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IMPACT OF HYDROGEL TYPE/MYCORRHIZAE ON PEPPER SEEDLINGS GROWTH

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Abstract:

Water deficit is the one of the main factors affecting crop productivity. A few technologies such as mycorrhizae (M), polyacrylamide (CLP), and superabsorbent polymers (SAP), were applied to improve water holding capacity and promote sustainable agriculture. Investigating the possible effects of 0.5 g/kg rate SAP or CLP alone or in combination with 5 g/kg mycorrhizae on the growth of pepper seedlings was the goal of the current study to evaluate the influence of two types of hydrogel/mycorrhizae on the growth of pepper seedlings at 70% evapotranspiration. Six treatments control (C), mycorrhizae (M), SAP, CLP, SAPM, and CLPM were incorporated into sandy loam soil in a pot experiment. Up to 40 days after transplanting, with daily watering at 70% of potential evapotranspiration (ETp), the shoot height and number of leaves per plant were measured every ten days. Shoot height and leaf count as a function of time were well described by a sigmoidal function, with R^2 greater than 0.865. The change rates of shoot height and leaf number were estimated using the sigmoidal function. Mycorrhizae and CLP had shoot peak rates of 1.08 and 1.101 cm/d, respectively. The CLP treatments had the fastest and largest leaf number change at the peaks (5.41 d^{-1}), while CLPM had the smallest peak (2.06 d^{-1}). Except for chlorophyll, the CLP-treated seedlings outperformed the other treatments in terms of improving all the seedling traits. The CLPM stored the greatest soil water, while the control held the

least. According to the findings of the current study, the CLP was much more suggested than mycorrhizae for sustainable pepper production. Generally, the CLP/mycorrhizae are recommended for soil water management.

Keywords: Superabsorbent polymers, polyacrylamide, irrigation cease, pepper seedling, sandy loam soil, evapotranspiration, sigmoidal function, mycorrhizae.

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Introduction:

A serious worldwide environmental issue, water scarcity is a pressing global environmental challenge that is impaired by climate change and population growth. The combined use of mycorrhizae and hydrogel could be a potential strategy for increasing pepper growth and sustaining agricultural productivity. Hameda et al. (2012) revealed that increasing hydrogel polymer combined with soil improved the morphological, anatomical, and physiological characteristics of sweet peppers. According to Hafiz-Afham et al. (2023), the optimal growth factors for *capsicum annuum* were 40 percent hydrogel and 60 percent topsoil per plant. Bdier et al. (2023) revealed that hydrogel serves to alleviate water stress, conserve soil moisture, and optimize water usage efficiency, reducing irrigation water use by 50% for pepper (*Capsicum Annuum*). Nayan et al. (2019) showed that Plant samples treated with PVA/chitosan hydrogel grew significantly faster than conventional fertilizer methods in terms of fruit number (43), total mass fruit yield (1654g), fresh and dry plant weight (139.5%), leaf number (130.6%) and width (19.8%), and chlorophyll content (0.037). 0.2% hydrogel could cut water use by up to 50% compared to regular plants while maintaining production (Joseph et al., 2020). The use of mycorrhizae in sustainable agriculture includes environmental and economic benefits. According to the research, inoculating pepper plants with mycorrhizae increased biomass, plant height and leaf diameter. Furthermore, the root length of plants treated with mycorrhizae was twice of root plants untreated with mycorrhizae (Soylu et al. 2023). The use of mycorrhizae can contribute to sustainable agriculture by reducing applied artificial fertilizers while enhancing crop yield. Similarly, the phosphorus and potassium levels of aboveground plant sections differed significantly between mycorrhizae and control treatments. Almost all plant roots create mutualistic connections with mycorrhizae fungi, which help the plants absorb more water and mineral nutrients, particularly phosphate (Yilma, 2019). Inoculating pepper plants with arbuscular mycorrhizae fungi increased economic yield and improved maturity by improving nutrient uptake, lowering salt effect, and disease tolerance. Similarly, Beltrano et al. (2013) establish that mycorrhizae plants had higher root and shoot biomass at all salinity levels than non-mycorrhizae plants, regardless of P level. Al-Karaki (2017) exposed that pepper plants inoculated with arbuscular mycorrhizae (AM) exhibited higher shoot and root dry matter as well as plant height than non-AM plants, regardless of salinity levels. The results demonstrate that pre-inoculation of green pepper transplants with mycorrhizae fungi increased nutrient uptake and fruit output, particularly at moderate rather than severe salinity levels. According to Yilma (2019), pepper production rose in the presence of mycorrhizae fungi. According to the preceding work, the current study aims to evaluate the influence of two types of hydrogel/mycorrhizae on the growth of pepper seedlings at 70% evapotranspiration.

