

LEAF AREA AND YIELD OF *Physalis angulata* L. AS A FUNCTION OF POPULATION DENSITY AND SLOW-RELEASE UREA

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ABSTRACT

The genus *Physalis* includes species used for food, medicinal and artisanal purposes. The wild tomato (*Physalis angulata* L.), which is common in the mixed maize cultivation called “the milpa”, is cultivated in some localities of Jalisco because of its importance in the preparation of sauces. It is hypothesized that the management of planting density and fertilization application can improve the yield of this tomato. The objective of this study was to evaluate the leaf area and yield of *P. angulata* L. as a function of slow-release urea doses and planting densities, under open-field rainfed conditions. Nine treatments were evaluated, resulting from the combination of three planting densities and three fertilizer doses. The experimental design was randomized complete blocks with factorial arrangement. The data were analyzed with analysis of variance and the means of the treatments were compared with Tukey’s test ($p \leq 0.05$). The relationship between yield and study variables was estimated with simple linear regressions. The results indicated that with 2.5 plants m^{-2} the highest yield was obtained (6.4 Mg ha^{-1}); while with 140 units of slow-release urea the average yield was 5.76 Mg ha^{-1} . The interaction effect showed that with densities of 2.0 and 2.5 plants m^{-2} and with 120 kg of slow-release urea, the highest fruit yields were obtained, 6.44 and 6.87 Mg ha^{-1} . For each unit increase in the variables leaf area, leaf area index, number of fruits per plant and fruit weight per plant, fruit yield increased as well. The yield of *P. angulata* responded differently to planting densities and slow-release urea doses. The best yield could be obtained with the planting density of 2.5 plants m^{-2} and with the application of 30.4 g m^{-2} slow-release urea.

Keywords: growth, planting density, slow-release urea, field tomato, *Physalis angulate* L., yield.

INTRODUCTION

The centers of origin of agriculture and domestication help the evolution of local varieties, based on a history of use and management of native and cultivated species (Vargas *et al.*, 2016). The genus *Physalis* in Mexico includes wild and domesticated plants producing fruits that have medicinal, ornamental, forage, artisanal, ceremonial, and industrial use. As well as plant traps and edibles, such as fruit, sauces, *quelites* and other culinary applicabilities (Puente *et al.*, 2011; Rengifo and Vargas, 2013).

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Species of the genus *Physalis* are concentrated in Mexico in the Sierra Madre Occidental, Sierra Madre del Sur and the Trans Mexican Volcanic Belt. *P. angulata* is distributed throughout most of the country, except for the Baja California peninsula, and is found in greater abundance in Jalisco, Tabasco and Chiapas (López-Sandoval *et al.*, 2015).

Physalis angulata L. is a native germplasm planted as a vegetable in western Mexico (Valdivia *et al.*, 2016), and represents an alternative crop to the husk tomato (*Physalis ixocarpa* Brot. ex Hornem.) (Vargas *et al.*, 2016). This wild species in Mexico is known as “milpero” tomato and it is an option for subsistence agriculture for small producers, since it represents a source of economic income, due to a high commercial value and possibilities of cultivation in reduced agricultural surfaces (Junior *et al.*, 2017). Yet, this wild tomato is not sufficiently evaluated from an agronomic point of view to increase the yield and value of the species as a horticultural crop.

The proper management of plant nutrition, through the timely application of fertilizers, is part of the production process that, in combination with other factors, promotes increased yield and crop quality (Ramos *et al.*, 2002). The influence of different concentrations of nitrogen (N) on the growth and production of *P. angulata* L. was evaluated in a hydroponic system. The results showed that with the highest level of N in the nutrient solution (224 mg L⁻¹) plant height, fruit production, and total N accumulation in leaf and stem increased compared to the control (Da Silva *et al.*, 2017). In *Physalis peruviana* L. and *Physalis pubescens* L., different amounts of nitrogen were evaluated; it was observed that 250 and 350 kg ha⁻¹ increased fruit yield and biomass per plant (Junior *et al.*, 2017). Golubkina *et al.* (2018) found that in organic management of *P. angulata* cultivars Konditer 1 and Konditer 2 showed high yield potential with values of 11.3 and 11.0 Mg ha⁻¹ in that order; due to the increase in plant biomass that influenced the higher fruit weight.

