Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

FINAL REPORT

Project: Estudio del Efecto Experimental del Producto EF Polymer (polímero ecológico de origen japonés de la marca EP POLYMER Co. Ltd.) en el Cultivo de Jitomate en Condiciones Agroecológicas del Bajío Guanajuatense

Objective: To evaluate the biological effectiveness of the EF polymer product in tomato cultivation (effects on the efficient use of water and fertilizers).

Collaborators:

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Period:

Spring-summer, 2025.

Variety:

Pony express (determinate saladette tomato).

Methodology

Design and experimental unit:

- 3^k factorial experimental design.
- Experimental unit: two beds per repetition (bed 60.25 m long by 1.6 m wide).
- Plants per bed: 172.
- Sample: 4 plants per row.

Factors and their levels of study:

Factor	Factor 1 Polymer dose	Factor 2 Fertilization dose	Factor 3 Irrigation rate
Level	0	80	75
	15	100	100
	20		
	30		

Design of orthogonal combinations to evaluate single factors, double interactions and triple interactions, as well as double and triple combinations.

Table 1. Sixteen combinations determined for the evaluation of three factors.

ID	Combinations		
	Factor 1	Factor 2	Factor 3
C1	0	80	75
C1	0	80	100
C2	0	100	75
C2	0	100	100
C3	15	80	75
C3	15	80	100
C4	15	100	75
C4	15	100	100
C5	20	80	75
C5	20	80	100
C6	20	100	75
C6	20	100	100
C7	30	80	75
C7	30	80	100
C8	30	100	75
C8	30	100	100

Simple factor model

$$Y_{ijkl} = \mu + F1_i + F2_j + F3_k + (F1 * F2)_{ij} + (F1 * F3)_{ik} + (F2 * F3)_{jk} + (F1 * F2 * F3)_{ijk} + \varepsilon_{ijkl}$$

Double combination models (F1*F2=CD1, F1*F3=CD2, F2*F3=CD3)

$$Y_{ijk} = \mu + CD1_i + F3_j + (CD1 * F3)_{ij} + \varepsilon_{ijk}$$

$$Y_{ijk} = \mu + CD2_i + F2_j + (CD2 * F2)_{ij} + \varepsilon_{ijk}$$

$$Y_{ijk} = \mu + CD3_i + F1_j + (CD3 * F1)_{ij} + \varepsilon_{ijk}$$

Triple Combination (CT) Model

$$Y_{ij} = \mu + CT_i + \varepsilon_{ij}$$

Recorded variables:

Agronomics:

- Main stem length (cm)
- Stem diameter (cm)
- Number of bunches per plant
- Number of fruits per plant

Productive:

- Yield (kg ha^{-1})
- Yield per plant (kg)
- Water productivity (kg of product / liter of water)
- Efficient fertilizer use (kg of product / kg of fertilizer)

Fruit quality:

- • Individual fruit weight (g)
- • Polar and equatorial diameter (cm)
- • pH
- • ºBrix
- • Shelf life
- • Firmness

Data analysis:

The data were analyzed with the Tukey DHS mean test ($p \leq 0.05$) with corrected error (polymer and fertilization with error type A, and irrigation with error type B), in addition to a canonical discriminant analysis performed with the SAS statistical package (SAS, 2004).

Results

The analysis of variance showed highly significant differences ($p \leq 0.05$) for the fertilization factor in fruit number (FN). On the other hand, for the irrigation factor, plant height (PH), stem diameter (SD), total number of bunches per plant (BTP) and fertilization efficiency were highly significant ($p \leq 0.05$). On the other hand, there were no differences in the interaction between irrigation and fertilizer, but there were, for the polymer-fertilizer-irrigation combination in which significant differences were observed ($p \leq 0.05$) in height (PH), stem diameter (SD), number of fruits (FN), total number of bunches (BTP) and fertilizer efficiency (FE) (Table 2).

Table 2. ANOVA for 13 traits determined in tomato plants grown under different combinations.