Materials and methods:

<u>Outdoor experiment setting</u>

A sandy loam soil sample was collected from the Etehad area, Kom Hamada province, Beheira Governorate, Egypt, (30.7634° N, 30.6968° E). Two distinct hydrogels (SAP and CLP) were incorporated separately at a rate of 0.5 g/kg soil. Mycorrhizae (*Glomus spp*) were applied at a rate of 5 g/kg soil, either alone or in combination with SAP/CLP. For more details on both gels and soil properties, the reader is referred to Shehata et al., (2024). The governorate's climate is typically Mediterranean, with dry, hot summers and cool, wet winters. The annual average temperature and rainfall are 20.4°C and 102 mm, respectively (Weather and Climate, 2024). Pepper seedlings (30-day-old) were transplanted on September 27, 2024, into semi-conical plastic pots (average diameter of 10.5 cm and 12 cm soil height) packed with (1.5 kg) of sandy loam soil giving a bulk density of 1.44 Mg/m^{-3}. The seedlings were irrigated for 40 days, till November 6, 2024. Six treatments which proposed for the current study were depicted in Table 1. The pots were buried until the soil surface inside the pots was almost at the same level of the ground of open field to prevent heat stress on the pepper seedlings. Tap water was applied to each pot to bring the initial soil water content up to the soil field capacity of 0.31g/g. Tap water added to each pot on daily basis estimated by using Romanenko's equation (Abdelraouf et al., 2022, and 2023; and Ali et al., 2023), until 40 days after transplanting to provide sufficient soil moisture for well seedling growth. The daily watering was at 70% of potential evapotranspiration (ETp). The supplied water signified 70% of the potential evapotranspiration (ETp) (Kabir et al., 2021). Romanenko's equation used to evaluate the ETp. Ten grams of NPK fertilizer (20-20-20) diluted in one liter of water as a stock solution were applied for standing good development. The stock added as fertigation after 10, 20, and 30 days of seedling transplantation using Romanenko's equation as follows:

$$\mathbf{ET_p = 0.0018(25 + T_a)^2 \times (100 - h_m)} \qquad (1)$$

Table (1): The assigned treatments of pepper seedlings growth.

No.	Symbols	Treatment description
1	C	Control
2	M	Mycorrhizae
3	SAP	0.05% w/w using Superabsorbent polymer
4	CLP	0.05% using polyacrylamide polymer
5	SAPM	0.05% w/w using Superabsorbent polymer inoculated with mycorrhizae
6	CLPM	0.05% w/w using polyacrylamide polymer inoculated with mycorrhizae

Where ET_p is the potential evapotranspiration (ETp) from water (mm/month), T_a is the ambient temperature in Celsius, and h_m is the relative humidity (%).

Mathematically Growth Characterization

The number of leaves and shoot height measured every ten days beginning with the transplantation. A functional three-parameter logistic model used to fit the shoot height and leaf numbers at various times (Javaid et al., 2018; Ali et al., 2023). The appropriate sigmoidal function was:

$$\mathbf{F(x)} = \frac{\boldsymbol{a}}{\mathbf{1} + \boldsymbol{exp}(-(\frac{\boldsymbol{x}-\boldsymbol{x_0}}{\boldsymbol{b}}))} \qquad (2)$$

Where F(x) represents shoot height/leaf counts at time x (day), and a, b, and x_0 are fitting constants. The first derivative of the equation represents the slope of the sigmoidal function. The slope would be calculated using the equation below (which also includes the growth rate as a function of time).

$$\frac{\partial F}{\partial x} = \frac{a}{b}\frac{(\exp(-(x\text{-}x_0)/b))}{(1+\exp(-(x\text{-}x_0)/b))^2} \qquad (3)$$

Some growth parameters such as the number of branches and pods, chlorophyll was measured using SPAD-502plus (Süß et al., 2015), leaf area (Pandey and Singh, 2011), soil water content was recorded when irrigation ceases. Additionally, blooming time was recorded during the sapling growth while the shoot dry weight was recorded 57 days after transplanting.

