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VARYING THE VEGETATIVE AND MORPHOLOGICAL TRAITS OF *Thymus kotschyanus* L. SUBMITTED TO POTASSIUM SILICATE NANOPARTICLES, SUPERABSORBENT HYDROGEL, EFFECTIVE MICROORGANISMS AND ANIMAL MANURE

VARIAÇÃO DAS CARACTERÍSTICAS VEGETATIVAS E MORFOLÓGICAS DE Thymus kotschyanus *L. SUBMETIDA A NANOPARTÍCULAS DE SILICATO DE POTÁSSIO, O HIDROGEL SUPERABSORVENTE, OS MICROORGANISMOS EFETIVOS E O ESTERCO ANIMAL*

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ABSTRACT: To study the effects of some new facilitators on the vegetative and morphological traits of *Thymus kotschyanus*, nine treatments were tested in the experimental rangeland field at the University of Mohaghegh Ardabili, Ardabil, Iran. Treatments included control, potassium silicate nanoparticles (PSN) with two levels of 500 and 1000 mg/lit, superabsorbent hydrogel (SH) with two levels of 10 and 30 g/kg, animal manure (AM) with two levels of 100, 200 g/kg, and effective microorganisms (EM) with two levels of 1 and 2%. Data were subjected to one-way analysis of variance (ANOVA). Results of mean comparisons of treatments for *Thymus kotschyanus* characteristics showed that the highest amount of studied traits were observed in the treated SH 30 g/kg. These traits include plant height (19.44 cm), basal area (4.66 cm), canopy cover (99.11%), number of secondary branches (9.44) and depth of rooting (16.49 cm), aerial parts volume (26.77 cm^3), root volume (17.66 cm^3), aerial parts fresh weight (14.40 g), aerial parts dry weight (7.18 g), root fresh weight (3.98 g), and root dry weight (2.07 g). In general, the impact of treatments on *Thymus* growth traits were ranked as follows: SH 30 g/kg, PSN 1000 mg/lit, AM 200 g/kg, SH 10 g/kg, PSN 500 mg/lit, AM 100 g/kg, EM 2%, and EM 1%. In addition, the lowest plant traits were found in control. Overall, it is recommended extending the cultivation of this native medicinal plant by considering ecological conditions in each region. In addition, to promote the establishment and facilitate the growth of planted species, it is recommended using the facilitators utilized in the present work.

KEYWORDS: Facilitator. Nanomaterial. Superabsorbent hydrogel. Medicinal plant.

INTRODUCTION

Climate change and its low quality are among of the major challenges for natural resources in many regions of the world (ORIKIRIZA et al., 2013). Previous studies have shown that drought affects the growth and physiological traits of plants (SINGH et al., 2014). Easy absorption, storage, and release of water are the main functions of the soil for plant growth. This feature differs in different soils, depending on the fine or coarse size of soil particle and its minerals (BANEDJSCHAFIE et al., 2006). Various technologies, compatible with the soil in each region, are required for soil moisture conservation (SIX et al., 2002). One of the existing technologies is the use of hydrophilic superabsorbent (DORRAJI et al., 2010). Superabsorbent polymers are hydrophilic networks that absorb a large volume of water (200-500 ml/g dry weight). This substance is able to absorb water in the soil up to saturation point and hold it for a long time within its network. So, the water in the network could be gradually absorbed by the plant (POLITE et al., 2004). Several studies have been performed on the application of superabsorbent, their physical and chemical properties of them (BAI et al., 2010), and their impacts on soil and plants (WU et al., 2012). Previous studies have reported that hydrophilic polymers led to the increased water-holding capacity in sandy soils and reduced water losses through leaching (EKEBAFE et al., 2011). Zangooei Nasab et al., (2013) reported the

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positive and significant effect of using superabsorbent on the growth indices of *Haloxylon persicum* including height, shoot fresh, dry weight, root fresh, dry weight, and root length.