Source	PH	SD	FN	FYP	IFW	BTP	PD	ED	pH	ºB	Fir	WP	FE
Fertilization	20.63	0.02	**165.67*****	1390632.43	159.21	2.31	0.02	0.06	0.02	0.11	0.029	0.000005	3.35
Irrigation	**1086.57*****	**0.37*****	0.01	426948.91	139.37	**29.66*****	0.06	0.08	0.06	0.11	0.019	0.000009	**42.91*****
Interaction	24.50	0.02	2.19	5432.84	8.376	0.86	0.04	0.12	0.02	0.07	0.006	0.000000	0.06
Combinations	**93.50*****	**0.04***	**78.33***	679960.39	87.51	**3.46***	0.03	0.09	0.02	0.09	0.018	0.000003	**4.45***
CV	5.12	8.98	9.86	13.41	11.83	11.23	3.49	5.39	4.45	8.99	9.87	13.65	13.97

PH= Plant height; SD = Stem diameter; FN = Fruit number; FYP= Fruit yield per plant; IFW= Individual fruit weight; BTP= Bunches total per plant; PD= Polar diameter; ED= Equatorial diameter; pH; ºB= Brix degrees; Fir= Firmness; WE= Water efficiency; FE= Fertilizer efficiency.

For the polymer-fertilizer-irrigation interaction, the results indicated significant differences ($p \leq 0.05$), and the effect of the combinations (Table 3) on plant height (PH), stem diameter (SD), fruit yield per plant (FYP), total number of bunches per plant (BTP) and fertilizer efficiency (FE).

Table 3. Behavior of 13 characters determined in tomato plants grown under the effect of interaction of different combinations of polymer-fertilizer-water.

Comb	PH	SD	FN	FYP	IFW	BTP	PD	ED	pH	ºBrix	Fir	WP	FE
C1-100	90.91ab	1.62ab	48.45ab	5696.5b	94.43a	11.25ab	6.54 a	5.28 a	4.68 a	3.72 a	3.02 a	0.0105 a	7.85d
C1-75	75.29c	1.53ab	47.54b	5575.7b	92.91a	8.25b	6.81 a	5.74 a	4.73 a	3.87 a	2.99 a	0.0114 a	9.61abcd
C2-100	91.83ab	1.76ab	59.91ab	5900.8ab	99.83a	11.51ab	6.84 a	5.66 a	4.68 a	3.72 a	3.02 a	0.0109 a	8.13d
C2-75	78.33bc	1.52b	59.15ab	5687.3b	96.10a	10.04ab	6.68 a	5.77 a	4.71 a	3.62 a	2.98 a	0.0116 a	9.81abcd
C3-100	90.08ab	1.68ab	59.64ab	6061.8ab	101.57a	11.91ab	6.88 a	5.62 a	4.61 a	3.77 a	3.04 a	0.0112 a	8.36d
C3-75	79.75abc	1.69ab	59.25ab	5807.8b	98.27a	9.71ab	6.69 a	5.61 a	4.45 a	3.64 a	2.99 a	0.0119 a	10.01abcd
C4-100	**92.83 a**	1.74ab	60.04ab	6521.3a	108.69a	11.91ab	6.75 a	5.56 a	4.63 a	3.47 a	3.09 a	0.0120 a	8.99bc
C4-75	82.83abc	1.54ab	61.33ab	6280.1ab	102.86a	10.04ab	6.55 a	5.51 a	4.76 a	3.61 a	3.07 a	0.0128 a	10.82abc
C5-100	**92.45 a**	1.76ab	61.75ab	**6702.3a**	108.53a	11.71ab	6.65 a	5.81 a	4.56 a	3.79 a	3.06 a	0.0124 a	9.24bcd
C5-75	82.54abc	1.67ab	62.42ab	6444.5ab	103.82a	10.54ab	6.69 a	5.65 a	4.78 a	3.83 a	3.11 a	0.0132 a	**11.11abc**
C6-100	**91.91 a**	1.71ab	60.62ab	**6792.3a**	112.15a	**12.12 a**	6.83 a	5.33 a	4.64 a	3.84 a	3.07 a	0.0125 a	9.36bcd
C6-75	83.33 abc	1.51b	62.83ab	6625.9a	105.23a	10.83ab	6.69 a	5.77 a	4.62 a	3.84 a	2.97 a	0.0135 a	**11.42ab**
C7-100	87.45 abc	**1.98a**	64.25ab	**6771.1a**	105.72a	11.87ab	6.86 a	5.94 a	4.61 a	3.725 a	3.17 a	0.0125 a	9.33bcd
C7-75	83.66abc	**1.56a**	63.37ab	6657.1a	105.08a	10.91ab	6.69 a	5.56 a	4.72 a	4.31 a	3.028 a	0.0136 a	**11.47ab**
C8-100	90.58ab	1.81ab	65.62a	**6985.6a**	106.12a	**12.12 a**	6.85 a	5.59 a	4.64 a	3.68 a	3.20 a	0.0129 a	9.63abcd
C8-75	86.20abc	1.62ab	64.67ab	**6844.3a**	105.51a	11.51ab	6.84 a	5.87 a	4.87 a	3.73 a	3.22 a	0.0141 a	**11.79 a**
DHS	13.37	0.45	17.92	2571.2	36.85	3.74	0.71	0.92	0.62	1.02	0.91	0.005	2.27