Statistical analysis

An analysis of variance was performed to examine statistical differences using PROC GLM, followed by Fisher's protected least significant difference for the mean of growth parameters with SAS 13.1 statistical software (SAS Institute, 2013).

Results and Discussion

The growth characteristics of pepper seedlings were described quantitatively utilizing certain sigmoidal functions (Eq. 2). It is evident that the seedlings were generally vigorous at 40 days after transplantation. The CLP produced the most biomass visibly, followed by the mycorrhizae treatment. It concluded that irrigation at 70% ET did not produce water stress in the seedlings, and that the irrigation water was adequate for seedling growth. During the 40-day growing period, the total irrigation water used was 1.4 liters per pot. The sigmoidal function represented the shoot heights as a function of time for the six treatments (Figure 1). The sigmoidal model accurately characterized all of the observed data for each treatment. Shoot heights had determination coefficients (R^2) of 0.868, 0.957, 0.962, 0.974, 0.974, and 0.987 for C, M, SAP, CLP, SAPM, and CLPM, respectively. CLP-treated seedlings outperformed all other treatments in terms of shoot height enhancement, but CLPM had the least effect (Figure 1). The shoot heights after 40 days of transplanting were 33.3, 41, 36.5, 43.3, 32, and 27 cm for the C, M, SAP, CLP, SAPM, and CLPM, respectively. Notably, both the CLP and mycorrhizae treatments increased shoot height similarly when compared to the other treatments. This finding is consistent with Soylu et al., (2023), who stated that mycorrhizae inoculation boosted pepper plant root, shoot fresh and dry weight, plant height, and leaf diameter. Furthermore, plants with mycorrhizae inoculation had longer root lengths (3921 cm pot^{-1}) than plants without mycorrhizae (with 1945 cm pot^{-1}). The water preserved by CLP or mycorrhizae treatments may reduce water stress on pepper seedlings during the growth time that result in plant cell division. Furthermore, CLP covers a set of amides that can release nitrogen, boosting pepper seedling growth. According to Yilma (2019), mycorrhizae increase a plant's ability to absorb water and nutrients. However, the combination of hydrogel and mycorrhizae did not show any increase in shoot height. Because of the findings in the current study, it is superior to use hydrogel and mycorrhizae separately for long-term pepper production. According to Díaz-Urbano et al. (2023), bio-inoculants can improve nutrient uptake, increase phytohormones levels, and protect plants from infections and pests by triggering defense mechanisms, competing for space, or producing antimicrobial metabolites.

