Journal of Agriculture and Environmental Sciences
December 2014, Vol. 3, No. 4, pp. 93-106
ISSN: 2334-2404 (Print), 2334-2412 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jaes.v3n4a7
URL: http://dx.doi.org/10.15640/jaes.v3n4a7

Assessment of the Impact of Compost and Hydrogel as Soil Moisture Retainers on the Growth and Development of Forage Maize (Zea mays L.)

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Abstract

The availability of water is one of the most critical factors for food production in arid lands. The aim of this study was to determine the efficiency of compost and hydrogel in holding soil moisture and to monitor their effects on the growth and development of forage maize. This study was conducted in the experimental area of Chapingo University North Campus at Bermejillo, Durango, Mexico. The experiment was arranged in split plots within randomized blocks with three replications. The doses of hydrogel (0, 12.5 and 25 kg ha^{-1}) were the main plots, and the compost doses (0 and 20 ton ha^{-1}) were the subplots. Hydrogel doses of 12.5 and 25 kg ha^{-1} significantly increased ($P \leq 0.05$) plant height and stem thickness and flag leaf length and width, mainly 74 days after planting. These responses followsa higher moisture content, measured at three depths (15, 30 and 60 cm), in the hydrogel-treated soil than in the untreated control. Additionally, the root volume was significantly larger when the hydrogel was applied at any of the doses tested in this study. The growth and development of the plants were not affected by the compost application.

Keywords: Arid lands, Crop, Soil, Water, Organic matter

1. Introduction

The average annual rainfall in the northern Mexico, specifically in the states of Durango and Coahuila, is 250 mm.

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The rainy season starts in July and ends inSeptember. Low average rainfall and high temperatures with high evaporative demand are the main problems that the agriculture faces on this region of the country.Furthermore, the high temporal and spatial variation of rainfall makes this region very risky for the agricultural sector. These fluctuations have a decisive influence on water availability in the area (Castro, 1997). To cope with a water deficit, local strategies for using water should be generated (Molina, 1991).Some conservation practices as the use of organic amendments have had an increased interest among farmers in the region. This type of organic matter, which provide nutrients and improve the soil physical properties,havealso been used to conserve soil moisture (Navarro, 2009).

In addition, chemical compounds as polyacrylamide have raised interest among farmers as soil water holders claiming that there is not side effect on the environment. The efficiency of these chemicals relies in that they increase the capacity of the soil to retain moisture, improving the aeration and maintaining temperature parameters that foster better plant development and thereby increase the yield, in different crops like soybean (Gales *et al* 2012); forest seedlings (Maldonado*et al*., 2011); forest plants (Ríos *et al*., 2012); celery (Kosterna*et al.,* 2012). However, there are not enough studies of the effect on other crops of economic importance, mainly in arid regions where the water is the most important restrictive natural factor. The aim of this study was to determine the effects of hydrogel and compost on soil moisture retention capacity in maize and on morphometric traits that are associated with maize growth and development.

2. Materials and Methods

The study was conducted in the experimental area of the Chapingo University North Campus located in Mapimí, Durango State, Mexico. This region is situated between the parallels of 26º00' and 26º10' north latitude and the meridians of 104º10' and 103º20' west longitude over an elevation range of 1,119 m above sea level. According to the Köppen climate classification system, as modified by García (1981), the climate of the area is BWhw type (e), which is extremely arid and warm, with summer rainfall and temperature extremes. The average annual rainfall is 250 mm (1981-2006), and July and August are the wettest months, with rainfalls of 36.1 and 39.7 mm, respectively.

2.1 Experimental design. A randomized block design was used in a split-plot arrangement with three replications. The main plots were the doses of hydrogel (0, 12.5 and 25 kg ha^{-1}); the subplots were one dose of compost and the control (0 and 20 ton ha^{-1}). Compost dose,agree with the average commercial recommendation. The experimental unit consisted of 4 rows, having 0.75 m wide and 30 m long.

2.2 Experimental execution. The compost was applied manually before sowing for the respective treatments. A three-hopper precision seeder was used for simultaneous sowing and hydrogel application: one hopper was used for the seed, a second for the granulated hydrogel and a third for fertilizers. The distance between plants was 17 cm, with a density of 78,204 plants ha^{-1}. The cultivar seed DK-2040 was the genetic material used in the experiment. This cultivar is used for the dual purposes of grain and forage production. The compost was obtained by a composting process based on red worms (*Eisenia fetida*) and was produced at the Chapingo University North Campus (Pedroza *et al*., 2010).

