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Article

Application of superabsorbent polymers in chayote under rainfed conditions

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Abstract

Superabsorbent polymers (SAPs) provide an innovative alternative for soil moisture retention, improving water use efficiency and crop productivity. The study aimed to evaluate the application of SAPs in chayote cultivation under rainfed conditions, using four doses (0, 100, 150, 200 g plant-1). The research was carried out on an agricultural plot in Chocamán, Veracruz, from October 2023 to April 2024. The experimental design employed a generalized randomized block design with two blocks, four treatments, and two replications per block. The variables evaluated were soil moisture content, growth, leaf area, and yield. The SAP treatments maintained higher moisture levels, with a maximum increase of 7.8%, particularly during periods of higher rainfall. The treatment with the highest dose (T4 200 g plant-1) presented the highest vertical growth and yield (97.3 kg plant-1). No significant differences in leaf area were found between some treatments. The application of SAPs improved soil moisture retention, favoring growth and yield. Their use is a viable strategy to improve water availability and chayote yield under rainfed conditions; nevertheless, the optimal dose could vary depending on soil properties and rainfall distribution.

Keywords:

hydrogel, moisture retention, *Sechium edule.*

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Introduction

Agriculture is currently facing significant challenges due to climate change, resulting in limited availability of water resources (Murray-Tortarolo *et al*., 2024). In their findings, Flores and Ruiz (1998) mention that, in regions where rainfed conditions prevail, soil moisture retention is crucial for plant growth and development. According to the 2022 Agricultural Census, Mexico has 25.7 million hectares of agricultural land, of which 26% is irrigated and 74% is rainfed (INEGI, 2023). In the case of chayote, of the 2 871.2 ha planted in 2023, only 25% was cultivated under irrigation and 75% under rainfed conditions (SIAP, 2024).

Superabsorbent polymers (SAPs), also known as hydrogels, represent an innovative and efficient alternative to enhance moisture availability for the plant (Neethu *et al*., 2018). Hydrogel is a hydrophilic, soft, and elastic polymer with the ability to expand with water, increasing its weight, without losing its structure; when dehydrated, it appears in the form of crystals (Ahmed, 2015). When polyacrylamide hydrogel is hydrated and added to the soil, mainly in the rhizosphere, it releases water gradually, increasing the availability of water and nutrients for plants, also acting as a soil conditioner (Bernardi *et al*., 2012).

In soils treated with polymers, the survival of woody and herbaceous plants was prolonged under conditions of water scarcity. Khodadadi-Dehkordi (2017) reported that superabsorbent polymers retained more water in the soil during water-deficit conditions and promoted salinity and drought tolerance in rooted cuttings of *Eucalyptus saligna*. The application of superabsorbent polymers to cowpea plants under drought stress conditions preserved adequate soil water capacity. Khodadadi-Dehkordi *et al*. (2023) reported that, in situations of deficit irrigation, the two corrective materials - fulvic acid and hydrophilic polymer- significantly improved corn yield.

Most research has been conducted in controlled environments and with various substrate mixtures. It is necessary to evaluate this type of technology in the open field to understand the dynamics of its behavior in the soil and determine its effects on the morphological development and yield of the chayote (*Sechium edule*) crop, which is of economic and nutritional relevance and faces challenges due to the scarcity of water in the rainfed regime. This study evaluated the application of SAPs in chayote under rainfed conditions and their effect on soil moisture retention, growth, leaf area (LA), leaf area index (LAI), and crop yield.

Materials and methods

Study area

The research was conducted on an agricultural plot located in the municipality of Chocamán, Veracruz, with coordinates 19° 00’ 51” north and 97° 02’ 19” west of Greenwich and an altitude of 1 440 m. The climate is (A)C(m)(f), semi-warm humid, with an average annual temperature of more than 18 °C and an average annual rainfall of 1 902 mm. The rainy season takes place in summer, with a winter percentage greater than 10.2% of the annual total.