The use of urea as a fertilizer has the advantage of providing a high nitrogen content (46%), which is essential for plant nutrition. The main drawback of this fertilizer is the loss of nitrogen (N) in the form of ammonia (NH₃), coming from decomposition when applied to the soil (Morales-Morales *et al.*, 2019).

Slow-release fertilizer has a coating or microencapsulation that makes it different from conventional fertilizer. This coated fertilizer is a semi-permeable material, which controls water penetration, releases the most soluble nutrients that plants use according to their needs and reduces losses by volatilization after the hydrolysis phase and by leaching after ammonium nitrification (Shavit *et al.*, 2013; Morales-Morales *et al.*, 2019).

Nitrogen fertilization should consider agronomic and environmental aspects to increase plant yield and contribute to less pollution of agricultural systems and make them more sustainable (Constanza *et al.*, 2015). Slow-release fertilizers integrate these two visions and the application of this type of fertilizer is expected to increase the yield of *P. angulata* under rainfed conditions.

In order to determine the plant population and the appropriate distance between individuals, detailed studies of plant growth are very useful as they allow the quantitative assessment of the duration of the cycle, definition of developmental

stages, and distribution of photoassimilates by organs (Azofeifa and Moreira, 2004). Husk tomato (*P. ixocarpa* Brot. ex. Hornem.) is a species close to *P. angulata*, since they belong to the same taxonomic section; in the cultivated species it was found that in field conditions the adequate population density is 20 750 plants ha⁻¹, which was achieved with rows separated at 1.20 m width and 0.40 m between plants (Peña *et al.*, 2014). This research proposes to find more adequate planting densities for the growth and development of a native wild tomato, under the hypothesis that the management of planting density and fertilization with slow-release urea can improve crop yield. Then, the objective of this study was to evaluate the leaf area and yield of *Physalis angulata* L. under rainfed conditions, as a function of planting density and different doses of slow-release urea.

MATERIALS AND METHODS

Location of the experimental site

The experiment was conducted in 2018 under rainfed conditions at the Centro de Investigación y Estudios Avanzados en Fitomejoramiento, which is located at 19° 24' N, 99° 54' W, and 2611 m altitude. The climate is temperate sub-humid, with average annual temperature 12.8 °C. Annual rainfall is 900 mm, with rains in summer, and less than 300 mm in winter.

Crop management

Physalis angulata seed was sown (April 6, 2018) in polystyrene trays with 200 cavities with peat (70%) and Agrolite® (30%) as substrate. At transplanting, the root system of the seedling was immersed in a rooter commercially identified as Rooter QF (indolbutyric acid, indolacetic acid, naphthalacetic acid, nicotinamide and fulvic acid) to stimulate root growth and plant adaptation to field conditions. This activity was made when plants had two pairs of expanded leaves, 35 days after planting (dds). The initial level of nitrogen in the soil where the crop was transplanted was 0.16% of total N; this indicated medium nitrogen availability (FAO, 2013). As base fertilization in pure form, 80 kg of triple calcium phosphate (P₂O₅) and 120 kg of potassium chloride (K₂O) were applied manually at the time of transplanting (Vargas *et al.*, 2016). To prevent fungal incidence, Mancozeb 80% PH was sprayed at a dose of 1 kg ha⁻¹ every 7d, and weed control was manual.

Experimental design and variables evaluated

To contrast the treatments, a randomized complete block design was used with four replications in a factorial arrangement that included three planting densities as treatments: 3.3, 2.5 and 2.0 plants m⁻² and three nitrogen levels: 21.7, 26.1 and 30.4g m⁻², as a source of slow-release urea (46% N) equivalent to 100, 120 and 140 units of nitrogen ha⁻¹.

Each experimental unit (treatment) consisted of 5 furrows. The distance between furrows was 1m. The distance between plants was 0.30m, 0.40m and 0.50m, for each

of the planting densities. Each treatment consisted of a plot of 10m² (5×2m), where the useful plot was 3m² (3×1m).