2.3 Irrigation system. Surface flood irrigation from a pumped water source was used. Three irrigations were applied: the first12 days before planting, the second and third 30 and 60 days after planting. The water flow was 9 L s^{-1}, the irrigation time was 5 hours, and the water depth appliedfor irrigation was 17.05 cm.

2.4 Fertilization and crop management. Commercial fertilizers were applied nitrogen (46%) at 200 kg ha^{-1} and ammonium phosphate at 200 kg ha^{-1}. These fertilizers were applied twice: at the time of planting and 30 days after planting.

2.5 Variables measured. Soil moisture variation was measured at depths of 15, 30 and 45 cm on three sampling dates: 10, 20 and 30 days after the second supplementary irrigation (DASSI), which was performed 84 days after seeding. A moisture meter model HB-2 Manufacturer Rittenhouse of St.Catharines, Ontario, Canada was used, providing real-time readings. The recorded variables were plant height, stem thickness, and flag leaf width and length, which were all measured in centimeters during the following crop phenological stages: 4-5 leaves, 12-14 leaves and flowering and maturity, corresponding to 30, 52, 74 and 96 days after planting (DAP).Additionally, two samplings at 60 and 100 DAP were performed to determine the root volume in cubic centimeters.

2.6 Data processing. Typical analyses of variance and Tukey tests were performed to determine the effect of the studied factors on soil moisture retention and on the growth and development of the crop. Additionally, regression techniques were applied to characterize the behaviour of the plant responses.SAS version 9.0 software was used.

3. Results

Statistical analysis was done by treatments as result of all interactions with hydrogel and compost doses, but not effects were found in any variables measured in this survey. In additional analysis but for separated factors (hydrogel and compost) was identified that only the hydrogel affected significantly (P <0.05) the crop developmentindependently of the use of compost, this latter without any effect on plant growth.

Plantheightwas significantly greater (P <0.05) foreitherdoseof hydrogelapplied(12.5or25kg ha^{-1}); this effect was more noticeable at the beginningand the end ofthe recording period (30 and96DAP). During the dates ofintermediateevaluation, thedose of 25kg ha^{-1}showedan intermediateeffectbetween dose of12.5kg ha^{-1}and the control, the latter with significantlyless effect onall evaluation dates (Table 1).

The regression analysis for each of the two hydrogel doses and the control indicates that plant height was increased linearly over time after planting, between 30 and 96 DAP. Higher ratesof increasing height were obtained at doses of 12.5 and 25 than at 0 kg ha^{-1} during the sampling period (Figure 1).

Table 1: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Plant Height in Forage Corn (ZeaMays L.)

	PLANT HEIGHT (CM)			
Hydrogel dose (kg ha^{-1})	**30 DAP**	**52 DAP**	**74 DAP**	**96 DAP**
0	16.2 b	38.0 b	155.2 b	192.1 b
12.5	21.3 a	51.5 a	193.2 a	221.6 a
25	21.5 a	43.7 ab	175.9 ab	214.3 a

Values within columns followed by different letters differ significantly by Tukey's test (P < 0.05). DAP is days after planting.