Soil characteristics

According to the analysis carried out by the Soil Physics Laboratory of the College of Postgraduates, the textural classification of the soil is sandy clay crumbs (clay 24%; silt 27%; sand 49%); among its physical properties are field capacity (FC) of 42%, permanent wilting point (PWP) of 26%, bulk density (Bd) of 1.11 g cm^3 and basic infiltration rate of 1.9 cm h^{-1} (double ring infiltrometer).

Experimental design

There is a gradient of variation in the slope of the land; for this reason, two blocks were defined: one with a slope of 18% and the second with 14%. A generalized randomized block experimental design (GRBED) was used, consisting of two blocks, two replications per block and four treatments, for a total of 16 experimental units. The treatments consisted of four doses of non-hydrated polymer for each plant: T1, 0 g; T2, 100 g; T3, 150 g and T4, 200 g.

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The experimental unit consisted of a 9 x 7 m plot, with a 0.9 x 0.9 x 0.4 m planting hole to transplant the chayote. Doses were defined based on the manufacturer's recommendations and previous studies that report positive effects with applications between 12.5 and 30 kg ha^{-1} in crops such as onions, Anaheim chili and corn (López-Elías *et al*., 2013; Yáñez-Chávez *et al*., 2014; El Bergui *et al*., 2023). Considering the chayote planting framework, the doses applied in this study were as follows: T1= 0 kg ha^{-1}; T2= 15 kg ha^{-1}; T3= 23 kg ha^{-1}; T4= 32 kg ha^{-1}.

Application of treatments

The SAPs used were potassium polyacrylate, based on 94.13% polyacrylamide (PAM) and 5.87% moisture, in solid granular form, white in color and with a granulometry range of 0.3-2 mm. The treatments were applied manually to the planting hole on the same day of transplantation. The SAPs were applied dry, without prior hydration, and mixed homogeneously with the soil used to fill the previously excavated planting hole. The chayote crop was transplanted in the second week of October 2023. Two germinated seeds were established per planting hole, with a 9 x 7 m planting frame and a trellis of 2 m in height.

Crop management

The crop was managed traditionally, according to the region, and fertilized with 18-46-00 nitrogen, phosphorus, and potassium in the vegetative development stage. For the flowering and fruiting stages, the crop was reinforced with foliar applications based on cytokines and essential microelements.

Measuring response variables

The moisture content was measured using the gravimetric method, with a Veihmeyer auger to extract the samples. Samples were collected at depths of 0-20 cm, 20-40 cm, and 40-60 cm, on various dates, from October 18, 2023, to April 5, 2025. The rainfall was recorded with a rain gauge graduated in millimeters. Daily climatic information from Station 30342 Huatusco was used to estimate chayote evapotranspiration using the FAO Penman-Monteith equation.

Vertical growth was measured from 15 days after transplantation (DAT) using a 5 m tape measure until the height of the trellis was reached. The measurement was made from the soil surface to the tallest and youngest branch of the main vine. The FA was determined by a function obtained from linear measurements of the leaf (Sauceda-Acosta, 2017). Leaves of different sizes were sampled in an adjoining plot and then digitized using a high-resolution desktop scanner; the images obtained were processed with ImageJ software, where the length (L) and width (W) were measured and the leaf area was calculated. The data obtained were used to fit a power regression to obtain the function.

Yield was evaluated during 12 cuts, from March 7 to April 18, 2024, using a digital scale with an accuracy of 1 g. The harvest was carried out manually in all experimental units; the fruits were collected in their state of commercial maturity and kept in the shade after harvest to prevent overheating and damage their quality.

Statistical analysis

The effects of the studied factor on moisture retention and crop growth and development were determined using an analysis of variance (Anova) performed with the R software, version 4.4.1 (R Core Team, 2024) and a comparison of means, applying Tukey's test with a 95% confidence level.

