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Article

Potassium acrylate to reduce water use in greenhouse tomato cultivation

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Abstract

Hydrogels are materials that absorb large amounts of water and have been used for horticultural purposes. This work aimed to make a technical and economic assessment of the use of potassium acrylate (PA) hydrogel to reduce water consumption in tomato cultivation by using three doses of PA (0, 3 and 6 g L^{-1} substrate), two substrates (sand and mixture: 50% sand - 40% compost - 10% perlite) and two varieties (Aquiles and Moctezuma). The experimental work was carried out in one of the greenhouses of the Antonio Narro Autonomous Agrarian University, Laguna Unit, in the city of Torreón, Coahuila, Mexico, during the spring-summer cycle of 2020. The experimental design was in randomized blocks, 12 treatments and four repetitions. The variables evaluated were: plant height, stem thickness, polar and equatorial diameter of the fruit, pulp thickness, number of locules, degrees Brix, yield, and water footprint. The economic analysis was based on the partial budget methodology proposed by the International Maize and Wheat Center for the analysis of experiments. No statistical differences were found in fruit quality. Yield increased with PA and the water footprint decreased. Marginal income (MgI) exceeded marginal cost (MgC) in the two doses of PA analyzed. PA saved water (20.1% and 21.1%) when incorporated into the substrate mixture, increased yield (25.1 t ha^{-1}), improved income (MgI>MgC) and maintained fruit quality.

Keywords:

Solanum lycopersicum, hydrogel, substrates, water footprint.

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Introduction

Tomato (*Solanum lycopersicum* L.) is the main vegetable in Mexico in terms of production and export as more than 3 800 000 t are produced annually in more than 49 400 ha (SADER, 2020). Within greenhouse crops, tomato is of great importance nationally and internationally, both in the economy and in the diet (SAGARPA, 2017).

Agriculture faces complex challenges, between now and 2050 to feed a population that will reach 9 000 000 000 people, more water will be needed to produce an estimated 60% of the additional food needed to meet demand (FAO, 2019). The decrease in water resources coupled with the impacts of climate change, and the increasing demand from an ever-growing population, makes the effective use of water resources a necessity (Ayas, 2019).

Economic growth, development and population are putting pressure on water resources, with some estimates suggesting that if current practices continue, by 2030 the world will face a 40% deficit between projected demand and available water supply. The volume of water use has increased sixfold in the last 100 years (Ramos-Cruz *et al*., 2018).

Water stress is one of the main factors affecting crop growth, productivity, and fruit quality. Production is also influenced by adverse physical and chemical properties of the soil such as low infiltration rates, low water retention, and low cation exchange capacity (Nirmala and Thirupathaiah, 2019). The need to feed a growing world population will challenge agricultural dependence on water as we know it now; a higher proportion of greenhouse-produced vegetables would help mitigate the situation (Stanghellini, 2014).

Hydrogels are materials that retain large amounts of water without dissolving and substantial amounts of aqueous solutions. They are polymers that absorb many times their weight in water (Neethu *et al*., 2018) and have been widely proposed for horticultural purposes over the past 40 years with the idea of using their swelling and water-releasing properties to improve water availability to plants (Montesano *et al*., 2015).

Some of its main characteristics are: hydration, supply and rehydration capacity, reduction of irrigation needs and reduction of water stress in plants (Rivera-Fernández and Gallo, 2018). When the hydrogel mixes with the soil, it forms an amorphous gelatin-like mass associated with hydration and is unsurpassed in absorption and desorption over a long time.

It acts as a slow supply of water in the soil (Abobatta, 2018), decreasing the water footprint (WF), which are the liters of water applied for each kilogram of harvested product (Hoekstra *et al*., 2011). The working hypothesis is that, with the use of potassium acrylate, incorporated into the substrates, the amount of irrigation water will decrease, the growth and development of the plants will improve and an increase in the quality, production and income of the producers will be obtained.

In this context, this work aimed to carry out a technical and economic assessment of the use of potassium acrylate (PA) to reduce the amount of irrigation water and increase productivity in greenhouse tomato cultivation.