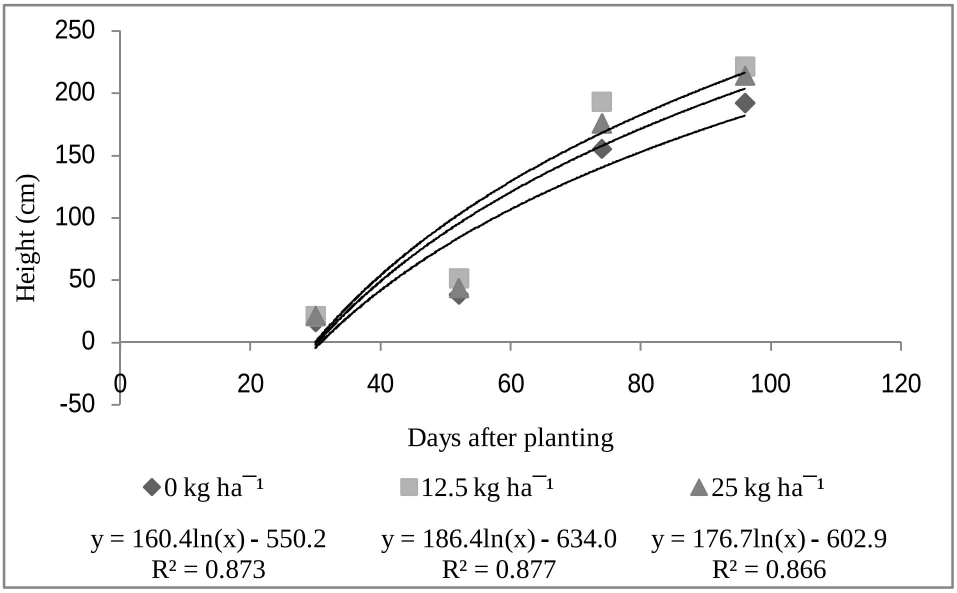

Figure 1: Regression Analysis of the Plant Height in Forage Cornusing Three Hydrogel Doses Applied to Retain Soil Moisture

The stem thickness was not affected by the hydrogel dose at the first two evaluations (30 and 52 DAP), but showed significant effects in the subsequent assessments (74 and 96 DAP), without statistic difference between hydrogel dose (12.5 and 25 kg ha^{-1}), which means that the effect is more delayed for this variable(Table 2), in comparison with the plant height.

The regression analyses, shows that the stem thickness at each hydrogel dosesand the control increased linearly over time after planting between 30 and 96 days; importantly, the stems were thicker at the two higher doses than in the control without hydrogel (Figure 2).

Table 2: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Stem Thickness in Forage Corn.

	STEM THICKNESS (CM)			
Hydrogel dose (kg ha^{-1})	**30 DAP**	**52 DAP**	**74 DAP**	**96 DAP**
0	0.94 a	1.43 a	2.08 b	2.30 b
12.5	0.84 a	1.76 a	2.29 a	2.51 a
25	1.00 a	1.76 a	2.34 a	2.57 a

Values within columns followed by different letters differ significantly by Tukey's test ($P < 0.05$). DAP is days after planting.

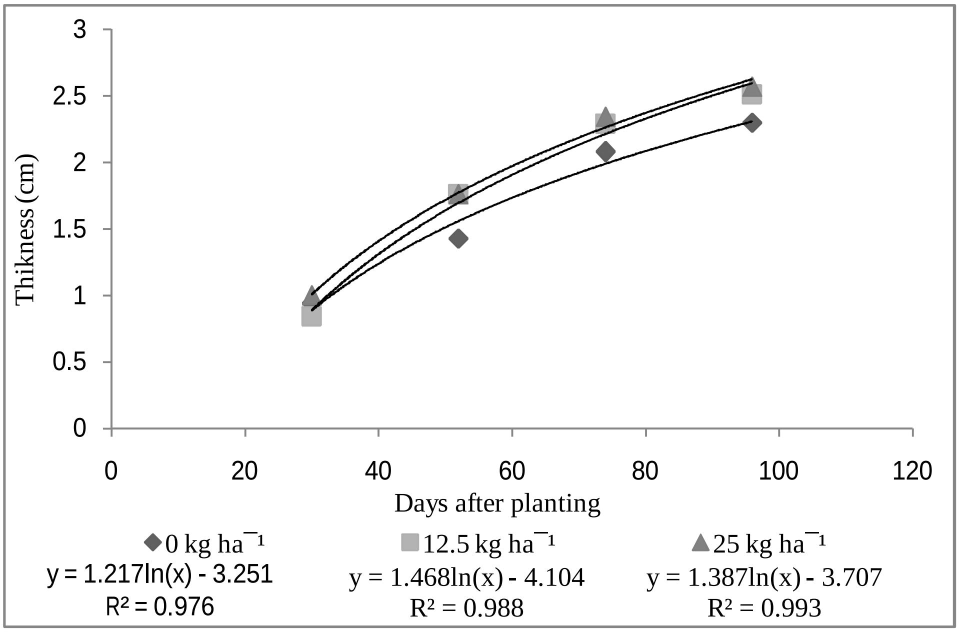

Fig. 2: Regression Analysis of the Stem Thickness in Forage Cornusing Three Hydrogel Doses Applied to Retain Soil Moisture

Similarly of the stem thickness, the length of the flag leaf was the variable that showed a statistic response to hydrogel, mainly from 74 to 96 DAP; since the first two evaluation dates (30 and 52 DAP) did not have statistic difference with the control (Table 3).