Besides, nanotechnology and biotechnology are the emerging fields that have tremendous potentials to renovate agriculture, natural resources, and allied fields. Nanoparticles (NPs) are commonly accepted as materials with dimensions between 1 and 100 nm (BALL, 2002). Unique properties of nanoparticles include very large specific surface area, high surface energy, and quantum confinement (NEL et al., 2006). Products that are derived from nanotechnology are known as a nanomaterial (DUTSCHK et al., 2014). The aim of using nanomaterial in the field of agriculture and natural resources is to improve the efficiency and sustainability of these practices by putting less input. Heavy use of nitrogen (N) and phosphorus (P) fertilizers has become the major anthropogenic factors resulting in worldwide eutrophication problems in freshwater bodies and coastal ecosystems. Thus, relevant research is required to minimize nutrient losses in fertilization and increase the crop yield through the exploitation of new applications with the help of nanomaterials and nanotechnology (CONLEY et al., 2009).

Most of the applied fertilizers remain unavailable to plants due to factors such as leaching and degradation by hydrolysis, insolubility, and decomposition at a high rate and have caused major environmental issues for a long period in the agriculture and natural resources field (SINGH et al., 2015). In recent years, due to rising costs of chemical fertilizers and environmental problems, organic fertilizers such as animal manure are considered for solving the nutritional requirements of plants and soil (NEISANI et al., 2012). Bio-fertilizers provide a valuable biological resource in addition to the advantages of ecological and environmental stability, which play an effective role in agriculture and natural resources (FALLAH et al., 2007). Bio-fertilizers are made up of microorganisms that are useful for a specific purpose, such as nitrogen fixation and release of phosphate, potassium, and iron ions. The microorganisms, which usually develop around the roots, help plants in the nutrient uptake, reduce plant disease, improve soil structure, stimulate plant growth both quantitatively and qualitatively, and increase plants resistance to environmental stresses (NAGANANDA et al., 2010). Reports have shown improving productivity EM effect on pomegranate and almond (SHOKOUHIAN et al., 2013). Pampuro et al., (2018) stated that pelletized compost derived from animal manure typically increases soil organic matter content and improves soil quality and fertility. Results of Moameri et al., (2018) showed that the highest stem length and Allometric coefficients of *Onobrychis sativa* were observed in 1,000 ppm nanosilicate. And the highest fresh weight of seedling, vigor index and tissue water content were observed in the EM 2%.

Thymus kotschyanus (belonged to mint (Lamiaceae) family) is one of the valuable plants in rangelands. This plant has medicinal values and is important for beekeeping and food production (SHAHRAKI et al., 2015). *Thymus kotschyanus* plays an important role in the economy of local people in most regions as its cultivation helps the regional economy. Also, using *Thymus* in urban green spaces doubles the efficiency of this valuable plant (ABBASI KHALAKI; SHOKOUHIAN, 2017). In terms of quantity and quantity of medicinal ingredients, *Thymus* is fragrant, prominent, and famous. Therefore, in this study, the effects of different levels of some facilitators such as a superabsorbent hydrogel, potassium silicate nanoparticles, and animal manure and effective microorganisms on the vegetative and morphological traits of *Thymus kotschyanus* are evaluated to improve the establishment and a better growth of this important and useful medicinal plant.

MATERIAL AND METHODS

Experimental site

This research was carried out in order to accelerate the growth of *Thymus kotschyanus* as the medicinal plants regarding their benefits for proper economic management in Ardabil province, Iran. The experiment was conducted using a completely randomized design with three replications in experimental rangeland field at the University of Mohaghegh Ardabili. Ardabil County. The study area is located in coordinates of 38°12´ 44´´N and 48°17´46´´E with an altitude of 1380 m above sea level (a.s.l). The mean annual rainfall of the selected area is about 335 mm and the climate of the study area is semi-arid.

Cultivation of *Thymus kotschyanus* and implementation of treatments

On the selected area, experimental rangeland field was plowed, weeds were taken, and seedbed and growth media were prepared. The experimental area was divided into nine considered treatments. The nine treatments were selected as a control, SH with two levels of 10 and 30 g/kg, PSN with two levels of 500 and 1000 mg/lit, AM with two levels of 100, 200 g/kg, and EM with two levels of 1 and 2% concentrations. In each plot, 15 pits were created into three replications with 30 cm distance between rows and 20 cm distance between plants within rows (in the north to south direction to avoid the shading of shrubs on each other). In addition, three replications were considered for each treatment. Soil physical and chemical characteristics of the experimental location are demonstrated in Table 1.