Materials and methods

Establishment of the experiment

The experimental work was carried out in one of the greenhouses of the Antonio Narro Autonomous Agrarian University, Laguna Unit, in the city of Torreón, Coahuila, Mexico, which is located at a west longitude of 101° 40’ and 104° 45’ and north latitude of 25° 05’ and 26° 54’ during the spring-summer agricultural cycle of 2020. The greenhouse has an area of 200 m^2, plastic cover, gravel floor, automatic cooling system, wet wall and two air extractors.

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Experimental design

The following were evaluated: three doses of potassium acrylate (PA) (riego sólido®) (A1, A2, and A3) (0, 3, and 6 g L^{-1} substrate), two substrates (S1 and S2) (sand and mixture: 50% sand -40%compost -10% perlite) and two tomato varieties (V1 and V2) (Aquiles and Moctezuma from Harris-Morán®). The treatments were distributed in an experimental design in randomized blocks, with 12 treatments and four repetitions, for a total of 16 plants per treatment and 192 plants in the entire experiment.

Black polyethylene bags were used as pots, with a capacity of 20 L, which were filled with 12 L of each substrate. Prior to filling, the corresponding dose of hydrogel per treatment was added. All pots were washed prior to transplanting to leach excess salts by applying 30 L of running water for a week, until a pH of 6.5 and an electrical conductivity of 2.6 were reached, both measured with the Hanna® model HI98130 equipment.

Sowing

The two tomato hybrids were sown in 200-cavity trays, the substrate used was peatmoss moistened to field capacity.

Transplanting

Prior to transplanting the tomato, the pots were saturated with five L of water to have moisture in the substrate and hydrate the hydrogel as much as possible. Once the water had been drained from the substrates, the establishment was carried out manually.

Irrigation

Irrigation was carried out twice a day and the amount of water that was incorporated per pot was calculated based on the initial weight of each pot at field capacity (FC) in each of the treatments (Bernacchi and VanLoocke, 2015). A scale with a capacity of 100 kg (EQB-100/200, Torrey®) was used for this activity. Repetitions per treatment were weighed daily and the average weight was obtained. The difference between the weight of the pots at FC and the average weight per treatment before irrigating determined the amount of water that was added per treatment. Irrigation was carried out manually by measuring the amount of water to be applied with a graduated cylinder.

Harvest

To evaluate the yield, the commercial-grade fruits of each cluster were harvested and weighed on a digital scale with a capacity of 5 kg (Truper® Base-5EP) and one plant per repetition was used, with a total of four plants per treatment. The work was carried out in the spring-summer cultivation cycle.

Statistical analysis

The variables evaluated were: plant height (cm), stem thickness (mm), polar and equatorial fruit diameter (mm), number of locules, degrees Brix (Amerza® manual refractometer), yield (t ha^{-1}) and water footprint (WF). Data were analyzed using the SAS program version 9.0 (Statistical Analysis System, 2002). In the variables where there was statistical significance, the test of comparison of means by $LSD_{0.05}$ was performed.

Economic analysis

For the economic analysis, the methodology of the International Maize and Wheat Center (CIMMYT, for its acronym in Spanish) known as partial budget (CIMMYT, 1988) was used, which consists of analyzing and comparing the concepts of costs and incomes that differ between treatments. Marginal income (MgI) and marginal cost (MgC) were calculated to analyze the convenience of choosing the alternative treatment. The decision criterion for accepting a higher-cost treatment

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is when MgI> MgC, which implies that, when investing in a higher-cost treatment, the additional income obtained from the change must be greater than the cost of its application.

Results and discussion

Plant and fruit characteristics

The variables evaluated in the experiment, such as plant height, stem thickness, polar and equatorial diameter of the fruit, pulp thickness, number of locules and degrees Brix, did not present statistical differences in the treatments evaluated ($p \geq 0.05$).