PH= Plant height; SD = Stem diameter; FN = Fruit number; FYP= Fruit yield per plant; IFW= Individual fruit weight; BTP= Bunches total per plant; PD= Polar diameter; ED= Equatorial diameter; pH; ºB= Brix degrees; Fir= Firmness; WE= Water efficiency; FE= Fertilizer efficiency.

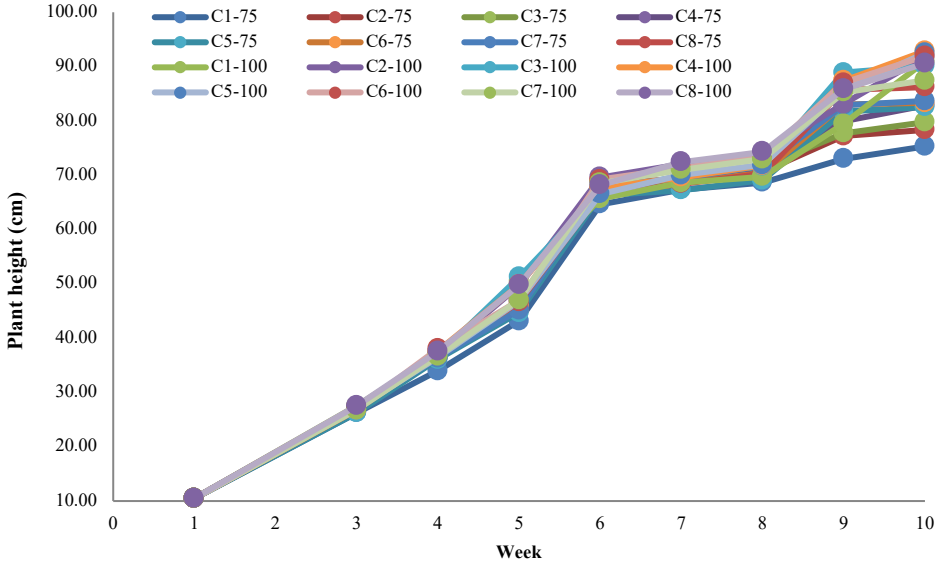
The interaction showed larger plants in the combination of C4, C5, and C6 with 100% irrigation. The highest SD was observed in C7 under both irrigation regimes. The C8-100 combination showed the highest number of fruits. The highest fruit yield per plant was observed in C5, C6, and C7 under 100% irrigation. Meanwhile, C8 under both irrigation regimes achieved the highest FYP, with no statistical differences compared to the other combinations under 100% irrigation, except for the control under both regimes. The highest BTP was recorded in the C6 and C8 combinations under 100% irrigation.

Fruit traits did not show significant differences, as did the WE combinations. However, differences were noted in EF, where C5, C6, C7, and C8 under 75% irrigation showed greater fertilizer use efficiency (Table 3).

Descriptive analysis of evaluated characters

Plant height

Figure 1 shows the plant growth behavior (PH). All combinations, except C7 with 100% irrigation, exceeded 90 cm in height. Particularly notable was the C4-100% combination, which surpassed C1-75% (control) by 17 cm.



Stem diameter

Figure 2 shows the growth trend in stem diameter (SD). Particularly noteworthy is the C7-100% growth pattern, which showed accelerated stem thickening in the first five weeks, surpassing C1-75 by 0.48 mm and C1-100 (controls) by 0.35 mm. The remaining combinations with 100% irrigation had higher SD than the combinations grown with 75% irrigation.