Table 1. Soil physical and chemical characteristics of experimental location

Soil texture	Apparent specific weight (g/cm^3)	EC (dS.m^{-1})	pH	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	Organic matter (%)
Sandy loam	1.46	0.4	8.3	0.01	28.6	174	0.08

Nanoparticle suspension

The characteristics of PSN were subjected to identification and morphological characterizations given in Figure 1. The morphological study of this nanoparticle was done by a scanning electron microscope (SEM) device. In this study, plants were irrigated three times in one month (Every 10 days) with nanoparticle suspensions. The solution was poured into the planting pits.

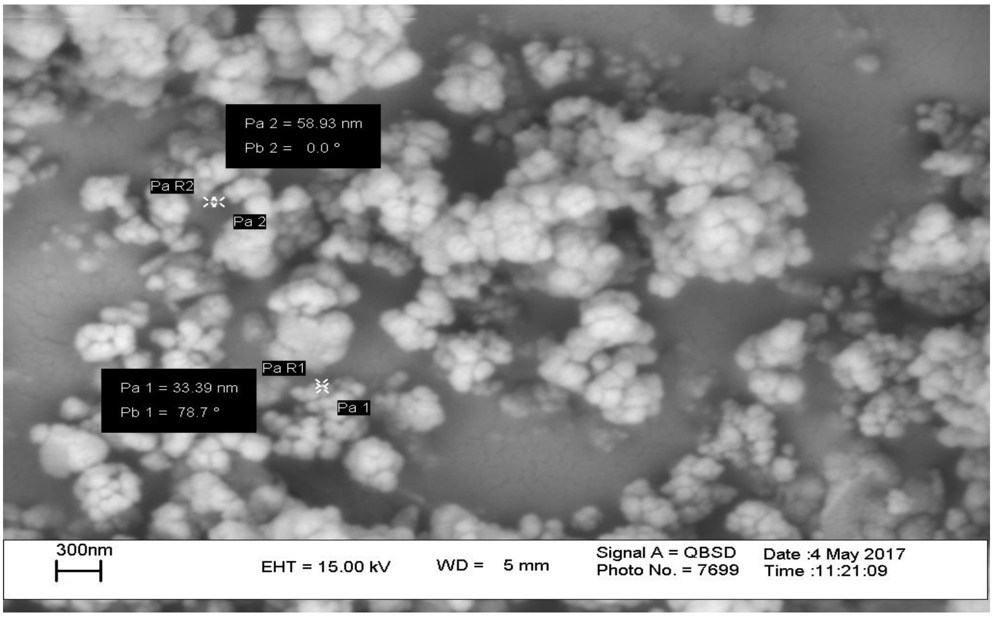

Figure 1. Scanning electron microscope micrograph of potassium silicate nanoparticles

Superabsorbent hydrogel treatment

First, 10 and 30 g of SH separately were blended with 1 kg soil. Then, these mixtures were poured at the bottom of each pit and shrub was planted. After rainfalls, hydrogel absorbed water and converted to a gel. Physical and chemical characteristics of studied SH are given in Table 2.

Table 2. Physical and chemical characteristics of used superabsorbent hydrogel

Appearance	Moisture (%)	Particle size (µm)	pH	Water absorption capacity (ml/g)	Odor and Toxicity	Mass density (g/cm^2)	Solubility
Brown powder	<5	200-400	6-7	500	-	0. 8	Insoluble

Bio fertilizers; effective microorganisms and animal manure

Two concentrations of 1 and 2% of EM were made. Moreover, the establishment plants were treated three times every 10 days by pouring solution into the pits and at the place of roots. Characteristics of EM are shown in Table 3.