The rate of crop growth is explained by the slopes of the regression lines, as shown in Figure 3, which indicates that the daily increase in length was 0.99 cm for the two nonzero hydrogel doses.

Table 3: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Flag Leaf Length in Forage Corn

	FLAG LEAF LENGTH (CM)			
Hydrogel dose (kg ha^{-1})	**30 DAP**	**52 DAP**	**74 DAP**	**96 DAP**
0	10.8 b	17.8 a	53.0 b	62.0 b
12.5	13.4 a	21.4 a	63.7 a	72.1 a
25	12.2 ab	19.9 a	61.7 a	71.1 a

Values within columns followed by different letters differ significantly by Tukey's test ($P < 0.05$). DAP is days after planting.

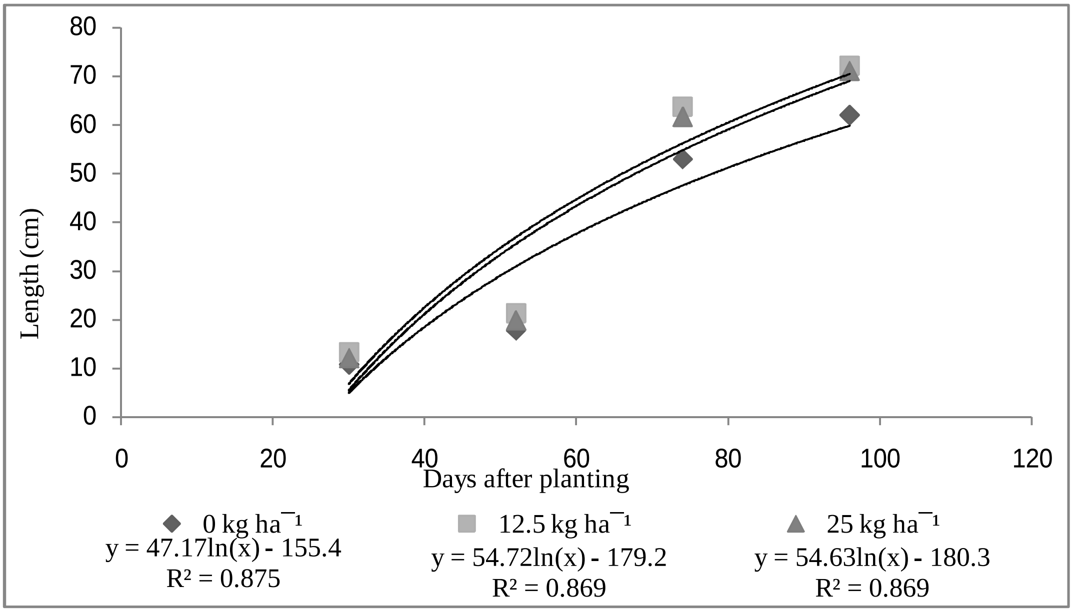

Figure 3: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Flag Leaf Length in Forage Corn

Regarding the flag leaf width the same trend wassignificantly greater in the last two dates of evaluation (74 and 96 DAP) when the hydrogel was applied which showed no statistic difference with the control (Table 4). Also, the effect for hydrogel as retainer of soil moisture is delayed for this variable.

Table 4: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Flag Leaf Width in Forage Corn

	FLAG LEAF WIDTH (CM)			
Hydrogel dose (kg ha^{-1})	**30 DAP**	**52 DAP**	**74 DAP**	**96 DAP**
0	1.8 b	3.9 a	8.0 b	9.1 b
12.5	2.4 a	4.9 a	9.0 a	10.0 a
25	2.2 ab	4.6 a	9.0 a	10.1 a

Values within columns followed by different letters differ significantly by Tukey's test ($P < 0.05$). DAP is days after planting.