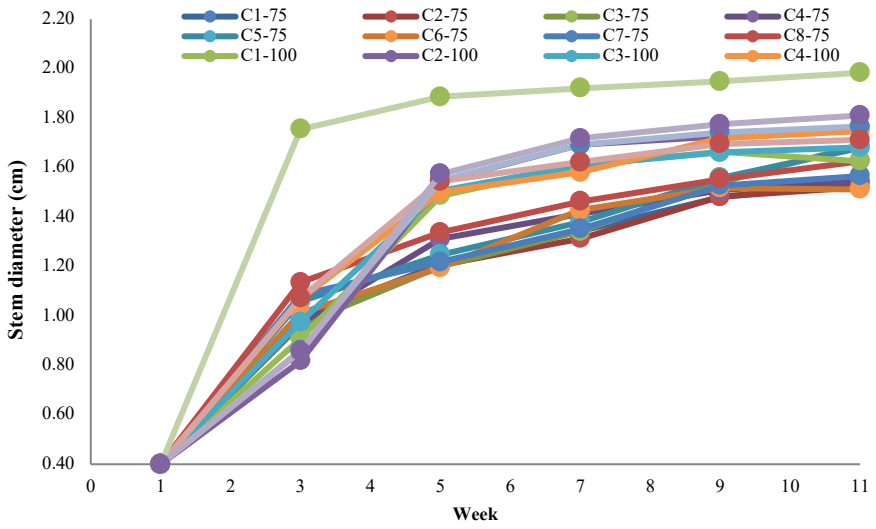
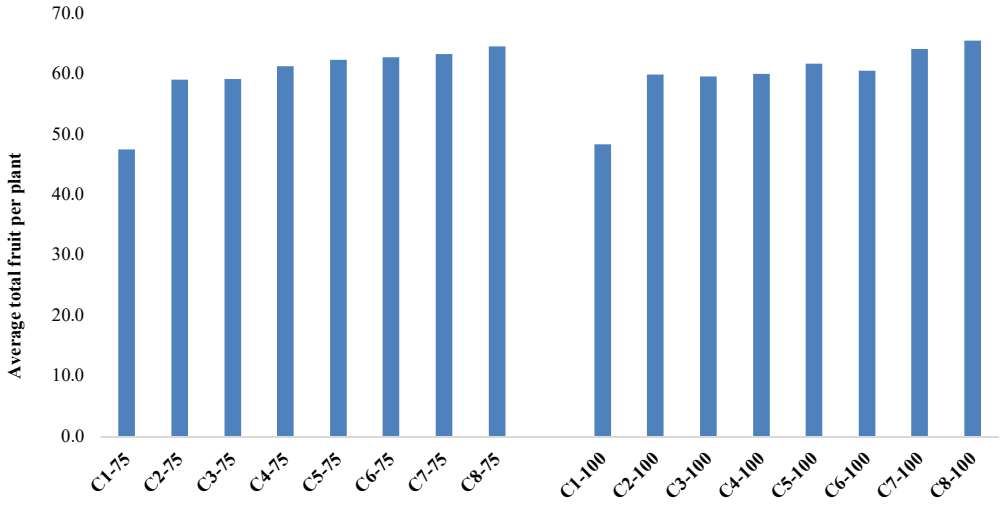


Figure 3 shows the average number of fruits (FN) obtained in each combination. C8 combinations under both irrigation regimes produced the highest FN, exceeding their respective controls by more than 15 fruits. In contrast, the differences between the combinations that included polymer did not exceed six fruits per plant.



Fruit yield per plant

Figure 4 shows the average fruit production per plant (FPP), which was significantly different ($p \leq 0.05$). The highest yield was obtained in the C8 combinations under both irrigation regimes. The difference between C8 and its respective controls averaged 18.5%; however, the difference between C8 under both irrigation regimes and the best combinations that included polymer input was variable (Table 4). The difference in fruit production ranged from 0.75% to 16.86%.