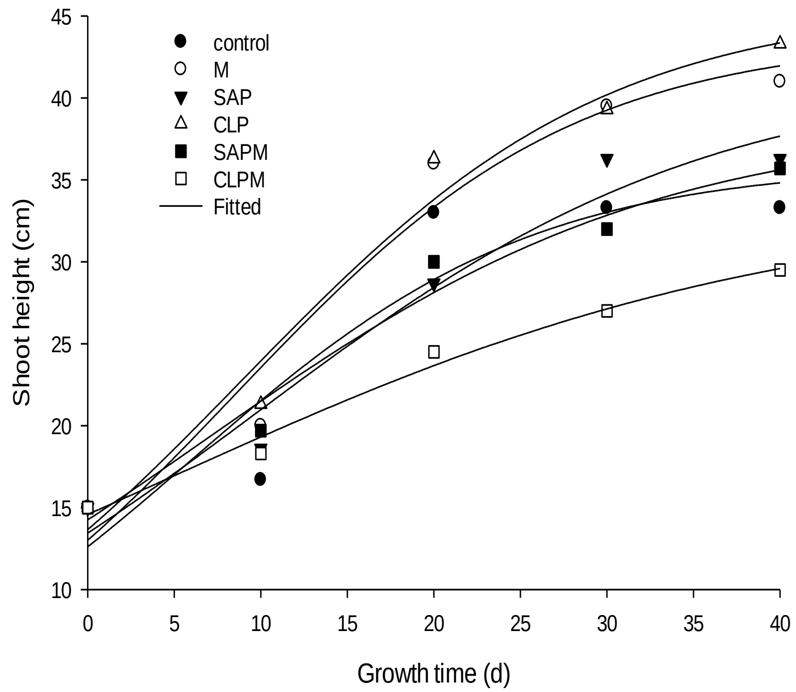

Fig.1: The shoot height as a function of time, observed (symbols), fitted (solid lines).

The leaf number of pepper seedlings calculated using a sigmoidal function (Eq. 2). Figure (2) depicts the number of leaves per plant as a function of time under the studied treatments. The sigmoidal model accurately described the observed data for all treatments. The determination coefficients (R^2) for leaf numbers were 0.993, 0.974, 0.985, 0.993, 0.973 and 0.973 for C, M, SAP, CLP, SAPM, and CLPM, respectively. The leaf numbers were 69, 63, 74, 106, 69, and 54 for C, M, SAP, CLP, SAPM and CLPM, respectively (Figure 2). Obviously, CLP treated seedlings were superior among all treatment for enhancing the leaf numbers while. The treated seedlings with a combination of CLP and mycorrhizae (the CLPM) gave the lowest leaf numbers among all treatments (Figure 2). Overall, the shoot heights trend performed similarly to leaf number one. As previously noted, the CLP increased both shoot height and leaf counts. Similarly, Hafiz-Afham et al.'s (2023) study of *capsicum annuum* found that 40 percent hydrogel and 60 percent topsoil per plant generated the best growth metrics.

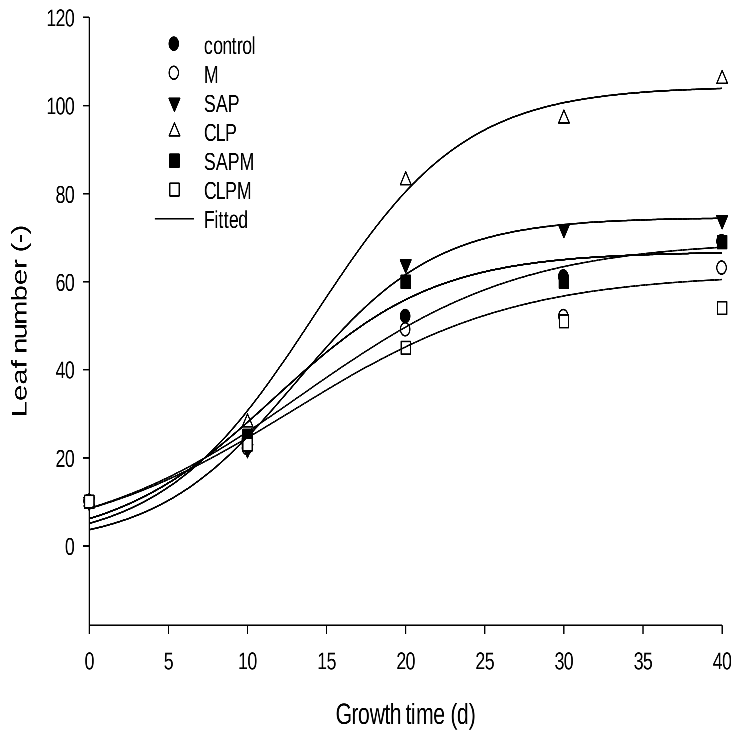

Fig.2: The leaf number per plant as a function of time, observed (symbols), fitted (solid lines).