The effect of hydrogel on the root volume was highly significant (P <0.01), compared with the control, mainly during the first 60 DAP, because at 100 DAP only the highest dose of hydrogel (25 ton ha^{-1}) was capable to maintain this effect; whereas the low hydrogel dose (12.5 kg ha^{-1}) was similar to control (Tables 5). That means that the root volume is affected at the beginning and this effect is maintained only in the high hydrogel dose.

Table 5: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Root Volume in Forage Corn

	ROOT VOLUME (CM^3)	
Hydrogel dose (kg ha^{-1})	**60 DAP**	**100 DAP**
0	37.3 b	537.1 b
12.5	96.0 a	859.8 ab
25	92.8 a	989.3 a

Values within columns followed by different letters differ significantly by Tukey's test (P < 0.05). DAP is days after planting.

The soil moisture response to hydrogel was quite similar to the plant growth and development, meaning that when the hydrogel was applied, the moisture content was significantly higher (P<0.01) at each evaluated depth compared to the control without hydrogel. This effect was more evident at the 25 kg ha^{-1}dose at either soil depth. Atdoses of 12.5 kg ha^{-1} the effect was moderated over time, this effect was only significant higher in soil moisture content at 15 cm of soil depth during the first and thirdevaluation date (10 and 30 DASSI, respectively); but did not have affect in the second evaluation (20 DASSI) for any soil depth (Table 6).

Table 6: Effect of Three Hydrogel Doses Applied to Retain Soil Moisture on the Soil Moisture Content at Three Depths

	10 DASSI DEPTH (CM)			20 DASSI DEPTH (CM)			30 DASSI DEPTH (CM)		
Hydrogel dose (kg ha^{-1})	**15**	**30**	**60**	**15**	**30**	**60**	**15**	**30**	**60**
0	18.5 b	22.8 c	26.8 c	16.0 c	20.5 c	24.5 c	14.0 b	18.5 c	22.1 c
12.5	22.5 a	28.0 b	32.1 b	20.1 b	25.5 b	29.6 b	18.1 a	23.5 b	27.5 b
25	24.6 a	31.5 a	35.5 a	22.3 a	28.6 a	32.5 a	20.0 a	26.6 a	30.3 a

Values within columns followed by different letters differ significantly by Tukey's test (P < 0.05). DASSI is days after second supplementary irrigation.

According to the logistic regression using the following equation:

$$\frac{\partial}{\partial x} f(a, b, x) = \frac{\partial}{dx}[a. \text{In}(x) - b] = a. \frac{\partial}{\partial x}(\text{In}(x)) = \frac{a}{x}$$

Where, the first function derivate, indicate the change of rate among successive samplings, it was possible to obtain the rate for each curve and sample date. According results shown in figures 4 and 5 the soil water content at both 15 and 30 cm of soil depth, where most of the crop roots grows, is higher when hydrogel is applied in relation to the control. The rate of soil moisture depletion are very similar in the treatments without the hydrogel; moreover, at 15 cm of depth the permanent wilting point is reached faster, in relation to the 30 cm of soil depth, among other reasons, because upper soil layer is exposed to higher temperatures and wind that triggers more soil evaporation.

Soil water depletion fits a logistic model. The slope of the soil moisture depletion curve depicts the rate of change of soil moisture between two consecutive samplings. According the results of table 7, the rate of change plant height, leaf longitude and leaf width were higher when the hydrogel was applied in either doses compared with the control. The highest rates were at 52 days after planting. The stem thickness was not affected for hydrogel application.

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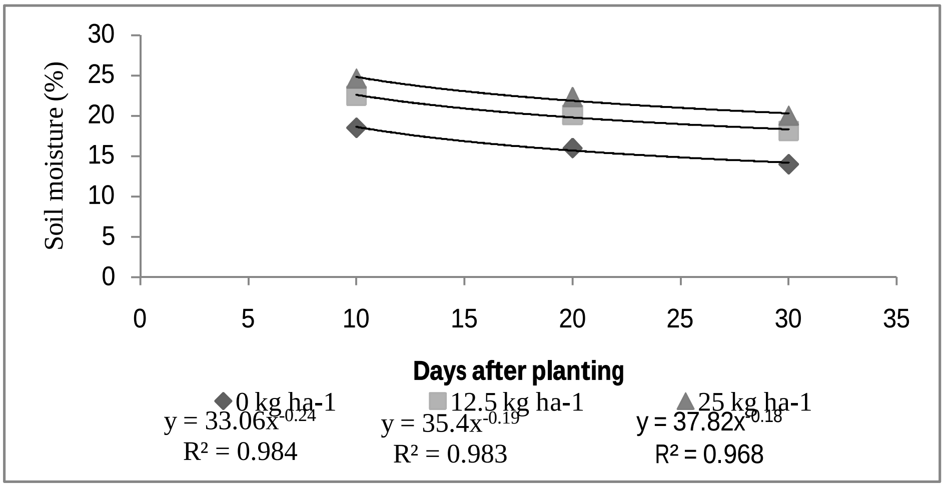

