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Hydrogel, biocompost and its effect on photosynthetic activity and production of forage maize (*Zea mays* L.) plants

Hidrogel, biocompost y su efecto en la actividad fotosintética y producción de forraje en plantas de maíz (*Zea mays* L.)

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Abstract

The increase in the incidence and intensity of drought caused by climate change is a critical factor in agricultural production in some regions of the world. Dry lands are often severely affected by water shortages caused by low rainfall. This study evaluated the effect of compost and hydrogel used to retain soil moisture on photosynthetic activity and forage corn production. The experiment was designed as a randomized block with a split plot design; the main plots were the hydrogel application rates (0, 12.5 and 25 kg ha^{-1}), and the subplots were the compost application rates (0 and 20 t ha^{-1}). Photosynthetic activity increased by 20.2-28.0% when the hydrogel was applied at rates of 12.5 and 25 kg ha^{-1}, respectively, compared with the control. As a result, the production of fresh forage increased from 19.5 t ha^{-1} in the control to 77.6 and 81.6 t ha^{-1} when the hydrogel was applied at rates of 12.5 and 25 kg ha^{-1}, respectively. A similar effect was observed for dry matter production. The compost had a weakly effect on photosynthetic activity.

Keywords: Aridity, biofertilizers, edaphic moisture, stress physiology, corn productivity.

Resumen

El aumento en la incidencia e intensidad de la sequía provocada por el cambio climático, es un punto crítico para la producción agrícola en diferentes regiones del planeta. Las tierras áridas son a menudo las más afectadas por la disponibilidad de agua debido a la escasez de precipitación pluvial. El objetivo del presente estudio fue evaluar diferentes dosis de hidrogel y composta, como retenedores de humedad en el suelo y su efecto en la actividad fotosintética e impacto en la producción de maíz forrajero. Un diseño experimental de bloques al azar en un arreglo de parcelas divididas fue utilizado, donde las parcelas grandes correspondieron a las dosis de hidrogel (0, 12.5 and 25 kg ha^{-1}) y las parcelas chicas fueron las dosis de composta (0 y 20 t ha^{-1}). La actividad fotosintética se incrementó 20.2-28.0% cuando el hidrogel fue aplicado a dosis de 12.5 y 25 kg ha^{-1}, respectivamente. Como resultado, la producción de forraje fresco aumentó de 19.5 t ha^{-1} en el testigo a 77.6 y 81.6 t ha^{-1} cuando el hidrogel fue aplicado en dosis de 12.5 y 25 kg ha^{-1}, respectivamente. Un efecto similar se observó para la producción de forraje seco. La composta tuvo un débil efecto sobre la actividad fotosintética.

Palabras clave: Aridez, biofertilizantes, fisiología del estrés, humedad edáfica, productividad de maíz.

Introduction

Corn is a grain global production, which is produced in at least 113 countries in the world. Among its main uses include human consumption, animal production and starch production. The corn is the main crop in Mexico, since represents 18% of the production value of the agricultural sector, and accounts for 33% of the planted surface in the country (7,5 million. ha^{-1}). The northern of Mexico, is one of the major maize growing region. In this zone, water scarcity is characterized by the erratic distribution of rainfall throughout the year. Thus, in most of the semi-desert regions, there is insufficient rainfall to satisfy the water required for agricultural production. Therefore, we must develop methods to improve the efficiency of water use in the production process.

Several organic and chemical products as moisture retainers in the soil are being probing and using to improve crop production. Compost is one of organic product for the soil moisture retention by increasing the soil porosity and aeration, which positively affect beneficial soil microorganisms. Other practical and commercially available products to help retain soil moisture are available, especially soil amendments containing cross-linked copolymers. These latter products, are chemical compounds as polyacrylamide have raised interest among farmers as soil water holders claiming that there is not side effect on the environment. The aim of this research was to assess the effect of hydrogel and biocompost in photosynthetic activity and production of forage maize plants.

Material and methods

The study was conducted in the experimental area of the Chapingo University Campus in Mapimí in the state of Durango, northern Mexico. The region is located among 26º 00' and 26º 10' north and 104º 10' and 103 º 20' west at an altitude of 1,119 meters above sea level. The climate of this area is very arid and semiarid with summer rainfall and extreme temperatures. The average annual rainfall is 250 mm.