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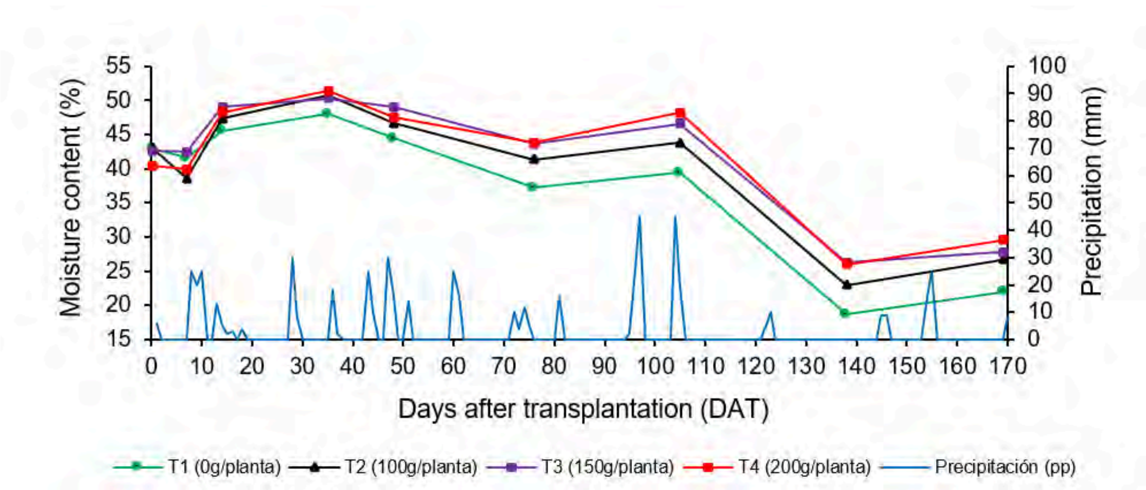
Results and discussion

Soil moisture content

To analyze the soil moisture dynamics, nine samplings (0, 7, 14, 35, 48, 76, 105, 138 and 169 DAT) were carried out for the depth of 20-40 cm. Polymer treatments (T2, T3 and T4) maintained the highest moisture levels, particularly during periods of higher precipitation, suggesting a positive correlation between polymer use and moisture retention under high precipitation conditions (Figure 1).

Figure 1. Behavior of moisture content in the study period (20-40 cm).



Differences in soil moisture content between different dates, calculated as the difference between the current measurement and the previous one, were compared. Treatments with SAPs had a statistically significant effect (*p* # 0.05) on the variable of difference in moisture content (increase or decrease) in four of the nine periods analyzed for the depth of 20-40 cm (Table 1). At depths of 0-20 cm and 40-60 cm, no significant differences were found.

Table 1. Analysis of variance for the variable of variation in soil moisture content (20-40 cm).

SV	DF	Days after transplantation (DAT)			
		0-14	48-76	76-105	138-169
Treatment	3	0.0241*	0.0042**	0.0254*	0.0416*
Block	1	0.0005***	NS	0.0251*	NS
Treatment*block	3	NS	NS	0.0435*	NS

NS= not significant; *, **, ***= significant at the 0.05, 0.01 and 0.001 levels of probability, respectively.

The T4 presented the greatest variation, going from 40.5% to 48.3%, an 8.37% increase in 14 days. It was followed by T3 (6.4%), T2 (4.2%) and T1 (2.5%). These results indicate that a higher concentration of SAPs improves the soil's ability to retain water. During this period, 94 mm of precipitation was recorded, which explains the increase in moisture depending on the dose applied (Table 2).

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Table 2. Behavior of moisture content in the range of 7 to 14 DAT (18/10-01/11) and 48 to 76 DAT (05/12-02/01).

Treatment	DAT		Difference (%)	DAT		Difference (%)
	0	14		48	76	
T1 (0 g plant)	43	45.5	2.5b†	44.5	37.3	-7.2b‡
T2 (100 g plant)	43.2	47.3	4.2ab	46.6	41.3	-5.4ab
T3 (150 g plant)	42.6	49	6.4ab	49.1	43.6	-5.5ab
T4 (200 g plant)	40.5	48.3	7.8a	47.5	43.8	-3.6a

† and ‡ in columns, similar letters indicate that the values are statistically equal (Tukey, $p \leq 0.05$).