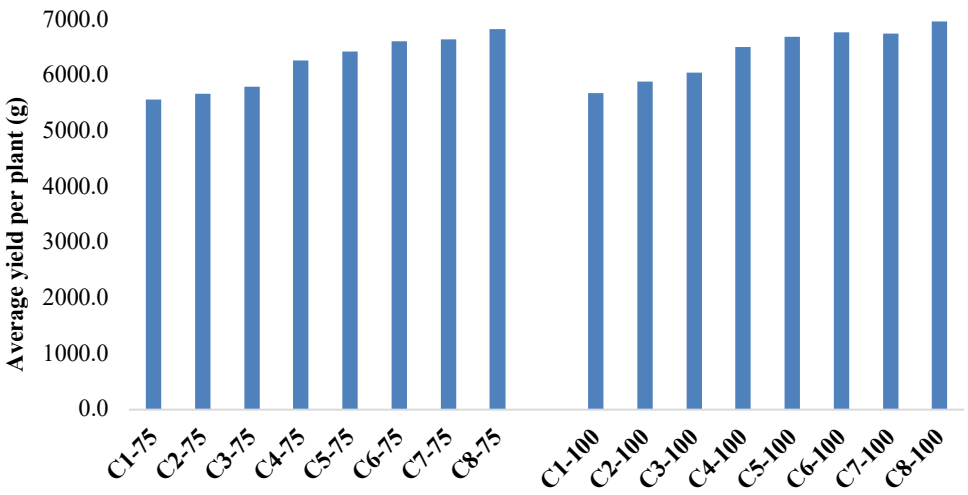


Table 4. Percentage difference in fruit production per plant between C8 in both irrigation regimes and combinations that include polymer supply.

Combination	Irrigation rate of 75%					Irrigation rate of 100%				
	C7	C6	C5	C4	C3	C7	C6	C5	C4	C3
C8-75	2.74	3.19	5.84	8.24	15.1	1.06	0.75	2.07	4.71	11.47
C8-100	4.71	5.14	7.74	10.11	16.86	3.07	2.76	4.05	6.64	13.2

Yield per hectare

In the yield per hectare calculated based on the planting density of 23 thousand tomato plants per hectare, it was observed that the C8-100% combination reached the highest yield, exceeding by 18.5% the yield obtained in the C1-75 and C1-100 combinations, but with minimal difference to C8-75 and C6-100 (Table 5).

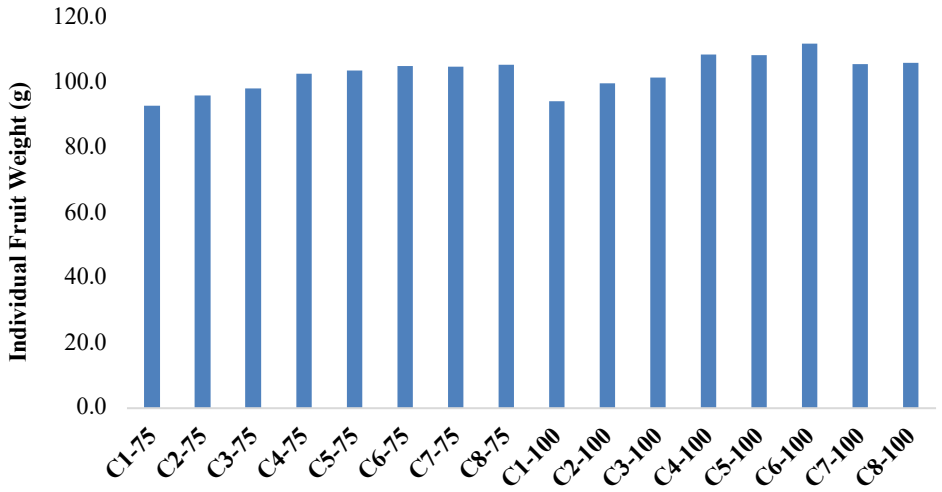
Table 5. Tomato yield per hectare obtained in the different polymer-fertilizer-irrigation combinations**.**

Combination	FYP	YPH	Combination	FYP	YPH
C1-75	5.57	128.11	C1-100	5.69	130.87
C2-75	5.68	130.64	C2-100	5.91	135.93
C3-75	5.80	133.40	C3-100	6.06	139.38
C4-75	6.28	144.44	C4-100	6.52	149.96
C5-75	6.44	148.12	C5-100	6.71	154.33
C6-75	6.62	152.26	C6-100	6.79	156.17
C7-75	6.65	152.95	C7-100	6.77	155.71
C8-75	6.84	157.32	C8-100	6.98	160.54

FYP = Fruit yield per plant (kg); YPH 0 Yield per hectare (t ha^{-1}).