Figure (3) shows the calculated shoot height rates for the pepper seedlings as a function of time and the treatment types using Eq.3. The values of the rates differ greatly among the treatments used. All rates behaved similarly in their trends with time. They increased with time to show a peak then followed by a decreasing trend after their peaks. The timing of the peaks differed among the treatments. The peak time for CLP and mycorrhizae was ten days while the other treatments passed 5 days for the peak of the rates. The peak rates are 1.08 and 1.101 cm/d for the CLP and mycorrhizae, respectively. The trend of shoot height rates supports the previous results of shoot height presented in Figure 1. Joseph et al. (2020) and Bdier et al. (2023) found that pepper has a favorable influence on water consumption. The latter author observed that hydrogel helps to ease water stress, conserve soil moisture, and optimize water usage efficiency, reducing irrigation water use by 50% for pepper (*Capsicum Annuum*). Hydrogels had effectively employed to boost water-holding capacity while requiring less irrigation than typical plants for both chilly and lady's finger. It discovered that even 0.2% hydrogel could cut water use by up to 50% compared to regular plants while maintaining production (Joseph et al., 2020). The combination of hydrogel and mycorrhizae was not suggested for pepper seedlings since it may have a harmful effect on their cell division.

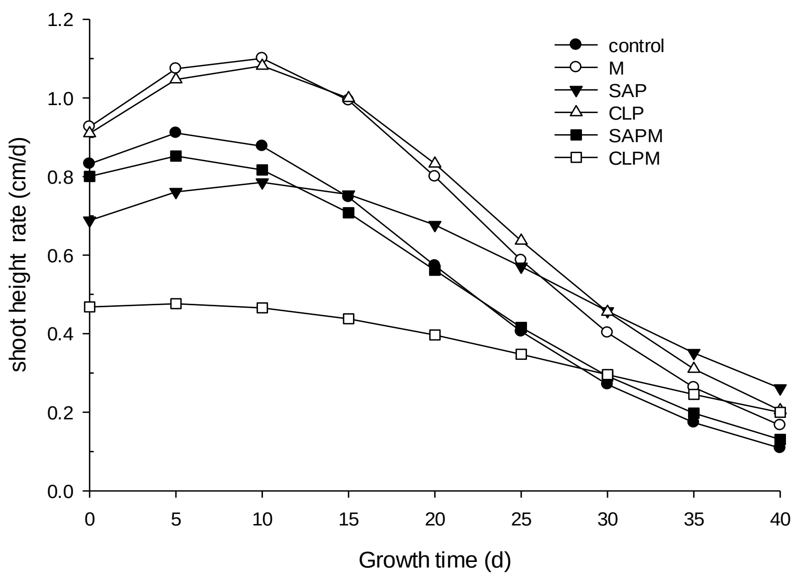

Fig.3: The calculated shoot height rates as a function of time under the treatments used.

Figure (4) shows the estimated leaf number rates for the seedlings as a function of time under the six-treatments using Eq.3. The values of the leaf number rates differ greatly among the treatments. All rates behaved similarly in their trends with time except the control that exhibited nonlinearly reduction with time. The leaf number rates for the hydrogel or mycorrhizae treated seedlings increased with time to show a peak then followed by a decreasing trend after their peaks. Nevertheless, the CLP treatments gave the highest and fastest change rates at the peaks (5.41 d^{-1}) and the least peak was for CLPM (2.06 d^{-1}). It is worth noting that the CLP accelerated greatly the leaf number rates to 15 d after the transplanting followed by decreasing in the rates with time. The differences in the rates among the treatments might be attributed to the soil water availability in the treated hydrogel soil especially CLP soil. Joseph et al., (2020) and Bdier et al., (2023), gave similar explanation. The arbuscular mycorrhizae can be employed to compensate for Zn and P deficit in P and Zn deficient soils for pepper plants (Ortas et al., 2011), which resulted in increased growth in the current study. Inoculating the root zone with Mycorrhizae Fungi resulted in high-grade sweet pepper harvests. Mycorrhizae fungi applied to the root system during seedling production improved pepper yield and biometric parameters, resulting in fruits with the thickest pericarp and biggest bulk (Franczuk et al., 2023).