Experimental design

A randomized block design was carried out with a split plot design, with three replications. The main plots were the application rates of hydrogel (0, 12.5 and 25 kg. ha^{-1}), and the subplots were the two application rates of compost (0 and 20 t. ha^{-1}). Each experimental unit consisted of four rows that were 0.75 m wide and 30 m long.

The compost was applied manually in the respective treatments before sowing the seed. A precision seeder containing three hoppers was used to simultaneously sow the seed and apply the hydrogel. One of the hoppers was used for the seed, other was used for the granulated hydrogel, and the third was used for the fertilizers. The distance between plants was 17 cm, resulting in a density of 78,204 plants ha^{-1}. Hybrid seed DK- 2040 was performed in this experiment. This variety is a dual-purpose (grain and forage production) cultivar. The compost was produced at the Universidad de Chapingo, Mexico with a composting process involving the red worm (*Eisenia fetida*).

Irrigation system

A surface flood irrigation method was used because a source from which to pump water was available. Irrigation was conducted three times: once prior to sowing and twice during the experimental period. At each irrigation, the water flow was set at 9 L s^{-1}, the irrigation timing was established in five hours, and the water depth, 17.05 cm.

Fertilization and crop management

Commercial fertilizers were applied. Nitrogen (46%) was applied at a rate of 200 kg. ha^{-1}, and ammonium phosphate was applied at a rate of 200 kg. ha^{-1}. The fertilizers were applied twice, at the time of planting and before the first harvest.

Variables measured

The moisture content was measured to a depth of 30 cm using a soil tester Model HB-2 Manufacturer Rittenhouse of St. Catharines, Ontario, Canada, which provide real-time readings. The following physical and biological variables were measured: photosynthesis (μmol CO^2 m^{-2} s^{-1}), transpiration (mmol H_2O m^{-2} s^{-1}), stomata conductance (mol H_2O m^{-2} s^{-1}), plant temperature (°C), chlorophyll index, fresh and dry plant matter (g) and fresh and dry forage yield (t ha^{-1}). The physiological variables were measured using an Infrared Ray Gas Analyzer (IRGA) Model LI-6400. The fresh and dry matters were determined following the destructive sampling of three randomly selected plants within each treatment.

Data processing

An analysis of variance and a Tukey test, were conducted to determine the effects of the hydrogel and compost application rates on the soil moisture and their subsequent impact on crop growth and development. The SAS Program version 9.0 was used for all analyses.

Results and discussion

Photosynthetic activity

The application of the hydrogel increased the moisture content of the soil by 20.8% compared to the control, facilitating increased photosynthetic activity and other physiological variables and therefore resulting in increased biological yields, such as fresh forage in the grain filling stage immediately before maturity. The photosynthetic activity was increased by 20.1 and 28.0% with the application of 12.5 and 25 kg ha^{-1} of hydrogel, respectively, although other variables such as transpiration, stomata conductance, temperature and chlorophyll content were not affected (Table 1).

Table 1. Effect of the hydrogel application rate on the physiological activity of forage maize (*Zea mays* L.)

Hydrogel application rate (kg ha^{-1})	Photosynthesis (μmol CO_2 $m^{-2} s^{-1}$)	Transpiration (mmol H_2O $m^{-2} s^{-1}$)	Stomata conductance (mol H_2O $m^{-2} s^{-1}$)	Plant temperature (°C)	CCI
0	24.30 b	20.74 a	0.856 a	33.01 a	4.97 a
12.5	29.19 ab	24.14 a	0.682 a	32.70 a	5.00 a
25	31.12 a	23.54 a	1.307 a	33.22 a	5.00 a

Values with different letters within the same column are significantly different based on the results of the Tukey test ($P < 0.05$). CCI = Chlorophyll Content Index.

The application of compost increased weakly the photosynthetic rate from 27.0 to 30.0 µmol. CO_2 m^{-2} s^{-1}; the transpiration rate was similarly increased, whereas there was no significant effect on the remaining physiological variables (Table II).