The harvest period started at 99d after transplanting (ddt) until 120ddt, when four cuttings were made and samples of five plants per treatment were taken to evaluate the following variables. Leaf area (AF, cm²) was estimated with a LI-COR 3100 integrator (Lincoln, Nebraska, USA) without including the petiole. Leaf area index (IAF) was calculated with the AF, plant density m⁻² (DP) and area sown (AS), with the ratio:

$$IAF = \frac{(AF)(DP)}{AS}$$

In addition, the number of fruits per plant (NFP), fruit weight (PF, g) and yield (REN, Mg ha⁻¹) were recorded for every sample. All the variables evaluated were added for each of the cuttings during the harvest period to obtain a cumulative value in the end.

Statistic analysis

With the data collected, an analysis of variance was performed; where statistical variation was detected, the Tukey test for comparison of means ($p \leq 0.05$) was performed in SAS® (SAS Institute, 2004). In the case of the interaction, Tukey's test was applied as follows:

$$Tukey = q_t.Nt \alpha \sqrt{\frac{CME}{n}}$$

where N is the total number of observations, t is the number of factor levels, n is the sample size of each factor level, CME is the mean square of the error, q_t , Nt is the Student's interval distribution of the variables in the t groups and $N-t$ degrees of freedom, with a probability of error.

To explain the increase in REN and the variables AF, IAF and NFP, the corresponding linear regression were estimated.

RESULTS AND DISCUSSION

Analysis of variance

The differences between planting density (D) and slow-release urea (U) were significant for all variables, except number of fruits per plant for the factor (U). The D×U interaction was significant for leaf area and fruit yield. Coefficients of variation were low and ranged from 3.02 to 4.79% for fruit weight and yield (Tables 1 and 2).

Planting density

The number of plants ha⁻¹ determines the leaf area of the cultivated plants. Leaf area is a key variable for determining growth indices and predicting biomass production, radiation use efficiency and yield potential (Ali and Singh, 2017).

Table 1. Analysis of variance and comparison of means for the variables leaf area (AF), leaf area index (IAF), number of fruits per plant (NFP), fruit weight (PF) and fruit yield (REN), for the factors planting density (D) and slow-release urea (U) in *Physalis angulate*, Summer 2018.

Factor (variable independiente)	AF (cm ²)	IAF	NFP	PF (g)	REN (Mg·ha ⁻¹)
Densidad de plantación (D)	†	†	†	†	†
D1 (3.3 m ²)	1885 c	0.62 c	48.4 b	2.80 c	4.48 c
D2 (2.5 m ²)	4926 b	1.23 a	60.44 a	4.23 b	6.41 a
D3 (2.0 m ²)	5721 a	1.14 b	62.11 a	4.49 a	5.58 b
Tukey ($p \leq 0.05$)	202.5	0.05	4.27	0.19	0.42
Urea de liberación lenta (U)	†	†	ns	†	†
U1 (100 kg ha ⁻¹)	3868 b	0.93 c	55.22 a	3.70 b	5.11 b
U2 (120 kg ha ⁻¹)	4232 a	1.01 b	58.44 a	3.83 ab	5.60 a
U3 (140 kg ha ⁻¹)	4431 b	1.06 a	57.33 a	4.00 a	5.76 a
Tukey ($p \leq 0.05$)	202.5	0.05	4.27	0.19	0.42
D×U	¶	ns	ns	ns	¶
CV (%)	3.04	3.03	4.70	3.02	4.79

Mean values of treatments with different letter per column within each study factor indicate statistical difference ($p \leq 0.05$). CV: coefficient of variation. Statistical differences at [†] $p \leq 0.01$, [¶] $p \leq 0.05$ and ns, no statistical difference. D×U= interaction between planting density and slow-release urea.

Table 2. Analysis of variance of the variables leaf area (AF), leaf area index (IAF), number of fruit plant⁻¹ (NFP), fruit weight (PF) and fruit yield (REN), for the factors planting density (D) and slow-release urea (U) in *Physalis angulate*, Summer 2018.