Figure 4: Effect of Three Hydrogel Doses in Soil Moisture Decrease at 15cm of Depth

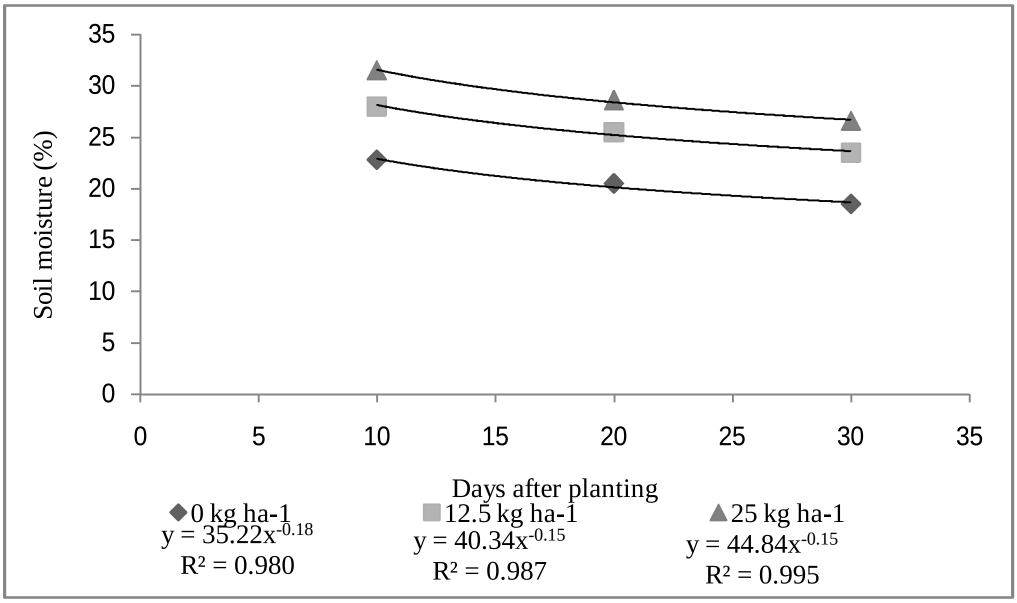

Figure 5: Effect of Three Hydrogel Doses in Soil Moisture Decrease at 30 of Depth

Table 7: Growing Rates Variation in Some Morphometric Variables Using Different Doses Ofnhydrogel in Maize for Forage

Variable	Hydrogel doses (kg ha^{-1})																	
	0.0						12.5						25.0					
	Parameters		$\frac{\partial}{\partial x}f(x)-\frac{a}{x}$				Parameters		$\frac{\partial}{\partial x}f(x)-\frac{a}{x}$				Parameters		$\frac{\partial}{\partial x}f(x)-\frac{c}{x}$			
	a	b	30	52	71	96	a	B	30	52	71	96	a	b	30	52	71	96
Plant highht	160.43	550.22	5.3	3.0	2.1	1.67	186.11	634.05	6.21	3.58	2.5	1.91	176.75	602.91	5.8	3.4	2.4	1.8
Stem thickness	121.78	3.251	4.0	2.3	1.6	1.2	1.16	4.10	0.04	0.02	0.01	0.01	1.38	3.70	0.04	0.02	0.01	0.01
Leaf longitude	47.17	-155.42	1.6	0.9	0.6	0.5	54.72	-179.26	1.82	1.05	0.73	0.57	54.63	-180.33	1.82	1.05	0.73	0.56
Leaf Widht	6.63	-21.21	0.2	0.1	0.08	0.06	6.91	-21.46	0.23	0.13	0.09	0.07	7.19	-22.69	0.23	0.14	0.09	0.07

4. Discussion

Regarding plant height the results of this studycoincide with those reported by Gutiérrez *et al*. (2008), who measured the response of horticultural crops to the use of a polymer. In addition, Barón*et al*. (2007) reported an increase in plant height in horticultural species when using hydrogel, achieving remarkable growth. Similarly, Galeş *et al*. (2012) conducted a study on the morphophysiological effects of hydrogel on corn and soybeans and showed that the average plant height was positively influenced by a dose of 15 kg ha^{-1}.