For day 76 DAT, compared to day 48 DAT, a significant decrease in moisture content was observed (Table 2). T1 presented the biggest reduction (-7.2%), while the lowest variation was in T4 (-3.6%). This indicates that a higher concentration of SAPs contributed to moisture retention, gradually releasing them as needed by the crop. The reduction in moisture is due to low rainfall and the increased water demand of the crop. During the period from day 48 to 76 DAT, the accumulated precipitation was only 86 mm, representing a minimal contribution of water over 28 days. The rapid growth of the crop and the expansion of its vines on the trellis increased evapotranspiration and soil water consumption.

Between days 76 and 105 DAT, a recovery in soil moisture content was observed, especially in SAP treatments (Table 3). T4 showed the largest increase (4.3%), indicating that the higher dose of SAPs improved soil moisture retention and the use of 153 mm of precipitation.

Table 3. Behavior of moisture content in the range of 76 to 105 DAT (02/01-31/01) and 138 to 169 (05/03-05/04) DAT.

Treatment	DAT		Difference (%)	DAT		Difference (%)
	76	105		138	169	
T1 (0 g plant)	37.3	39.5	2.2b†	18.7	21.9	3.1ab‡
T2 (100 g plant)	41.3	43.8	2.6ab	22.9	26.6	3.7a
T3 (150 g plant)	43.6	46.6	3ab	26.3	27.7	1.4b
T4 (200 g plant)	43.8	48.1	4.3a	26	29.5	3.5ab

†, ‡ in columns, similar letters indicate that the values are statistically equal (Tukey, $p \leq 0.05$).

As of day 105, DAT (30/01/2024), soil moisture dropped due to low rainfall. Nonetheless, between days 138 and 169 DAT, rainfall (58 mm) led to a slight recovery. Treatment T2 showed the highest increase (3.7%); in contrast, T3 showed the lowest increase, with only 1.4%. T1 had a recovery of 3.1%; however, this value remained below the permanent wilting point (PWP), which represents a limitation for the crop's optimal development. On the other hand, in treatments T3 and T4, the moisture values remain slightly above the PWP (Table 3).

The largest increases in moisture occurred within the first 14 days, with a maximum of 7.8%, within the ranges reported by López-Elías *et al*. (2013); Rivera-Fernández *et al*. (2018), who report values between 1.5% and 14%. These results are comparable to Rivera and Mesías' (2018) findings. In the 0-14 and 76-105 DAT ranges, rainfall was recorded, which contributed to soil water availability. During these periods, treatment T4 showed a significant difference from T1, but did not show significant differences compared to T2 and T3. These results align with those reported by Akhter *et al.* (2004); Yáñez-Chávez *et al.* (2014), who pointed out that the addition of hydrogel to the soil improves moisture availability, thereby favoring plant establishment.

Qin *et al.* (2020) findings confirmed that the effect of SAPs is intensified by increasing the concentration from 0.1% to 1%, thereby improving water retention, which coincides with Idrobo *et al.* (2010). In addition, the lowest water loss was recorded in the treatment with higher polymer content, confirming the effectiveness of hydrogel in conserving soil moisture and optimizing water use in agriculture. The irregular distribution of rainfall limits moisture retention and favors percolation.