Fuente de variación	GL	AF (cm ²)	IAF	NFP	PF (g)	REN (Mg·ha ⁻¹)
Bloques	3	3774090 ^{ns}	0.201 ^{ns}	39.92 ^{ns}	0.312 ^{ns}	2.043 [¶]
Urea de liberación lenta (U)	2	6584200 [†]	0.350 [†]	31.94 ^{ns}	0.625 [†]	1.303 [†]
Densidad de plantación (D)	2	98377000 [†]	2.606 [†]	1335.93 [†]	19.716 [†]	22.479 [†]
U×D	4	6546970 [¶]	0.233 ^{ns}	118.55 [†]	0.141 ^{ns}	1.288 [¶]
Error experimental	24	14007700	0.748	119.17	1.322	2.728
Total	35	121190000	4.068	1698.52	21.518	28.441

Statistical differences at [†] $p \leq 0.01$, [¶] $p \leq 0.05$; ns, no statistical difference.

In this research for *P. angulata*, planting density influenced fruit yield; with 2.5 plants m⁻² a production of 6.41 Mg ha⁻¹ was achieved, which was due to the higher average in IAF and NFP variables (Table 1). López-Sandoval *et al.* (2018) found similar results when they evaluated the net assimilation rate in wild genotypes of *Physalis* in two locations in the State of Mexico, *P. angulata* achieved on average a fruit production of 6.04 Mg ha⁻¹.

In another research, yield and fruit quality of *P. angulata* were estimated at a density of 2.5 plants m⁻², where cultivars 'Violet', 'Karolek', 'Lakomka', 'Lezhky', 'Konditer 1' and 'Konditer 2' reached yields that fluctuated between 7.7 ('Lezhky') and 11.3 Mg ha⁻¹ ('Konditer' 1) (Golubkina *et al.*, 2018). Jimenez *et al.* (2012) stated that the factors contributing to low yields in the cultivation of wild species of the genus *Physalis* are the use of genotypes with little genetic improvement. The great diversity of wild *Physalis* species existing in Mexico such as *P. angulata* offers an opportunity for agronomic studies, for the adaptation of this species and the use of increasingly valued genetic material, which can increase yield as well, diversifying food sources (Cobaleda *et al.*, 2013).

Another study conducted by Ponce *et al.* (2012), where they assessed the effect of planting and pruning density on husk tomato (*P. ixocarpa*) under greenhouse conditions, found that fruit yield was 10.6 Mg ha⁻¹ with a planting density of 18 plants m⁻². In Russia, they obtained 0.0058 Mg ha⁻¹ of fruit with a stocking density of 4 plants m⁻² (Naumova *et al.*, 2019) in *P. ixocarpa* under open field conditions. Previous studies indicated a trend in the cultivated species *Physalis ixocarpa*, the higher the population density, the higher the yield increased. In *Physalis angulata*, the subject of this research, there was an increase in yield with the intermediate planting density.

Slow-release urea

Slow or controlled release fertilizers supply nutrients to the plant over an extended period of time. This allows reducing the number of applications and fertilizer units. Adequate levels of nitrogen are maintained in the soil throughout the plant development cycle; therefore, losses are minimized, also excess or deficiency, which are characteristic in other more traditional forms of application, is avoided (Morales-Morales *et al.*, 2019).

In *P. angulata*, an increase in yield would be explained by the increase in slow-release urea. With the application of 26.1g m⁻² urea (120kg N ha⁻¹) and 30.4g m⁻² (140kg ha⁻¹), respective yield values of 5.6 Mg ha⁻¹ and 5.76 Mg ha⁻¹ were obtained (Table 1). In the first case, the NFP was influenced by NFP, and in the second by PF. With an increase in NFP and PF, yield increased (Table 1). López-Sandoval *et al.* (2018) added 200 kg N ha⁻¹ of conventional urea to different *Physalis* species and found that yield ranged between 2.73 Mg ha⁻¹ (*P. microcarpa*) and 14.73 Mg ha⁻¹ (*P. ixocarpa*). In this study, it was also observed that *P. angulata* produced 7.1 Mg ha⁻¹ of fruit in Texcoco, Mexico (López *et al.*, 2018). Silva *et al.* (2015) found in Colombia that the yield of *P. peruviana* (cape gooseberry) in response to nitrogen fertilization doses was 3.01, 3.48 and 4.49 Mg ha⁻¹ with 80, 150 and 300 kg of urea ha⁻¹, in that order; a lower yield compared to *P. angulata* in this study. In another study on nitrogen demand in *Physalis ixocarpa*, it was observed that in order to obtain a yield of 2.16kg of fruit per plant, the nitrogen demand was 8.03g in the total aerial biomass, which is equivalent to 3.71kg of N per Mg of fresh fruit (Castro-Brindis *et al.*, 2004).