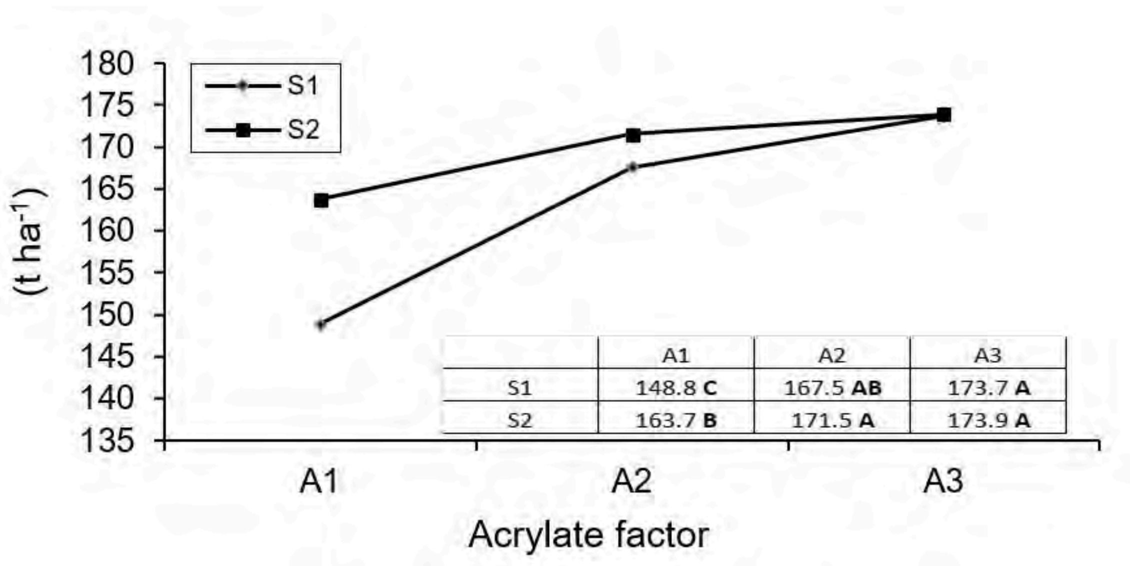
Yield

The analysis of variance for the variable of yield in t ha^{-1} found highly significant differences ($p \leq 0.01$) in the following factors: acrylate, substrate, and acrylate*substrate interaction. No statistical difference was found in the variety factor (V1 and V2) ($p \geq 0.05$).

Figure 1 shows that four of the treatments were statistically the same (S1*A2, S1*A3, S2*A2, and S2*A3), with yields of 167.5, 173.7, 171.5, and 173.9 t ha^{-1}, respectively. The highest yield was 173.9 t ha^{-1} and was obtained with the dose of 6 g of potassium acrylate per liter of substrate with the mixed substrate (S2*A3).

Figure 1

Dose of potassium acrylate (A1, A2, and A3) and tomato crop yield (t ha^{-1}) in sand (S1) and mixed (S2) substrates under greenhouse conditions. Different letters indicate a significant difference, $LSD_{0.05}$.



The control without potassium acrylate in the mixed substrate (S2*A1) was statistically different ($p \leq 0.05$) from previous treatments, with a yield of 163.7 t ha-1. The lowest yield was 148.8 t ha-1 and was obtained from the control without acrylate in the sand substrate (S1*A1), which was statistically different and lower in yield than the rest of the treatments ($p \leq 0.05$).

Water

Table 1 shows the water footprint (WF) for treatments with acrylate at different doses and without potassium acrylate, as well as the amount of water saved as a percentage (%) with doses of 0, 3, and 6 g of potassium acrylate. In both substrates, as the acrylate doses are increased, greater water savings are obtained, which also reduced the water footprint (Figure 2).

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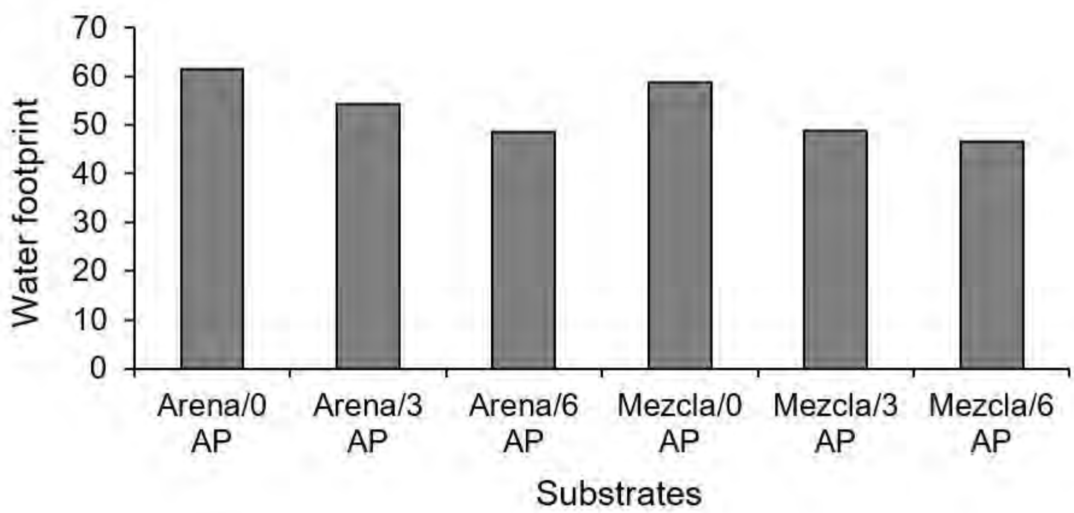
Table 1. Water footprint (WF) and water saved in greenhouse tomatoes with 0, 3, and 6 grams of potassium acrylate per liter of substrate (g L^{-1}).