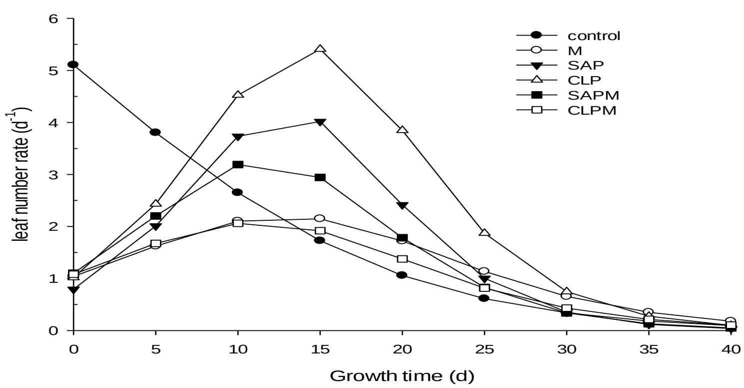

Fig.4: The calculated leaf number rates as a function of time under the treatments used.

Table (2) presents the branch and pot number, chlorophyll and leaf area after 40 d of transplanting. According to means values of trait studied, there are significant differences among all means. The pod numbers were 12, 15, 14, 24, 10, and 3 for C, M, SAP, CLP, SAPM, and CLPM, respectively. The corresponding branch numbers were 11, 12, 16, 27, 13 and 11. The leaf area followed the trend of branches similarly. It is worth noticing that CLP gave the highest values of the traits while CLPM gave the lowest values. The greatest values using CLP hydrogel can be attributed to the increased conserved water and the release of nitrogen as plant nutrients of the amide group in the CLP. Leaf chlorophyll did not differ significantly among the treatments. However, the CLPM gave the greatest value among all the treatments by the M treatments. The leaf chlorophyll measurements were consistent with those of Bader et al. (2020). The blossoming time of flowers did not follow a set pattern. However, the time varied greatly between the treatment methods. The mycorrhizae speeded (19 d) the blooming of flowers while CLPM slowed (24 d) them (Table 2). The results of the present study are attributed to the availability of both soil water and plant nutrients. The gravimetrical residual moisture in soil (θm) after 40 days differed significantly among the treatments (Table 2) and ranged from 7.4 to 13.5%. The control stored the lowest soil water while the CLPM stored the highest value. According to the low soil moisture content, it is seemingly that the aeration is not limiting factor for the seedlings. Additionally, it inferred that the hydrogel/mycorrhizae treated soil lost less water by evapotranspiration in comparison to the control treatment. Badr et al. (2020) showed that plants with mycorrhizae exhibited better N and P uptake in plant, regardless of drought severity. Soil with mycorrhizae showed increased extractable N, P, and organic carbon, indicating improved fertility while dealing with a limited water supply. The shoot dry weight after 57 d. (40 d. irrigation and 17 d. irrigation cease) differed significantly among the six treatments (Table 2). The CLP possessed the greatest dry weight while the CLPM gave the lowest value. The shoot dry weight trend supports generally the other studied traits. The mixed treatment of soil generation superabsorbent polymers and mycorrhizae can have negative effects due to potential interactions that may disrupt the symbiotic relationship between mycorrhizae and plant roots or alter soil conditions unfavorably. Below are some potential negative effects and their explanations: disruption of mycorrhizae symbiosis; altered soil chemistry; competition for resources; reduced root growth and microbial imbalance (Rillig & Mummey, 2006; Gianinazzi et al. 2010; Smith & Read, 2010; And. Dubey et al .2014).

Table 2: Some seedling growth characters and gravimetric soil water contents

Parameters	C	M	SAP	CLP	SAPM	CLPM	$LSD_{0.05}$
Pod numbers	12 b	15 b	14 b	24 a	10 c	3 d	4.0
branch numbers	11 c	12 c	16 b	27 a	13 c	11 c	1.48
Leaf surface area (cm^2)	8.7 c	10.4 b	11.3 b	17 a	12.2 b	8.7 c	1.0
Leaf chlorophyll (Spad unit)	62 a	66.8 a	65.4 a	64.5 a	62.5 a	68.3 a	2.38
Bloom time (d)	22 c	19 e	20 d	23 b	22 c	24 a	0.95
Gravimetric residual soil water (%) *	7.4 f	9.0 d	11.4 b	9.4 c	11.6 b	13.5 a	0.31
shoot dry weight (gm/plant) **	2.61 d e	2.88 c d	3.48 b	4.64 a	3.14 b c	2.32 e	0.35

*40 d. after transplanting with irrigation, ** 57 d (40 d. irrigation and 17 d. cease irrigation).