In another research, when evaluating different sources of nitrogen fertilizers in basil (*Ocimum basilicum* L.), it was found that organic fertilizers caused changes in soil

porosity, producing nitrogen leaching. Fast-release fertilizers (calcium nitrate, and ammonium sulfate) performed better for foliar dry mass, foliar nitrogen and apparent recovery efficiency; whereas slow-release fertilizers (coated urea, vermicompost, and poultry manure) did so for soil properties, with efficiency in nutrient utilization and water use (Daza-Torres *et al.*, 2018). Slow-release fertilization promotes increased yields in cultivated and wild species, as it was demonstrated in this research with the native milpero tomato *P. angulata*.

Interaction of planting density with slow-release urea (D×U)

The use of two factors to increase crop yield, in this case planting densities and doses of slow-release urea, is an alternative to generate greater growth and quantity of photo-assimilates by the species (Morales-Morales *et al.*, 2019). With the density of 2 plants m^{-2} (D3) and 140 nitrogen units per hectare, the largest leaf area was attained with 6036 cm^2 per plant (Figure 1). In cape gooseberry (*P. peruviana*), leaf area is an indicator of higher photosynthetic activity, which is expressed in a higher yield (Aguilar-Carpio *et al.*, 2018). It is likely that higher values in both leaf number and leaf area are the result of greater nutrient availability, which favors growth and biomass production (Hawkesford *et al.*, 2012).

The dose of nitrogen applied at each planting density directly influenced fruit yield (Figure 2). At densities D2 and D3 with 120 $kg N ha^{-1}$, the maximum yields 6.44 and 6.87 $Mg ha^{-1}$ were obtained, suggesting that this amount of slow-release urea and at those planting densities were adequate. When evaluating yield in different *Physalis* species, López-Sandoval *et al.* (2018) found that with densities of 4.2 plants m^{-2} with

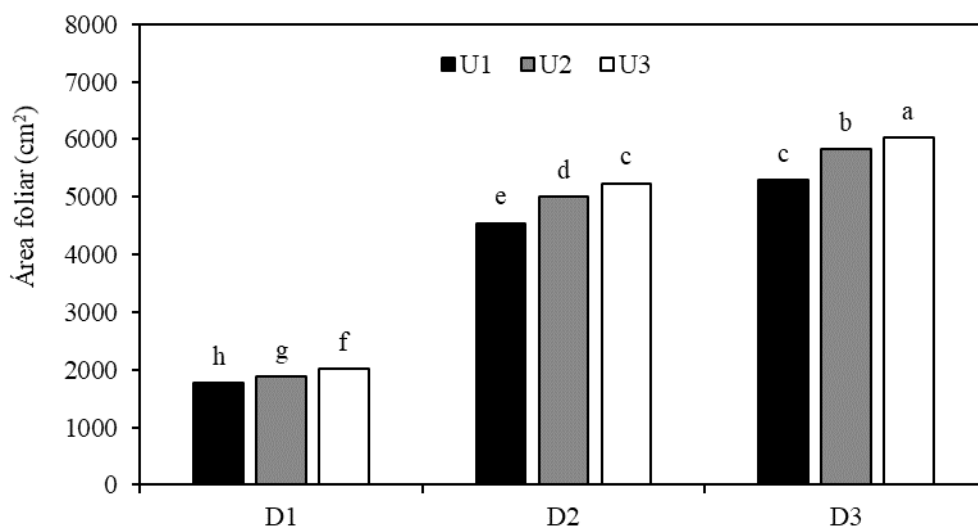


Figure 1. Leaf area of *Physalis angulata* in response to the interaction planting density and slow-release urea (D×U) dose during Summer 2018. Means with different literals indicate statistical difference (Tukey, $p \leq 0.05$). D, planting density. (D1: 3.3 m^{-2} ; D2: 2.5 m^{-2} ; D3: 2.0 m^{-2}). U, slow-release urea (U1: 100 $kg ha^{-1}$; U2: 120 $kg ha^{-1}$; U3: 140 $kg ha^{-1}$).