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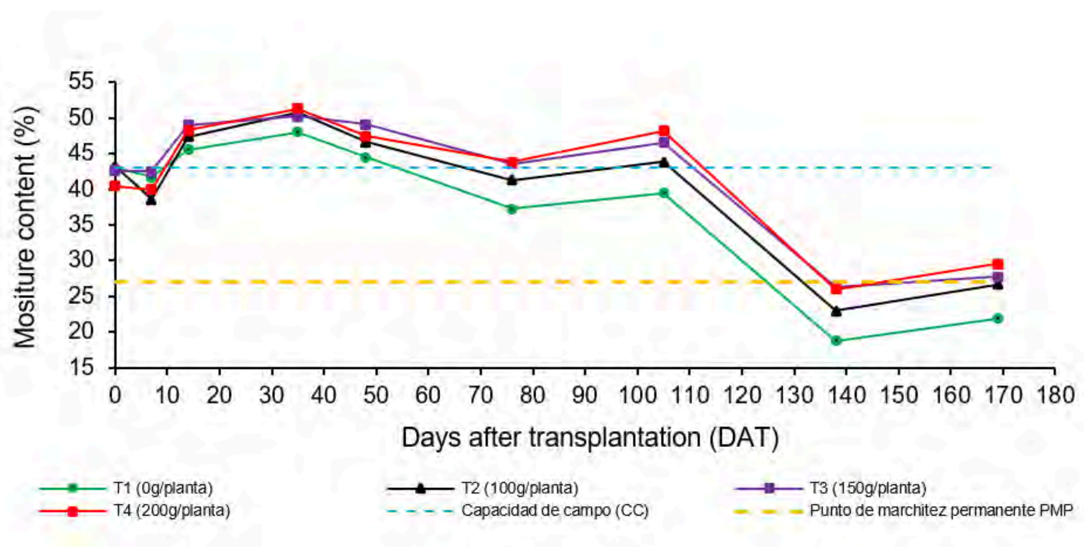
AbdAllah *et al.* (2021) mention that the application of SAPs reduces this effect; they found that percolation decreased from 41.76% to 4.8%-6.02% with 0.45% w/w of SAPs. In rainfed conditions, their use improved water storage, significantly increasing moisture after two consecutive rains (50 mm).

From day 138 DAT, all treatments reached the permanent wilting point (PWP) due to moisture depletion resulting from a lack of rainfall and water consumption by plants (Figure 2). Treatments T1 and T2 recorded the lowest moisture values, reaching PWP earlier, while T3 and T4 maintained higher moisture for longer, delaying the PWP by 12 days compared to T1 and five days compared to T2.

Figure 2. Soil moisture content in relation to FC and PWP.



This trend coincides with what was reported by Akhter *et al.* (2004), who found that the onset of PWP was delayed by 1 to 5 days in sandy loam soil when the concentration of hydrogel increased (0.1%, 0.2%, and 0.3%). In loam soils, PWP was delayed by four days at all concentrations, and hydrogel slowed moisture loss, prolonging the time before seedling wilt.

Growth

The increase in vertical growth was determined when at least one plant reached the height of the trellis. The plants in treatment T4 showed significantly higher growth (Table 4), which could be attributed to greater moisture retention, improving nutrient availability and the plant's physiological response.

Table 4. Response to treatments in vertical growth, leaf area and leaf area index.

Treatment	DAT Increase (m)		FA (cm^2)	FAI	
	14	48			
T1 (0 g plant)	0.53	1.54	1.02b	13 059ab#	3.63ab#
T2 (100 g plant)	0.39	1.41	1.02b	8572b	2.38b
T3 (150 g plant)	0.36	1.46	1.1b	10 519ab	2.92ab
T4 (200 g plant)	0.43	1.81	1.38a	13 466a	3.74a

FA= leaf area; FAI= leaf area index; Π and Θ in columns, similar letters indicate that the values are statistically equal (Tukey, $p \leq 0.05$).

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This is consistent with studies by Yáñez-Chávez *et al.* (2014); El Bergui *et al.* (2023), which demonstrated a significant increase in corn height with higher doses of hydrogel. In addition, Abobatta (2018) indicated that hydrogel polymers improve plant growth by increasing soil water retention and delaying the wilting point, which may explain the results observed in this study.

During the evaluation of the treatments' effect on plant growth, rainfall events favored moisture retention in the soil. AbdAllah *et al.* (2021) report that rainwater retention increases leaf water potential and favors growth. In addition, they point out that the incorporation of SAPs optimizes water use, reducing percolation losses and prolonging the availability of moisture, thus improving growth and avoiding drought stress.