Acrylate (g L^{-1})	Substrate	WF	Water saved (%)	(t ha^{-1})	(m^3 t^{-1} ha^{-1})
	Sand	61.5	0	148.8	9 151.2
3	Sand	54.3	11.7	167.5	9 095.2
6	Sand	48.6	21	173.7	8 441.8
0	Mixture	58.7	0	163.7	9 609.1
3	Mixture	48.7	17	171.5	8 352
6	Mixture	46.5	20.7	173.9	8 086.3

Figure 2 shows how the water footprint decreased as the dose of potassium acrylate per liter of substrate increased.

Figure 2 . Water footprint of greenhouse tomatoes in treatments with and without potassium acrylate in sand and mixed substrates.



Economic analysis. Marginal income (MgI) is defined as the increase in total income attributable to the increase in production of the alternative treatment. On the other hand, marginal cost (MgC) refers to the increase in the total cost attributable to the alternative treatment (CIMMYT, 1988; Krugman and Wells, 2006). The initial investment in pesos ha^{-1} for the acquisition of potassium acrylate for the dose of 3 g L^{-1} of substrate was \$107 820 ha^{-1}, while for the dose of 6 g L^{-1} of substrate, it was \$215 640 ha^{-1}.

Potassium acrylate has a shelf life of eight years, but its effectiveness decreases after six years, so it is necessary to incorporate a certain amount after that time. To carry out the economic analysis in this study, six years were considered, which is the period that its maximum effectiveness lasts.

Marginal product is the variation in the production of a good by increasing a factor of production by one unit (Krugman and Wells, 2006). If the marginal income is greater than the marginal cost, then technological change is accepted. Below is the breakdown of marginal cost and income calculations for the treatments analyzed.

Calculation of the marginal cost (MgC) for treatments of 3 and 6 g of acrylate L^{-1} of substrate. Potassium acrylate market price= \$119.8 kg^{-1}. Calculation for the treatment of 3 g of potassium

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acrylate. Pot capacity: 12 L= 36 g. Population density: 25 000 plants ha^{-1}. Total product used (36 x 25 000)= 900 kg ha^{-1}.

Initial cost for the acquisition of acrylate (900 x 119.8): $107 820 ha^{-1}. Annual cost of PA use= initial cost/6 years= $17 970 ha^{-1} per year. This cost of PA was divided by two because in the year harvest is carried out in the two agricultural cycles, spring-summer (S-S) and autumn-winter (A-W), so the cost/ha/agricultural cycle of 3 g of PA= $8 985.

Therefore, the MgC (or incremental cost) of going from 0 to 3 g of PA was $8 985 ha^{-1}. Calculation for treatment with 6 g of potassium acrylate. Pot capacity: 12 L= 72 g. Population density: 25 000 plants ha^{-1}.

Total product used (72 x 25 000)= 1800 kg ha^{-1}. Initial cost for the acquisition of acrylate (1800 x 119.8): $215 640 ha^{-1}. Annual cost of PA use= initial cost/6 years= $35 940 ha^{-1} per year. But the cost of PA was divided by two because in the year harvest is carried out in the two agricultural cycles, (SS) and (AW), so the cost/ha/agricultural cycle of 6 g of PA= $17 970 ha^{-1}.

Therefore, the MgC (or incremental cost) of going from 3 to 6 g of PA was $17 970-$8 985= $8 985 ha^{-1} per agricultural cycle. On the other hand, the calculation of the Marginal Income (MgI) for the treatments of 3 and 6 g of PA for the sand and mixed substrates was calculated using the formula: MgI= Pr x MgP. Where: MgI= marginal income; Pr= price of the product; and MgP= marginal product.