Table 3. Characteristics of effective microorganisms

Compounds						Number of EM	pH
water	Sugarcane molasses	Aloevera	Photosynthetic bacteria	Lactic acid bacteria	Yeasts	120	<4

AM as an alternative of superabsorbent was used during shrub establishment. For this purpose, 100 and 200 g/kg levels of this material were considered. First, these amounts of AM were combined with soil and pits were filled with them. Then, the shrubs were planted and 5 cm of pit surface was filled with soil. Table 4 presents the chemical characteristics of the AM.

Table 4. Chemical characteristics of animal manure

Type of fertilizer	Total nitrogen (%)	Phosphorus (%)	Potassium (%)	EC ($dS.m^{-1}$)	pH
Cow manure	0.57	0.09	1.1	6.1	6.8

Data collection

After five months, inventory of cultivated plants was prepared at the end of their growing season. For data collection, five plants of each plot were randomly selected, measured, and averaged in terms of studied vegetative and morphological parameters. These traits included plant height (cm), basal area (cm), canopy cover (%), root volume (cm^3), aerial parts volume (cm^3), plant fresh and dry weight (g), root length (cm), and a number of sub-branches. The last item is an early sign of plant growth and development (SAFARI-NED et al., 2013). Canopy cover was considered with measurement of plants large and small diameters (SIDDIQUI et al., 2015).

Data analysis

First, data normalization was done using the Kolmogorov-Smirnov test, then data were subjected to one-way analysis of variance (ANOVA) using the SPSS software (ver. 22). To investigate differences between treatments and their effects on considered characteristics of the soil and cultivated species, Tukey's mean comparison test was used.

RESULTS

The results of ANOVA showed a significant effect of PSN, SH, and biofertilizers on all of the vegetative and morphological traits of *Thymus kotschyanus* ($P \leq 0.01$) (Table 5).

Table 5. ANOVA results for vegetative and morphological traits of *Thymus kotschyanus*

Source of variation	df	MS				
		Plant Height (cm)	Basal Area (cm)	Canopy Cover (%)	Sub branch (n)	Depth of Rooting (cm)
Between Groups	8	71.06 **	5.87 **	7849.45 **	46.40 **	35.11 **
Within Groups	72	3.14	0.39	710.61	4.96	5.54

Source of variation	df	Aerial parts Fresh Weight (g)	Aerial parts Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Aerial parts Volume (cm^3)	Root Volume (cm^3)
Between Groups	8	107.17 **	27.61 **	8.46 **	2.38 **	331.53 **	110.13 **
Within Groups	72	7.87	2.76	0.77	0.32	18.48	11.85

**=Corresponding MS significant at 1%.

The mean comparisons among treatments for morphological traits of *Thymus kotschyanus* are presented in Table 6. For all of the studied traits, SH with 30 g/kg showed the highest mean values compared with the other treatments. Results showed that the highest values of plant height (19.44 cm), basal area (4.66 cm), canopy cover (99.11%), number of secondary branches (9.44) and depth of rooting (16.49 cm) were observed in superabsorbent 30 g/kg while the lowest values were obtained from the control. This result suggests that all materials are effective in improving and increasing the amounts of morphological characteristics.

Table 6. The mean comparison of the morphological traits of *Thymus kotschyanus* as affected under treatments of PSN, SH, EM and AM

Treatments	Factor	Plant Height (cm)	Basal Area (cm)	Canopy Cover (%)	Sub branch (number)	Depth of Rooting (cm)
Control	**0**	9.77 [e]	1.88 [d]	19.11 [c]	2.00 [c]	9.55 [c]
PSN	**500**	15.00 [cd]	3.44 [bc]	48.88 [bc]	8.22 [ab]	10.83 [bc]
(mg/lit)	**1000**	17.08 [ab]	4.05 [ab]	71.77 [b]	9.00 [a]	14.22 [ab]
SH	**10**	16.83 [b]	3.72 [b]	62.00 [b]	7.11 [ab]	11.05 [bc]
(g/kg)	**30**	19.44 [a]	4.66 [a]	99.11 [a]	9.44 [a]	16.49 [a]
EM	**1**	13.33 [d]	3.05 [c]	49.00 [bc]	5.88 [b]	12.38 [b]
(%)	**2**	13.88 [d]	3.44 [bc]	58.11 [bc]	7.66 [ab]	12.66 [b]
AM	**100**	13.33 [d]	3.55 [bc]	51.88 [bc]	8.00 [ab]	11.05 [bc]
(g/kg)	**200**	16.27 [bc]	3.88 [bc]	71.00 [b]	8.77 [a]	12.22 [b]

Different letters in each column indicate significant differences between means ($P<0.01$).