Leaf area and leaf area index

Leaf area (LA) and leaf area index (LAI) were determined when at least one plant reached the trellis height. Significant differences were found between T4 and T2, but not between T4, T3 and T1 (Table 4). The measurements were taken at 48 days DAT, a period in which the soil moisture content remained above the field capacity (FC), guaranteeing adequate water availability for optimal plant growth and development.

These results are consistent with those of AbdAllah *et al.* (2021), who found no significant differences in corn leaf area between SAP and control treatments, suggesting that, when soil moisture is not limited, the leaf area response to SAPs may not be significant. On the other hand, Adireddy *et al.* (2024) reported that wheat leaf area and crop growth rates were affected by the methods of SAP application and assessed water stress levels. This contrasts with the current study, where soil moisture was maintained above the FC, preventing water stress from causing a differential response of the leaf area between treatments.

Yield

The results show that the application of SAPs significantly improves the yield of chayote (*Sechium edule*) in both open-field and rainfed conditions (Table 5). Treatment T4 (200 g plant^{-1}) recorded the highest yield, with 97.3 kg plant^{-1}, indicating a positive response to the increased availability of water in the root zone.

Table 5. Crop yield by treatments.

Treatment	Yield (kg plant^{-1})
T1 (0 g plant)	53b†
T2 (100 g plant)	66.7ab
T3 (150 g plant)	55.7b
T4 (200 g plant)	97.3a

† in columns, similar letters indicate that the values are statistically equal (Tukey, $p \leq 0.05$).

This result is consistent with what El Bergui O *et al.* (2023) pointed out, who states that the use of hydrogels increases yield by improving water availability in the root zone and reducing water and nutrient losses. In this sense, Idrobo *et al.* (2010) reported higher yields in radish and less moisture loss with SAPs, highlighting that a higher amount of hydrogel improves water retention in sandy soil. Similarly, Akhter *et al.* (2004) observed that hydrogels increased the water storage capacity in the soil, both in sandy loam and loam soils.

Treatment T2 showed a yield of 66.7 kg plant^{-1}, with no significant differences compared to T3 (55.7 kg plant^{-1}) or T4 (97.3 kg plant^{-1}). The above indicates that intermediate doses of SAPs can improve yield, but not in a proportionate manner. T1 and T3 presented the lowest yields, with no differences between them, indicating that the effect of the polymer is not linear and may depend on factors such as soil structure or rainfall distribution.

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The loss of soil moisture in T1 is attributed to water percolation during rainfall, which reduced the yield, which is in line with what was observed by AbdAllah *et al.* (2021). The lack of rainfall during flowering and fruiting may have affected water availability. The positive effect of T4 is attributed to the retention and gradual release of moisture, benefiting the development of chayote during critical stages. Norodinvand *et al.* (2019) noted that the superabsorbent in the soil improved the availability of water and nutrients, mitigating the impact of drought stress and preventing the fall of flowers and pods under conditions of deficient irrigation.

The lack of significant effects in T3 could be due to insufficient compensation for water deficit and the high sensitivity of chayote to stress during the reproductive phase, affecting fruit formation and filling. According to Li *et al.* (2022), the efficacy of SAPs varies by dose and crop; they point out that intermediate doses do not always improve yield, and in corn, low doses generated higher yields.

Conclusions

The application of superabsorbent polymers (SAPs) improved soil moisture retention, reduced percolation, and delayed the permanent wilting point, which favored chayote growth and yield under rainfed conditions.

The dose of 200 g plant^{-1} (T4) showed the highest vertical growth, leaf area and yield (97.3 kg plant^{-1}), thanks to the gradual release of water during the critical stages of the crop, avoiding water stress. Nevertheless, the response was not linear in all doses, indicating that the efficacy of SAPs depends on water conditions.

Under conditions similar to those of this study, T4 is emerging as the most appropriate dose to improve water availability and crop yield. However, it is recommended to evaluate its economic viability and validate its effect on other soil types, application methods, and water regimes. In addition, since rainfed chayote is sensitive to drought, supplemental irrigation is necessary to ensure competitive yields, even when using SAPs.

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