The MgP is the additional amount of commercial tomato by which the production of a treatment exceeds the production of the previous treatment. The price of $5 542.79 t^{-1} was the average rural price of tomatoes during the 2020 (SS) cycle in La Laguna of Coahuila (SIAP, 2020).

For the sand substrate, when going from 0 to 3 g of PA, the marginal product (MgP) was: 167.5-148.8= 18.6 t ha^{-1}, which, multiplied by the price of tomato ($5 542.79 t^{-1}), results in a marginal income (MgI) of $103 096. For the sand substrate, when going from 3 to 6 g of PA, the marginal product (MgP) was: 173.7-167.5= 6.2 t ha^{-1}, which multiplied by the price of tomato ($5 542.79 t^{-1}), results in a marginal income (MgI) of $34 365.

For the mixed substrate, when going from 0 to 3 g of PA, the marginal product (MgP) was: 171.5-163.7= 7.8 t ha^{-1}, which, multiplied by the price of tomato ($5 542.79 t^{-1}), results in a marginal income (MgI) of $43 233. For the mixed substrate, when going from 3 to 6 g of PA, the marginal product (MgP) was: 173.9-171.5= 2.4 t ha^{-1}, which, multiplied by the price of tomato ($5 542.79 t^{-1}), results in a marginal income (MgI) of $13 302.

Table 2 summarizes the previous results and includes the decision criterion. In all cases MgI> MgC, so from an economic point of view, in the two types of substrates, the income derived from the application of the PA from 0 to 3 g and from 3 to 6 g is convenient because the income obtained by increasing the dose is greater than the cost of using it. In both types of substrates, it is profitable to apply 6 g of PA per liter of substrate.

Table 2
Marginal income(MgI) and Marginal cost (MgC) and decision criteria when using 0, 3, and 6 g of potassium acrylate L^{-1} of substrate in greenhouse tomato cultivation.

Acrylate (g)	Substrate	Yield (t ha^{-1})	MgI (marginal production x price)	MgI of treatments	MgC of treatments ($)	Decision
0	Sand	148.9	-	-	-	-
3	Sand	167.5	18.6 x $5 542.79	103 095	8 985	MgI> MgC
6	Sand	173.8	6.2 x $5 542.79	34 365	8 985	MgI> MgC
0	Mixture	163.7	-	-	-	
3	Mixture	171.5	7.8 x $5 542.79	43 233	8 985	MgI> MgC
6	Mixture	173.9	2.4 x $5 542.79	13 302	8 985	MgI> MgC

MgI= marginal income; MgC= marginal cost.

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In relation to the economic value of the water savings presented in Table 1, the results indicate that such savings are not as significant in their contribution to the producer's income as is the increase in yields. Considering that the cost of water is $1.56 m^{-3} (Ramírez-Barraza *et al*., 2019), the savings with the use of PA were as follows. In the sand substrate, when going from 0 to 6 g of PA, the savings were 709 m^{3}, with a value of $1 107.00 pesos.

In the mixed substrate for the same treatments, the savings were 1 523 m^{3}, with a value of $2 376.00 pesos. Both values, while important, are very far from what increases in yields per hectare bring to income.

Yield

The use of potassium acrylate had positive and significant results when sand and mixture (50% sand -40% compost -10% perlite) were incorporated into the substrates. The benefits of potassium acrylate were reflected in the yield variable, in water savings by reducing the water footprint, and in improved income. Yield increased with the incorporation of potassium acrylate in the two substrates studied, but it showed no significant difference ($p \leq .05$) when the dose of the hydrogel was increased from 3 to 6 g L^{-1}. Although there were significant differences ($p \leq .05$) between both substrates when not treated with the hydrogel, the incorporation of similar doses of 3 and 6 g L^{-1}, respectively, resulted in them being statistically equal.

Authors such as Ahmed and Fahmy (2019) conducted a study to evaluate the potential of natural polymers to improve water availability in tomatoes (*S. lycopersicum*), which was carried out in a sandy-loam soil at a dose of 2 g kg^{-1} of soil. The results showed that a yield 20.5% higher than the control was achieved.