The mean comparison of vegetative characteristics is shown in Table 7. For vegetative traits, SH with 30 g/kg and control treatment had the highest and lowest value, respectively. Results of mean comparisons among treatments for vegetative characteristics revealed that the highest values of aerial parts volume (26.77 cm^3), root volume (17.66 cm^3), aerial parts fresh weight (14.40 g), aerial parts dry weight (7.18 g), root fresh weight (3.98 g), and root dry weight (2.07 g) were observed in superabsorbent 30 g/kg.

Table 7. Vegetative traits of *Thymus kotschyanus* as affected under treatments of PSN, SH, EM and AM

Treatment	Factor	Aerial parts Volume (cm^3)	Root Volume (cm^3)	Aerial parts Fresh Weight (g)	Aerial parts Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
Control	**0**	7.22 [e]	4.33 [c]	2.54 [e]	1.29 [e]	0.81 [e]	0.33 [d]
PSN	**500**	13.00 [cd]	9.88 [bc]	7.68 [cd]	4.13 [c]	1.36 [de]	0.79 [cd]
(mg/lit)	**1000**	19.22 [bc]	11.22 [b]	12.40 [ab]	5.83 [ab]	2.47 [ab]	1.47 [b]
SH	**10**	14.77 [cd]	11.88 [b]	9.45 [bc]	4.75 [bc]	2.13 [bc]	1.23 [bc]
(g/kg)	**30**	26.77 [a]	17.66 [a]	14.40 [a]	7.18 [a]	3.98 [a]	2.07 [a]
EM	**1**	10.66 [de]	8.77 [bc]	5.01 [de]	2.87 [d]	1.29 [de]	0.71 [cd]
(%)	**2**	12.88 [cd]	9.22 [bc]	5.45 [d]	2.96 [d]	1.51 [d]	0.95 [bc]
AM	**100**	15.55 [cd]	10.66 [b]	7.39 [cd]	3.72 [cd]	1.93 [cd]	1.01 [bc]
(g/kg)	**200**	21.33 [b]	11.55 [b]	9.18 [bc]	5.00 [bc]	2.81 [b]	1.49 [b]

Different letters in each column indicate significant differences between means ($p<0.01$).

DISCUSSION

Effect of potassium silicate nanoparticles (PSN)

In this study, nanoparticles treatment had a significant difference with control. In addition, PSN with 1000 mg/lit concentration was more effective than 500 mg/lit concentration in all of studied morphological and vegetative traits of *Thymus kotschyanus*. A nano-fertilizer refers to a product that delivers nutrients to crops in one of three ways. Potassium is one of the essential elements for plant growth and sufficient concentration of it in the root has an effective role in the growth and its performance (MOJID et al., 2012). Plant performance improvement in the presence of nanoparticles can be due to the fact that these particles are able to penetrate easily into the cells of plants and leaves. As a result, they improving their growth by transferring chemicals into the plant cells and improve the performance of the transportation of nutrients in the plant (TORNEY et al., 2007). Yang et al., (2004) reported that the use of potassium nanoparticles increases the tillering of rice stem and its dry weight. In addition, this material increases the concentration of carbohydrates and rice production. Study of Pathak et al., (2008) has shown that the use of nano-potassium in a multi-step process increases plant growth of canola in vegetative and reproductive stages and enhances dry matter. According to the results of Tavan et al., (2014), the number of leaves of wheat that sprayed with nano-potassium fertilizer at a concentration of 0.3% and shoot and root length in 0.15% indicated a significant increase compared to other treatments and also with control. Mukhopadhyay et al., (2015) showed that the use of clay nanocomposites could improve plant establishment (80-98%) and growth (15- 30 cm) of wheat. In fact, large specific surface in clay nanocomposites causes the availability of nutrients of the soil for the plant. Abbasi Khalaki et al., (2016) reported that higher values of *Thymus kotschyanus* seed germination traits when using nanosilver (20%). Moreover, they observed that increasing silica nanoparticle concentration enhanced the seed germination.