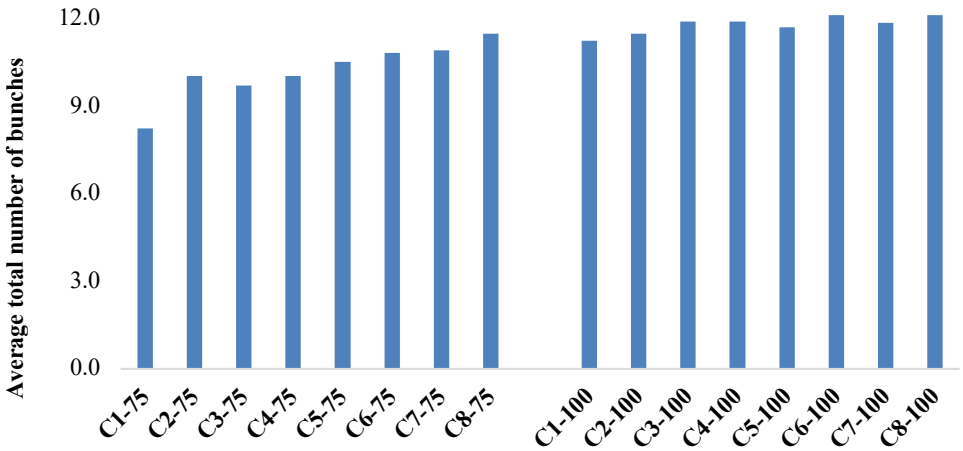
Individual fruit weight

There were no statistically significant differences for this trait ($p \leq 0.05$). As shown in Figure 5, all combinations had the same average fruit size. The lowest IFW (95.8 g) was observed in combinations C1, C2, and C3 under the 75% irrigation regime; however, the highest IFW was recorded under the 100% irrigation regime in combinations C4, C5, and C6, with an average weight of 109.8 grams of IFW.



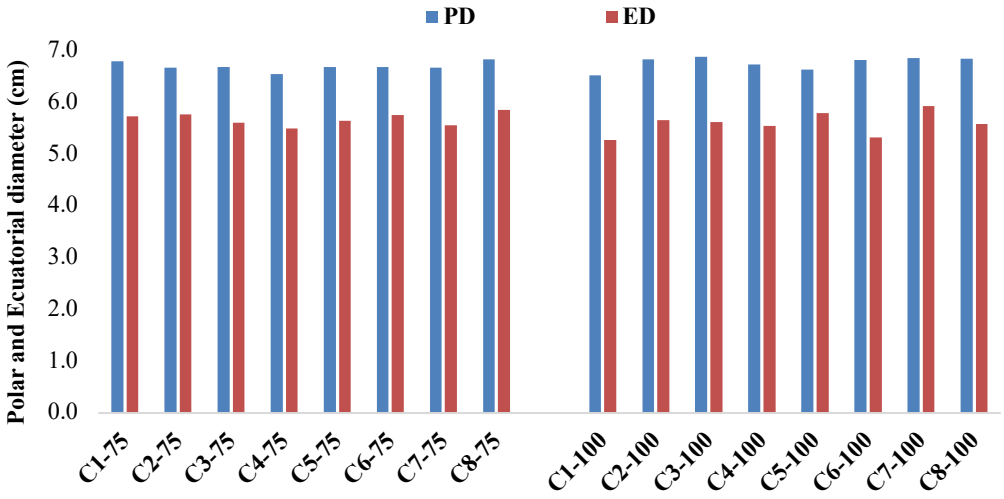
Number of bunches per plant (BTP)

Figure 6 shows the average total number of bunches produced per plant (BTP). The lowest number of bunches was recorded in the control (C1-75), with three fewer bunches than those recorded in C6 and C8 under 100% irrigation. Meanwhile, in the combinations with polymer under both irrigation regimes, the number of bunches ranged from 10 to 12 bunches per plant.



Polar and equatorial diameter

Figure 7 shows the polar diameter (PD) and equatorial diameter (ED) of the fruit. There were no differences; the PD averaged 6.5 cm, while the ED was 5.5 cm. The observed size was not influenced by any of the combinations, which is attributable to the intrinsic behavior of the variety used.



pH, ºBrix, y firmness

pH, °Brix, and firmness did not show statistically significant differences ($p \leq 0.05$). The pH ranged from 4.5 to 4.9, °Brix from 3.5 to 3.8, and firmness from 21.4 to 26.2 kg (Newtons). These results are attributable to the genetics of the plant material used.

Shelf life

Shelf life was not affected by any of the combinations, including the control. On average, the harvested fruits had a shelf life of 20 days.

