert sandy soils in Kazakhstan are widespread in the sandy pastures of the Southern Balkhash region, which, due to anthropogenic degradation, turned into mobile dunes in a short time, which began to bring inconvenience to the living population in places of their active manifestation. The study of sandy deserts in Southern Balkhash region allows qualitative assessment of the modern deflation processes intensity in this area. The sands of our study region are most affected by the deflation process. They consist mainly of fine sand (0.25-0.05 mm), the proportion of which ranges from 87.6 to 94.6% in the meter thickness. They have an eternal shortage of moisture, but despite this they are the soils of valuable pastures of the region's distilling livestock. The survival rate of seedlings of sand-strengthening forest shrubs due to the hot climate, high seasonal mobility of the relief of mobile sands and their low humidity is very low, and the creation of optimal soil moisture by irrigation, due to the low moisture capacity of sand, water scarcity and the difficulty of delivering it to the planting sites of seedlings in the summer months is almost impossible. Therefore, for the restoration of the soil and vegetation cover of sand dunes, the autonomous improvement of their water regime under the existing norms of atmospheric precipitation is relevant. Therefore, polymer hydrogels, which significantly increase the moisture capacity of not only sandy soils, but also sands, were promising in this regard. Our results suggest that mixing Polymer hydrogels with sandy soils could improve their moisture capacities. In addition, it was determined that Potassium polyacrylate recorded highest full and smallest moisture capacity than the starch-acrylonitrile, starch-acrylic-acid and polyacrylic acid on sand from sand dune compared to the untreated control treatment. However, further comparisons between the polymer hydrogels and soil physico-chemical properties and their influence on the polymers and the plant production are necessary on field conditions in this area.

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