Effect of superabsorbent hydrogel (SH)

In this study, SH 30 g/kg had a higher effect than 10 g/kg for all of the traits. In a comparison between treatments, this treatment (30 g/kg) has shown the highest performance. However, the concentration of 10 g/kg had a significant difference compared to control. This result suggests that this concentration has also improved means of vegetative and morphological characteristics of *Thymus kotschyanus*. The quality of the soil solution is improved by cation exchange properties and buffer feature of superabsorbent. In addition, the density of plant roots in the hydrogel results in good contact of the roots with Ca^{2+} and reduction contact with Na^{+} and Cl^{-} that it has an important role in increasing plant tolerance and improve its growth and establishment (CHEN et al., 2004). It may be due to the increased availability of nutrients and water in soil through its controlled release property. Puoci et al., (2008) showed the emergence and establishment of different plant species in arid and semi-arid areas of the most important issues. Moreover, this researcher reported the use of hydrophilic polymers to improve the physical properties of soil increased the germination and establishment of plants; this result is consistent with that of the present study. In addition, studying the impact of superabsorbent polymer on the soil microbial characteristics and the Chinese canola growth, Xi et al., (2013) concluded that these polymers play a significant role on root growth and plant yield. The results of Cheruiyot et al., (2014) showed that growth in both the height and root collar diameter of the *Cajanus cajan* was significantly different at three levels of hydrogels (7 g, 11 g and 15 g). This result implies that use of hydrogels retards plant growth in nursery soils but improves growth in the field; again, this result is in accord with our results.

Impact of effective microorganisms (EM)

Although the EM in this study compared to other treatments has less impact on the morphological characteristics of *Thymus kotschyanus*, it has shown a significant difference compared to control and caused to improve the *Thymus* studied characteristics. In addition, EM 2% was more effective than EM 1%. EM increases soil and plant biological activity. In addition, microorganisms producing hormonal compounds such as auxin increase the growth of root weight and height, as well as increasing the number and splits of the root, which causes changes in the morphology, and structure of the root. As a consequent, water absorption and nutrient uptake by the plant are improved (GERMAN et al., 2000). Previous studies have shown that this organism can affect the quality of soil, plant growth and quality, effective production performance, and efficiency of other operations. When EM is used with soil or sprayed on plants, it causes the expansion of photosynthetic bacteria and nitrogen stabilizer. This phenomenon causes plant growth and higher quality by increasing the efficiency of photosynthesis and nitrogen fixation levels (SHOKOUHIAN et al., 2013). Khan et al., (2007) reported that the use of EM in the tree *Albizia saman* increase growth factors such as the fresh and dry weight of the plant and the amount of chlorophyll in the leaves. Results of Shokouhian et al., (2013) showed effects of different EM and irrigation levels on almond growth. It was found that EM increased plant growth, number of leaves, leaf area, fresh and dry weight, storage chlorophyll, N, K, and P in leaves. Plants treated with EM showed an improved root system of the plant in water deficit condition because of the improved soil physical properties and direct absorption of water by the hyphae of fungi; hence, their growth compared to untreated plants was enhanced (ALLAHVERDIYEV et al., 2011).