In relation stem thickness when hydrogel was applied, the results are similar to those obtained in an assessment of forest seedlings by Maldonado*et al.* (2011), who reported higher average diameters (3 mm) using a hydrogel dose of 4 g L^{-1} in their substrate. These results of the present study are also similar to those obtained by Ríos*et al.*(2012), who demonstrated that 20 g of hydrogel per plant had the potential to increase the stem thickness of xerophytic forest plants.

The longer flag leaf when the hydrogel was applied is similar to reported by Kosterna*et al*. (2012), who evaluated the effect of a polymer on celery growth; the greatest increase in leaf growth rate was achieved at the highest polymer application rate, which was 54 g per plant. Similarly, Nnadi and Brave (2011) reported that without added polymer, the leaves of radish plants exhibited signs of dehydration during water stress and reduced growth, while the foliage of the plants growing in the soil with added polymer was healthier.

In addition, regarding root volume when the copolymer was applied, the results of this study are consistent with those reported by Taban and Movahedi (2006) where an evaluation of hydrogel and organic compost for soil moisture retention in maize grown with copolymer exhibited greater root weights and amounts of other root components. These authors attributed their results to an increase in the soil temperature and water content due to hydrogel application. In contrast,this study did not find not beneficial effects of compost application on the root volume. Dufault and Hair (1991) found that the use of the copolymer at a dose of 3.5 g L^{-1} of water to grow chili pepper seedlings, produced higher fresh and dry root weights in the treated plants.

Finally, the permanent wilting point (PWP)is reached more easily when no hydrogel is applied. Therefore, the use of hydrogel as a retainer soil water and delayer of the PWP, may explain the better growth and development of the crop. This result is consistent with the findings of a study by Akhter*et al.* (2004) in which the addition of hydrogel to the soil improved the availability of soil moisture and promoted the growth and development of plants.

The application of polymers can improve the vegetative growth of plants by retaining more moisture within the soil according to Choudhary*et al.* (1995) and Al-Harbi*et al*. (1999). Moreover, Roman and Sotomayor (2004) found that better soil-water relationships are achieved by applying a soil conditioner, in contrast to the negative results obtained in the present study for compost used alone or together with hydrogel. Perhaps, these differences occurred because the conditioners must remain in the soil a certain duration before producing an advantage; in this case of study, availability time and compost doses used could be related; moreover, if is known that organic-based nutrient management may therefore play a key role in organic systems in maintaining soil moisture and determining crop yield (Smith *et al*., 2007).

The not effect founded on the soil moisture content due the compost application, can perhaps be explained by the use of a dose (20 ton ha^{-1}) that was too low to impact crop variables. This explanation is consistent with information provided by Barrientos*et al*. (2006), who noted that compost doses greater than 40 ton ha^{-1} may affect yield components. Additionally, Tits *et al.* (2014) reported that compost applications (15 ton ha^{-1}every three years up to 45 ton 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 *et al*. 2012). Nevertheless, compost did not change other physical and chemical properties of the soil, such as PWP, usable water and field capacity.

5. Conclusions

Hydrogel at either of the applied doses (12.5 and 25 kg ha^{-1}) increased the height, stem thickness, and flag leaf length and width of maize, mainly from 74 to 96 days after planting.

The soil moisture content was greater at the three soil depths measured (15, 30 and 60 cm) in the hydrogel treatments than in the control treatment with no hydrogel, with effect more evident applying 25 kg ha^{-1}, which is more constant for maintaining the soil moisture over time.

The root volume was also significantly larger when hydrogel was applied at any of the tested doses in relation to control, mainly during the first 60 DAP, since 100 DAP the lower hydrogel dose (12.5 kg ha^{-1}) trended to decrease the effect.

The growth and development of the plants were not affected by the compost application.

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