Table 2. Effect of the compost application rate on the physiological activity of forage maize

Compost application rate (t ha^{-1})	Photosynthesis (μmol CO_2 $m^{-2} s^{-1}$)	Transpiration (mmol H_2O $m^{-2} s^{-1}$)	Stomatal conductance (mol H_2O $m^{-2} s^{-1}$)	Plant temperature (°C)	CCI
0	27.40 b	21.78 b	0.955 a	32.98 a	5.00 a
20	30.00 a	24.04 a	0.944 a	32.98 a	4.98 a

Values with different letters within the same column are significantly different based on the results of the Tukey test ($P < 0.05$). CCI = Chlorophyll Content Index.

According to regression analysis, the behavior of the treatments was linear, allowing an increase in the rate of plant photosynthesis, to the increase in hydrogel at a rate of 27.7 units (µmol.$CO_2$$m^{-2}$$s^{-1}$) by increasing the dosage of hydrogel (kg ha^{-1}) (R^2 = 0.97) as depicted by the slope of the curves shown in (Figure 1).

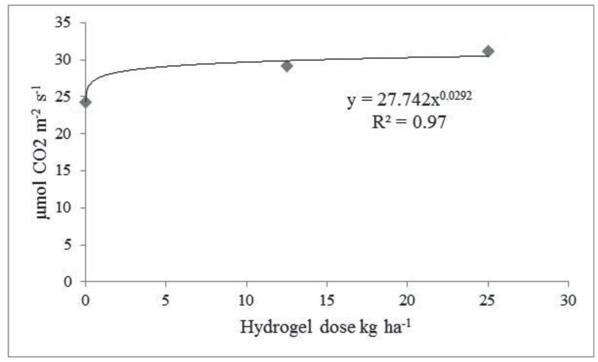

Figure 1. Effect of hydrogel doses on photosynthesis in corn crop

Production of fresh and dry forage

The production of fresh forage increased significantly ($P < 0.05$) from 51.9 to 77.6 and 81.6 t ha^{-1} when the hydrogel was applied at 12.5 and 25 kg ha^{-1}, respectively. Similarly, the production of dry matter increased from 19.5 to 26.5 and 27.8 t ha^{-1} when the hydrogel was applied at 12.5 and 25 kg ha^{-1}, respectively (Table III).

Table 3. Correlation among soil moisture and some productive and physiological variables in maize crop as forage

	CSM	FWP	DWP	FYH	DYH	PHOTO
CSM	1.000	0.842 0.0001	0.825 0.0001	0.842 0.0001	0.825 0.0001	0.552 0.021
FWP		1.000	0.984 0.0001	1.000 0.0001	0.984 0.0001	0.516 0.40
DWP			1.000	0.984 0.0001	1.000 0.0001	0.547 0.023
FYH				1.000	0.984 0.0001	0.546 0.40
DYH					1.000	0.547 0.023
PHOTO						1.000

Simple Pearson Correlation (P≤0.05).The letters means CSM=Content of soil moisture; FWP=Fresh Weight per Plant; DWP=Dry Weight per Plant; FYH=Fresh Yield per Hectare; DYH=Dry Yield per Hectare; PHOTO=Photosynthesis.

Fresh forage response had linear trend was observed, for each increase in dose hydrogel corresponded to an increase of production of fresh forage at a rate of 67.5 units (t ha^{-1}) aggregation in doses of moisture retainer (kg ha^{-1}) (R^2 = 0.99) (Figure 2). The dry forage yield was similar behavior linear for each increase in the dose of hydrogel attributed an increase in dry matter production at a rate of 23.9 units (t ha^{-1}) by addition of polymer dose (kg ha^{-1}) (R^2 = 0.99) (Figure 2).