Effect of animal manure (AM)

AM 200 g/kg, followed by the superabsorbent 30 g/kg and nanoparticle 1000 mg/lit had the greatest impact on growth and morphological characteristics of *Thymus kotschyanus*. Thus, AM 200 g/kg was better than the manure of 100 g/kg. However, both of them had significant difference compared to the control. AM is one of the most important sources of energy and nutrients of the soil ecosystem that increase crop yield by improving the physical, chemical, and biological properties of the soil (FALLAHI et al., 2009). Consuming suitable amounts of manure increases plant growth by improving the soil microbial activity and growth regulators by the microorganism, as well as supplying adequate amounts of nutrients to the plants (DARZI et al., 2006). The results of Ahmadian et al., (2004) about the influence of AM on the quantity and quality yield of cumin showed that the number of umbels per plant, the number of seeds per plant, biological yield, and economic performance were increased significantly by manure treatment. Pouryousef et al., (2011) reported that cow manure has a beneficial effect for increasing root growth, adequate supply of nutrients (nitrogen, potassium and sulfur), increases leaf area, and improves photosynthesis and better allocation of materials in *Plantago ovata* grains. In addition, Raesee et al., (2015) showed the significant effect of manure, fertilizer, iron, and zinc fertilizer on dry weight, yield, and number of seeds per plant, number of umbels per plant, plant height, seed weight, and essential oil content of *Cuminum cyminum*.

CONCLUSIONS

In general, the impact of treatments on the vegetative and morphological characteristics of *Thymus kotschyanus* were ranked as follows: SH 30 g/kg, PSN 1000 mg/lit, AM 200 g/kg, SH 10 g/kg, PSN 500 mg/lit, AM 100 g/kg, EM 2%, and EM 1% (Tables 6 and 7). SH had a significant effect on the growth of seedlings and thus the use of hydrogels to amend soils in the field had a positive impact on the growth of species. Moreover, the lowest plant vegetative and morphological traits that were found in control may be due to the low concentration of available nutrients in soil at later critical growth stages.

Thus, cultivation of medicinal species is suggested owing to their benefits in disease therapy and the tendency of people to use herbal medicine. Therefore, it is recommended extending the cultivation of native medicinal species, particularly *Thymus kotschyanus*, by considering ecological conditions in each region. In addition, it is recommended using the facilitators utilized in the present study in order to promote the establishment and facilitate the growth of planted species.

RESUMO: Para estudar os efeitos de alguns novos facilitadores sobre as características vegetativas e morfológicas de *Thymus kotschyanus L*., nove tratamentos foram testados no campo experimental de pastagens na Universidade de Mohaghegh Ardabili, Ardabil, Irã. Os tratamentos incluíram controle, nanopartículas de silicato de potássio (PSN) com dois níveis de 500 e 1000 mg/L, hidrogel superabsorvente (SH) com dois níveis de 10 e 30 g/kg, esterco animal (AM) com dois níveis de 100 e 200 g/kg e microorganismos efetivos (EM) com dois níveis de 1 e 2%. Os dados foram submetidos a uma análise de variância unidirecional (ANOVA). Os resultados das comparações médias dos tratamentos para as características de *Thymus kotschyanus L*. mostraram que a maior quantidade das características estudadas foi observada no tratamento com SH 30 g/kg. Essas características incluem altura de plantas (19,44 cm), área basal (4,66 cm), cobertura de dossel (99,11%), número de ramos secundários (9,44) e profundidade de enraizamento (16,49 cm), volume de partes aéreas (26,77 cm3), volume de raiz (17,66 cm3), peso fresco de partes aéreas (14,40 g), peso seco de partes aéreas (7,18 g), peso fresco de raiz (3,98 g) e peso seco de raiz (2,07 g). Em geral, o impacto dos tratamentos nas características de crescimento de Thymus foi classificado da seguinte forma: SH 30 g/kg, PSN 1000 mg/L, AM 200 g/kg, SH 10 g/kg, PSN 500 mg/L, AM 100 g/kg, EM 2% e EM 1%. Além disso, as características mais baixas da planta foram encontradas no controle. Em geral, recomenda-se estender o cultivo desta planta medicinal nativa considerando as condições ecológicas em cada região. Além disso, para promover o estabelecimento e facilitar o crescimento de espécies plantadas, recomenda-se utilizar os facilitadores utilizados no presente trabalho.

PALAVRAS-CHAVE: Facilitador. Nanomaterial. Hidrogel superabsorvente. Planta medicinal.

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