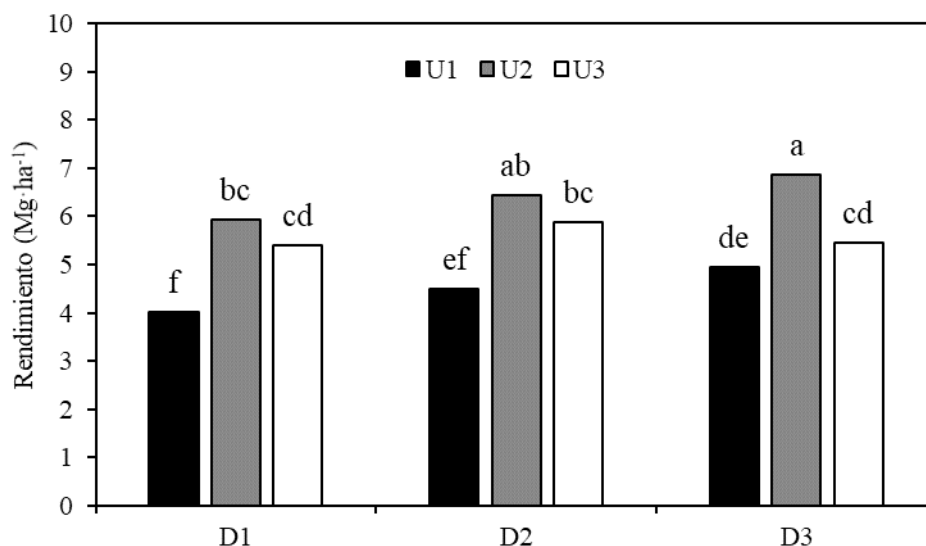


Figure 2. Fruit yield of *Physalis angulata* in response to the interaction between planting density and slow-release urea (D×U) dose during Summer 2018. Means with different literals indicate statistical difference (Tukey, $p \leq 0.05$). D, planting density (D1: 3.3 m²; D2: 2.5 m²; D3: 2.0 m²). U, slow-release urea (U1: 100 kg ha⁻¹; U2: 120 kg ha⁻¹; U3: 140 kg ha⁻¹).

200kg N ha⁻¹ (in the form of conventional urea) in Texcoco, Mexico a maximum of 7.0 Mg ha⁻¹ was obtained in *Physalis angulata*. Silva *et al.* (2015) reported 4.49 Mg ha⁻¹ in *Physalis peruviana*, where the best treatment was 300 (N)-150 (P)-300 (K), with 1.6 plants per m² in the Altiplano de Pasto, Colombia.

Relationship between yield and the variables leaf area, leaf area index, number of fruits per plant and fruit weight

Vegetative and reproductive growth in cape gooseberry (*P. peruviana* L.) develops during most of the life cycle simultaneously, therefore, leaf traits such as leaf area and leaf area index are important in the photosynthetic action of the plant, which is reflected in higher crop yield (Ali and Singh, 2017).

In this study on *P. angulata*, the regression lines between yield and leaf area (0.55) and leaf area index (0.79) obtained (Figures 3A and 3B) show significant coefficients of determination. The REN=1397.6 (FA)-3498.3 indicates that for each unit increased in yield the amount of AF increased by 2100.7 (cm²). These figures show that as leaf area increases, leaf area index increases, and as a consequence fruit yield also increases. López-Sandoval *et al.* (2018) found a positive trend between leaf area and fruit yield in species other than *Physalis*; because as the value in leaf area increased, fruit yield also increased. Fischer *et al.* (2014) reported that there was an increase in fruit yield in *P. peruviana* due to a higher length development of branches and consequently a high leaf area index (IAF of 8) under greenhouse conditions.