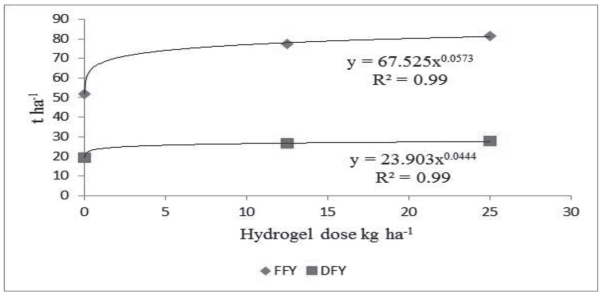

Figure 2. Effect of hydrogel doses on fresh forage yield (FFY), and dry forage yield (DFY) in corn crop

In different studies, the addition of small amounts of organic matter to the soil increases its capacity to retain water because of the positive correlation among the organic matter content, available water and yield (Julca-Otiniano, Meneses-Florián, Blas-Sevillano, & Bello-Amez, 2006); however, compost did not affect the fresh or dry matter or the forage yield in this research.

Regarding photosynthesis activity, demonstrate that although the photosynthesis is increased with a greater rate of carbon dioxide assimilation, the increased photosynthesis does not affect plant respiration, as neither the rate of conductance nor the plant temperature increased and the chlorophyll content remained stable. Thus, the increased rate of photosynthesis does not appear to have an effect on the other functional properties of the ground, suggesting that there is a higher photosynthetic efficiency at a higher rate of CO_2 capture under the unchanged conductance and transpiration conditions when the hydrogel is applied.

These results suggest that although the increased photosynthetic and transpiration rates were not indicative of a higher efficiency, they resulted in higher forage production because the moisture content was favorable and the plants were not water stressed (Figure 3).

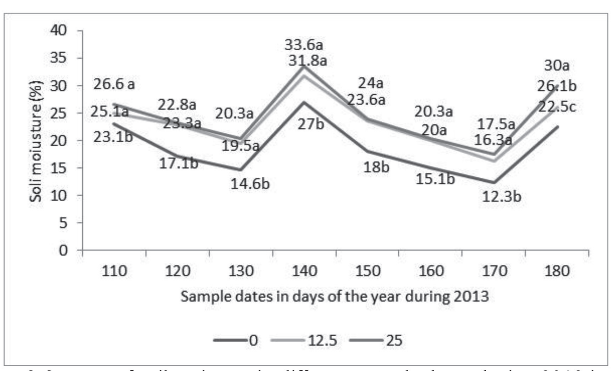

Figure 3. Content of soil moisture in different sample dates during 2013 in crop of maize as forage. Tukey Test (P≤0.05), the numbers with the same letters in side of the each sample date, there are not significantly differences.

These results agree with the data presented by Maldonado-Benítez, Aldrete, López-Upton, Vaquera-Huerta, & Cetina-Alcalá, (2011), who used chlorophyll concentration as an indicator of photosynthesis in forest plants treated with hydrogel substrates but did not detect a difference in the copolymer treatment application. Low photosynthetic rates in higher plants result in decreases in the relative water content (RWC) and leaf water potential (Lawlor and Cornic, 2002). This effect can be produced, since the polyacrylamide hydrogel are copolymers capable to absorb and contain large amounts of moisture and nutrients in the soil, and remain available for the plant, avoiding the water and nutritional stress, which promotes photosynthesis and vigor plant. In fact, hydrogel absorbs up to 150 times its own volume with a holding capacity of 980 mL of water L^{-1}, an availability of 95% of this resource, and a productive life of 5 years. In addition to the effect of water retention, the hydrogel improves aeration in the soil, thereby promotes better plant growth, with the consequent effect on the yield, as shown experimentally in crops such as soybeans (*Glycine max*) (Galeș, Răus, AilincăI, & Jităreanu, 2012), chard (*Beta vulgaris*) (Gutiérrez Castañeda, Sánchez Cohen, Cueto Wong, Trucios Caciano, Trejo Calzada, & Flores Hernandez, 2008), forest seedlings (Maldonado-Benitez *et al.,* 2011), forestry (Ríos-Saucedo, Rivera-González, Valenzuela-Nuñez, Trucios-Caciano, & Rosales-Serna, 2012) and celery (*Apium graveolens*) (Kosterna, Zaniewicz, Rosa, & Franczuk, 2012).