Conclusion

The water availability of hydrogel/mycorrhizae-treated soil enhanced the pepper seedling's growth characters. Generally, the uptake of water or nutrients is controlled by hydraulic properties of soil. The survival duration of seedlings treated by CLP/mycorrhizae is high which extend the irrigation period and saving water. Hydrogel/mycorrhizae treated soil stored a high amount of water compared to the control. Therefore, it can be concluded that CLP and mycorrhizae individually is preferred as a strategic management in sandy loam soils in a semiarid region. Noticeably, CLP/mycorrhizae are a promising solution for boosting the growth of pepper seedlings under water-scarce conditions. In a future study on the management of pepper seedling, using a wide range of low hydrogel percentages might be helpful for minimizing the agricultural production costs.

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تأثير نوع الهيدروجيل / الفطريات الجذرية على نمو شتلات الفلفل.

إبراهيم شحاتة - إبراهيم نصار - حسام أحمد - هبه زغلول

قسم الموارد الطبيعية والهندسة الزراعية، كلية الزراعة، جامعة دمنهور، دمنهور

الملخص

يعد نقص المياه أحد العوامل الرئيسية التي تحد من إنتاجية المحاصيل. كما تعد البوليمرات فائقة الامتصاص (SAP) والبولي أكريلاميد (CLP) / الفطريات الجذرية من بين العديد من التقنيات التي تعزز كفاءة استخدام المياه، مما يؤدي إلى الزراعة المستدامة. كان الهدف من هذه الدراسة هو التحقيق في التأثير المحتمل لمعدل 0.5 جرام / كجم تربة من البوليمرات فائقة الامتصاص (SAP) أو البولي أكريلاميد (CLP) مع 5 جرام / كجم من الفطريات الجذرية بشكل فردي على نمو شتلات الفلفل في ست معاملات (مجموعة التحكم (C)، الفطريات الجذرية (M) ، SAP، CLP، SAPM، وCLPM) . تم تسجيل طول السيقان وأعداد الأوراق كل 10 أيام حتى 40 يومًا بعد الشتل مع الري بنسبة 70٪ من جهد التبخر- النتح يوميًا. وصفت الدالة السيجمائية طول االسيقان وأعداد الأوراق جيدا كدالة للوقت مع R^2 أكبر من 0.865. تم استخدام الدالة السيجمائية لتقدير معدل تغير ارتفاع السيقان وأعداد الأوراق. كانت المعدلات العظمي للسيقان 1.08 و1.101 سم / يوم لكل من CLP والفطريات الجذرية على التوالي. أعطت معاملات CLP أعلى وأسرع معدلات تغيير في عدد الأوراق 5.41 يومً $^{-1}$ بينما ادني قيمة 2.06 يوم $^{-1}$ كانت لمعاملة CLPM. كانت الشتلات المعالجة بـ CLP متفوقة بين جميع المعاملات لتعزيز كل من سمات الشتلات باستثناء الكلوروفيل. خزنت معاملة الكنترول أقل كمية من مياه التربة بينما خزنت CLPM أعلى قيمة من المحتوي الرطوبي. بالنسبة لإنتاج الفلفل المستدام ولاستراتيجية إدارة المياه، يوصى بشدة بـ CLP / الفطريات الجذرية. لإنتاج الفلفل وفقًا لنتائج البحث الحالي.

الكلمات الدالة: البوليمرات فائقة الامتصاصSAP، بولي أكريلاميدCLP، الفطريات الجذرية mycorrhizae، وقف الري، شتلات الفلفل، الطميية الرملية، التبخر -النتح، الدالة السيجمائية.