Water productivity

For irrigation regimes, statistical differences ($p \leq 0.05$) were observed in plant height (PH), stem diameter (SD), fruit yield per plant (FYP), total number of bunches per plant (BTP), and fertilizer efficiency (FE). Significant values for these variables were shown when 100% irrigation was applied (Table 6).

Table 6. Behavior of 13 traits determined in tomato plants grown under the effect of two irrigation conditions.

F2	PH	SD	FN	FYP	IFW	BTP	PD	ED	pH	ºBrix	Fir	WP	FE
75	81.49b	1.58b	60.07a	6240.3b	101.22a	10.22b	6.71a	5.68a	4.71a	3.81a	3.04a	0.012a	10.75a
100	91.01a	1.76a	60.03a	6428.9a	104.63a	11.81a	6.78a	5.61a	4.63a	3.71a	3.08a	0.011a	8.86b
DHS	2.59	0.08	3.48	499.3	7.15	0.72	0.13	0.17	0.12	0.19	0.17	0.001	0.805

PH= Plant height; SD = Stem diameter; FN = Fruit number; FYP= Fruit yield per plant; IFW= Individual fruit weight; BTP= Bunches total per plant; PD= Polar diameter; ED= Equatorial diameter; pH; ºB= Brix degrees; Fir= Firmness; WE= Water efficiency; FE= Fertilizer efficiency.

The highest water productivity was evident when 100% irrigation was applied and was reflected in the PH, SD, FYP, BTP traits, but its effect was more notable in improving fertilizer efficiency (FE) when 75% irrigation was applied (Table 6).

Fertilizer efficiency

The behavior of the variables due to the effect of fertilization was only significant ($p \leq 0.05$) in the variable number of fruits (FN). The behavior of each variable was statistically similar in each fertilizer combination, but when combined with irrigation and polymer, the efficiency of the fertilizer improved. Thus, values greater

than 10 kg of fruit per 1.0 kg of fertilizer were observed when 20 and 30 kg of polymer were applied (Table 7).

Table 7. Behavior of 13 traits determined in tomato plants grown under the effect of fertilizer combinations.

F1	PH	SD	FN	FYP	IFW	BTP	PD	ED	pH	ºBrix	Fir	WP	FE
C1	83.1a	1.58a	48.01b	5636.1 a	93.67 a	9.75 a	6.67 a	5.51 a	4.71 a	3.81 a	3.01 a	0.0109 a	8.73 a
C2	85.1a	1.64a	59.53a	5794.1 a	97.97 a	10.77 a	6.76 a	5.72 a	4.69 a	3.67 a	3.01 a	0.0112 a	8.97 a
C3	84.9 a	1.68a	59.44a	5934.8 a	99.92 a	10.81 a	6.79 a	5.62 a	4.53 a	3.71 a	3.02 a	0.0115 a	9.18 a
C4	87.8a	1.64a	60.68a	6400.6 a	105.77 a	10.97 a	6.65 a	5.53 a	4.71 a	3.54 a	3.08 a	0.0124 a	9.91 a
C5	87.5a	1.72a	62.08a	6573.4 a	106.17 a	11.12 a	6.67 a	5.73 a	4.67 a	3.81 a	3.08 a	0.0128 a	**10.17 a**
C6	87.6a	1.61a	61.72a	6709.1 a	108.69 a	11.47 a	6.76 a	5.55 a	4.63 a	3.84 a	3.02 a	0.0131 a	**10.39 a**
C7	85.5a	1.77a	63.81a	6714.1 a	105.40 a	11.39 a	6.77 a	5.75 a	4.67 a	4.01 a	3.09 a	0.0131 a	**10.41 a**
C8	88.3a	1.71a	65.14a	6914.9 a	105.82 a	11.81 a	6.85 a	5.73 a	4.76 a	3.71 a	3.21 a	0.0134 a	**10.71 a**
DHS	8.2	0.28	11.07	1588.3	22.76	2.31	0.43	0.56	0.38	0.63	0.56	0.0032	2.56

PH= Plant height; SD = Stem diameter; FN = Fruit number; FYP= Fruit yield per plant; IFW= Individual fruit weight; BTP= Bunches total per plant; PD= Polar diameter; ED= Equatorial diameter; pH; ºB= Brix degrees; Fir= Firmness; WE= Water efficiency; FE= Fertilizer efficiency.