In relation to the compost weak effect on the photosynthetic activity, that may be in relation to the doses were not sufficient in time and doses. Cueto Wong, Reta Sánchez, Barrientos Ríos, González Cervantes, G., & Salazar Sosa, E. (2006) noted that compost doses greater than 40 t ha^{-1}, may affect yield components. Additionally, Tits, Elsen, Bries, & Vandendriessche (2014), reported that compost applications for 15 t ha^{-1} every three years up to 45 t ha^{-1} yearly, can replace a substantial part of mineral fertilization. Therefore, the literature results support the hypothesis that compost application modifies the plant-soil system and has consequences for the better use by plants of limited soil water (Aguilar-Benítez, Peña-Valdivia, García-Nava, Ramírez-Vallejo, Benedicto-Valdes, & Molina-Galan, 2012). In addition, the compost help stabilize soil structure and form aggregates, which creates a new distribution of porosity and thus contribute to improved moisture retention capacity and soil fertility (Pedroza & Duran, 2005).

Regarding the fresh and dry forage production, the results indicate that a higher soil moisture content throughout the crop cycle positively affects the growth and development of the plant (Table 4).

Table 4. Fresh and dry yields of forage maize (*Zea mays* L.) at different application rates of hydrogel, which was used to retain soil moisture

Hydrogel application rate (kg ha^{-1})	Fresh weight per plant (g)	Dry weight per plant (g)	Yield of fresh forage (t ha^{-1})	Dry forage yield (t ha^{-1})
0	717.5 b	249.2 b	51.9 b	19.5 b
12.5	993.0 ab	339.0 ab	77.6 ab	26.5 ab
25	1,044.0 a	355.5 a	81.6 a	27.8 a

Values with different letters within the same column are significant different based on the results of the Tukey test ($P < 0.05$).

Therefore, in addition to an increase in productivity, the plants were only irrigated twice (no considering the irrigation before plant) during the experimental period instead of three times, which is common in this region. This decreased irrigation indicates that optimal yields can be achieved in this region under scarce water supply. This finding is very important in areas such as the study region, where there is a severe water scarcity but forage production is necessary to sustain the dairy industry as the main economic activity. In addition, Simpson & Hayes (2006), revealed that a soil conditioner increased the crop yields and the percentage of water-stable aggregates in all of the soil types tested. The results obtained in the current study were similar to those reported by Galeş *et al.,* (2012), who reported that the application of a hydrophilic polymer at a rate of 30 kg ha^{-1} resulted in a higher soybean yield. According to Hayat & Ali (2004), the application of a copolymer contributed to a significant increase in the production of fruit and the vegetative growth of the plant. These authors noted that the addition of polymers to the soil has beneficial effects on the dry weight and quality of the fruit. Additionally, Majkowska-Gadomska (2006), reported that the average of the total marketable lettuce yields was 1.87 kg m^{-2} higher as a result of the application of the copolymer.

In relation of the compost not effect on the fresh and dry forage production, these results might be attributable to the application rate used (20 t ha^{-1}), which is insufficient to impact crop yield, as it was indicated before lines (Cueto, *et al.,* 2006; Tits *et al.,* 2014). In addition, the application of compost increases the soil organic matter content and improves some of its physical characteristics, such as the amount of hydrostable aggregates, bulk density, and porosity, which promote the flow of air and water and plant root development. However, the effects of compost depend on its biochemical nature and the soil properties, climate, and agricultural practices, such as the level of humification and the quantity and frequency of application (Abiven, Menasseri, & Chenu, 2009; Azarmi, Giglou, & Taleshmikail, 2008; Tejada, García, & Parrado, 2009; Román & Sotomayor, 2004).

Conclusion

The photosynthetic activity was increased by 20.2-28.0% when hydrogel was applied at rates of 12.5 and 25 kg. ha^{-1}, respectively, in comparison to the control. The increase in photosynthesis resulted in an increased production of fresh forage from 19.5 t ha^{-1} in the control to 77.6 and 81.6 t ha^{-1} with the application of hydrogel at 12.5 and 25 t ha^{-1}, respectively; similar results were observed for the dry matter.

A higher photosynthetic rate was measured under a high moisture content which resulted from the hydrogel application with a higher production of fresh forage and dry corn. The compost rate performed a weak affectation to the photosynthetic activity, and no performed any effect on the production of the fresh and dry forage.

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