The regression lines between yield and fruit number (0.70) and fruit weight (0.64) obtained (Figures 3C and 3D) show significant coefficients of determination. The

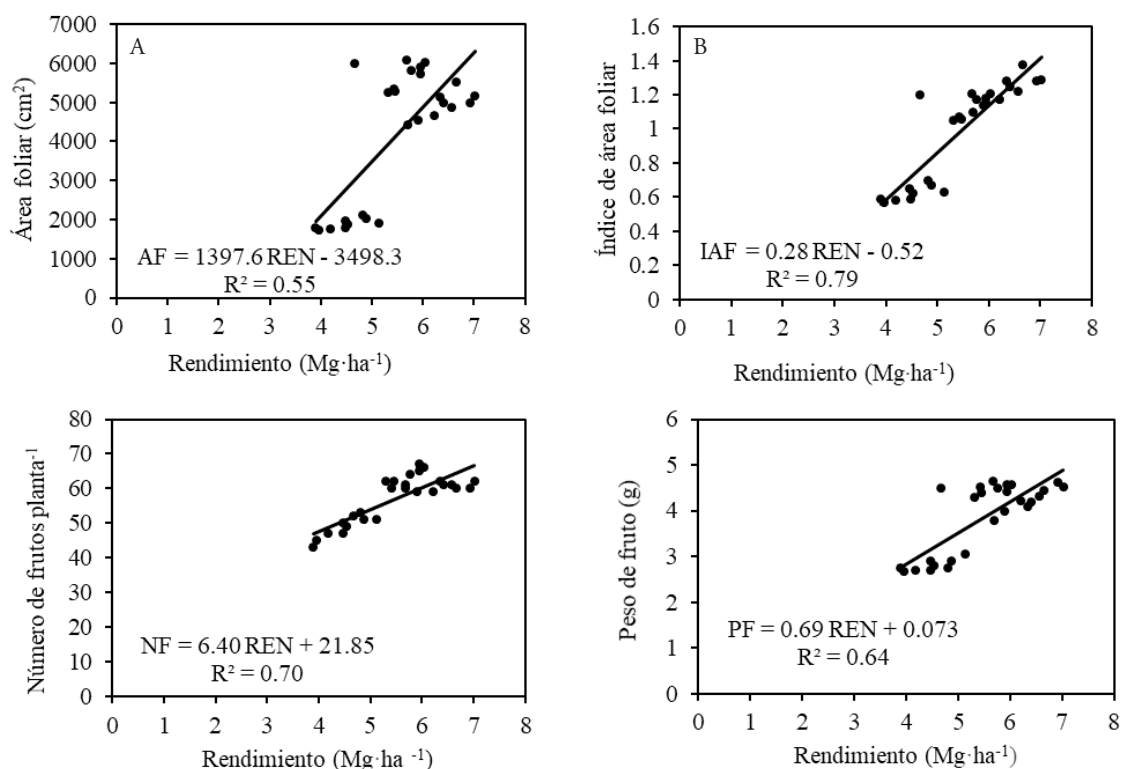


Figure 3. Relationship between yield and A, leaf area; B, leaf area index; C, number of fruits per plant; and D, fruit weight. AF, leaf area. IAF, leaf area index. NF, number of fruits. PF, fruit weight in *Physalis angulata*.

$REN=0.69 (FP)+0.073$ indicates that for each unit increased in yield, the amount of PF increased by 0.763 (g). In those figures, it is observed that as the value of these variables increased the yield also increased. Golubkina *et al.* (2018) confirmed the yield increase with the increase in the number and weight of fruits, observing that in *P. angulata* with 53 fruits and 8g per plant, the cultivar 'Konditer 1' expressed maximum yield, 11.3 Mg ha⁻¹.

CONCLUSIONS

The milpero tomato (*Physalis angulata*) obtained the highest yield with the maximum application of slow-release urea. The highest yield was obtained at a planting density of 2.5 plants m⁻². Leaf area, leaf area index, number of fruits per plant and fruit weight per plant positively affected yield. For each unit of increase in these variables, an increase in fruit yield was obtained. The regression lines between yield and fruit number (0.70) and leaf area index (0.79) showed significant coefficients of determination.

This study found that it is possible to increase the yield of this native wild tomato. Therefore, the species *P. angulata* is a valid proposal to expand the diversification of horticultural crops, and another alternative in traditional cooking.

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