Canonical discriminant analysis

Canonical discriminant analysis showed that two canonical roots (CAN) were necessary to explain 97.25% of the total effect of the combinations. This analysis revealed that CAN1 was positively correlated with plant height, PH, stem diameter (SD), and total number of clusters (TCN). Meanwhile, CAN2 was positively correlated with number of fruits (FN), fruit yield per plant (FYP), individual fruit weight (IFW), and total number of clusters (TCN). Finally, CAN3 was positively correlated with plant height (Table 8).

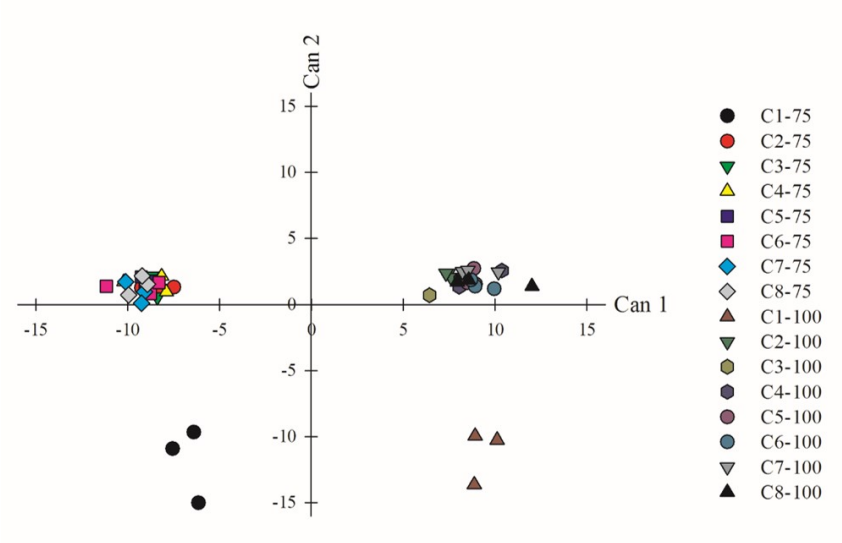
Table 8. Eigenvalues and total canonical structure of sixteen combinations of polymer-fertilizer-irrigation, using eleven agronomical productive traits.

Trait	CAN1	CAN2	CAN3
Eigenvalue	114.9053	28.8945	1.8823
Percentage of variance (%)	0.7771	0.1954	0.0127
Cumulative variance (%)	0.7771	0.9725	0.9852
P>F	<0.0001	0.0061	0.9934
Plant height (PH)	**0.709457**	0.224453	**0.417117**
Stem diameter (SD)	**0.508669**	0.253093	-0.329648
Fruit number (FN)	-0.037961	**0.668873**	0.075836
Fruit yield production (FYP)	0.102252	**0.324625**	0.162907
Individual Fruit Weight (IFW)	0.139449	**0.320154**	0.143672
Branches Total Production (BTP)	**0.514872**	**0.359068**	0.342618
Polar diameter (PD)	0.161117	0.124448	-0.114961
Equatorial diameter (ED)	-0.147925	0.175686	-0.31308
pH	-0.195012	-0.082508	0.333015
Brix degrees (Brix)	-0.148159	-0.065686	0.096034
Firmness (Fir)	0.078341	0.098263	0.04668

The two-dimensional diagram obtained from the canonical analysis shows the effect of the irrigation factor on the different combinations. Two large groups are observed: on the positive side of CAN1 are the combinations with 100% irrigation, which had an effect on pH, SD, and BTP; while on the negative side, it was observed that the combinations with 75% irrigation had an effect on FN, FYP, IFW, and BTP.

In CAN2, all combinations that included polymer are delimited on the positive side; while on the negative side are the combinations without polymer (controls).

The combinations with polymer showed higher values than the controls in both irrigation regimes for the variables evaluated (Figure 8).



Conclusion

The results obtained indicate that the combination C8-100 (30% polymer, 100% fertilizer and 100% irrigation) was the best treatment to produce tomato, but statistically equal to the combination of C8-75 (30% polymer, 100% fertilizer and 75% irrigation), and C6-100 (20% polymer, 100% fertilizer and 100% irrigation). These combinations positively affected plant growth, stem diameter, number of bunches, number of fruits, and yield per plant, which was corroborated by the canonical discriminant analysis that denoted the lowest values in the combinations where no polymer was applied and revealed the dominant effect of the irrigation factor.

Sincerely

Dr. Enrique González Pérez
Technical Project Manager