According to the productions found in this research, a yield 5.8% higher with respect to the control was obtained with the mixed substrate (S2) at a dose of 6 g of potassium acrylate (A3) and a yield 14.3% higher for the case of the sand substrate (S1) at the same dose. Although these results were statistically different, they are below those reported by these authors.

In another study on tomato, Mandal *et al*. (2015) found an increase in fruit production of 2.9 t ha^{-1} with respect to the control with the application of hydrogel when applied at doses of 50 kg ha^{-1}. According to the averages of this work, the minimum difference in yield with respect to the control was 10.19 t, but with an application of 900 kg ha^{-1} of potassium acrylate by considering the dose of 3 g.

The yields obtained with doses of 3 and 6 g L^{-1} of substrates were lower than those reported by Ortega-Torres *et al*. (2020) with tomato under greenhouse conditions by using a substrate consisting of coconut fiber mixed with potassium acrylate at concentrations of 0, 25, 75, and 100%, where a yield of 283 t ha^{-1} was obtained. Nassaj-Bokharaei *et al*. (2021) confirm both the positive effects of treatments with nanoparticle hydrogel on tomato growth and survival under conditions of water deficit stress, and the magnitude of responses to the treatment on growth parameters.

The concentration of nutrients and the activity of soil microorganisms depended on the concentration of the hydrogel applied and the severity of stress, so its addition may be suggested as a successful method to maintain soil moisture content and save water and nutrients.

Water

The water footprint for tomato production in this work decreased with the application of potassium acrylate on both substrates, it decreased even more when the dose was increased from three to six grams per liter of substrate. Regarding the economic aspect, the marginal income (MgI) was higher than the marginal cost (MgC) in the two doses analyzed and in the two strata, which implies that the use of hydrogel is economically affordable.

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According to Ortega-Torres *et al*. (2020), in tomato production, the coconut fiber mixture as a substrate, added with potassium acrylate, exerted a positive synergy in water retention at the beginning of the crop since 100% coconut fiber had the highest water loss, finding a positive correlation with this variable and the percentage of acrylate in the mixture.

A reduction in the porosity of the substrate with the mixture with potassium acrylate was also observed, as this polymer absorbed the water and occupied the pore space. The application of polyacrylamide (PAM) and potassium acrylate polymer to tomato crops, in weight ratios of 25 and 50 kg ha^{-1} in sandy-loam and clay-loam soils, increased the available water content by 101 to 192%, compared to untreated soils.

In this field experiment with weekly irrigation and irrigation of 20 L m^{-2} every three weeks, it did not have a significant effect on tomato plant height, yield, and fruit quality. Application of PA at 25 kg ha^{-1} with alternate-week irrigation not only produced the highest tomato yield, of 67.2 t ha^{-1}, but saved 1 800 m^{3} ha^{-1} of irrigation water during a growing season of the crop (Reddy *et al*., 2015).

These savings exceeded what was found in this study, where the maximum water savings achieved were 1 066 m^{3} with the dose of 6 g L^{-1} and substrate mixture and this difference is due to the higher volume of water that was applied in that experiment, but its yield was much lower than the 173. 9 t ha^{-1} obtained in this work.

Studies proposed by Sobrinho and Barbosa (2020) report that when hydrogel is added to the soil, its water absorption efficiency decreases regardless of the added fertilizer solutions and therefore it is important that more research is conducted with higher soil volumes and more polymer doses so that the effects of fertilizers can be better estimated on water retention when the hydrogel is in contact with the soil. The demand for absorbent materials will probably grow in agriculture in the short and medium term due to water scarcity derived from the lack of rainfall and depletion of aquifers worldwide (Llanes *et al*., 2020).

Conclusions

The use of potassium acrylate in greenhouse tomato cultivation resulted in a decrease in water consumption and an increase in yields, although increasing the dose from 3 to 6 grams did not result in statistical differences. The economic analysis showed that the marginal income, with the addition of potassium acrylate, exceeded the cost of its use and was therefore economically sufficient to justify its use.

Acrylate was shown to make a greater contribution to farmers' income by increasing yields than by saving water. The use of potassium acrylate, when incorporated into different substrates, helps to increase yield, maintain fruit quality, significantly save the amount of water used, and increase farmers' income. Future work should also consider the amount of fertilizer saved with the use of hydrogels.

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