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Organic yellow passion fruit productivity due to irrigation, semi protected cultivation and artificial pollination

Nilciléia Mendes da Silva[1], Sebastião Elviro de Araújo Neto[2], Luís Gustavo de Souza e Souza[3], Thays Lemos Uchôa[4], Wagner de Moura Francisco[5], Regina Lúcia Félix Ferreira[6]

Abstract – This study aimed to evaluate the effect of the combination between irrigation, semi-protected cultivation, and artificial pollination on the yield, number of fruits, and mass of yellow passion fruit grown under organic production. The experimental design was in randomized blocks set up in split plots (2x2x2) with eight treatments and four replications. The plot consisted of irrigation or rainfed conditions, the second factor corresponds to plant cover with plastic or direct sunlight, and the third factor refers to natural or artificial pollination. Irrigation was performed using a micro-sprinkler system, and pollination was either manual or natural (entomophilous). The evaluated parameters were the number of fruits per plant, the mean fruit mass, and the total and commercial yields in two crop years: from January to August 2019 and from September 2019 to August 2020. The yield per hectare and the number of fruits per plant were not affected by irrigation and semi-protected cultivation. Artificial pollination increased the passion fruit yield by up to 31% under organic cultivation. The number of fruits per plant did not significantly change with the treatments. However, there was a positive linear correction with the yield. The mean fruit mass is higher using the combination between semi-protected cultivation, rainfed conditions, and artificial pollination or direct sunlight with natural pollination regardless of irrigation.
Index Terms: Plant science. Fruit farming. Carpenter bees. *Passiflora edulis* Sims.

Produtividade de maracujá-amarelo orgânico em função da irrigação, cultivo semiprotegido e polinização artificial

Resumo – Objetivou-se avaliar o efeito da combinação dos fatores irrigação, cultivo semi protegido e polinização artificial sobre a produtividade, número e massa de fruto do maracujazeiro-amarelo em sistema orgânico de produção. O delineamento experimental foi em blocos casualizados em parcelas divididas (2x2x2), com oito tratamentos e quatro repetições. A parcela constituiu-se em irrigação ou sequeiro; o segundo fator corresponde à cobertura com plástico, ou pleno sol, e o terceiro, à polinização, natural ou artificial. A irrigação foi do tipo microaspersão, e a polinização manual ou natural (entomófila). Avaliaram-se o número de frutos, por planta; a massa média de frutos e a produtividade total e comercial, em duas safras: de janeiro a agosto de 2019 e de setembro de 2019 a agosto de 2020. A produtividade por hectare e o número de frutos por planta não são afetados pela irrigação e pelo cultivo semiprotegido, e a polinização artificial aumenta em até 31% a produtividade do maracujazeiro em sistema orgânico de produção. O número de frutos por planta não alterou significativamente com os tratamentos, porém teve correção linear positiva com a produtividade. A massa média dos frutos é maior na combinação de cultivo semiprotegido, sequeiro e polinização artificial ou em pleno sol com polinização natural, independentemente de ser irrigado.
Termos para indexação: Fitotecnia. Fruticultura. Mamangava. *Passiflora edulis* Sims.

Corresponding author:
selviro2000@yahoo.com.br

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[1]Agronomist, PhD in Plant Production, Federal University of Acre, Rio Branco-Acre, Brazil. E-mail: nilcileia-ac@hotmail.com (ORCID 0000-0002-1484-3717)

[2]Agronomist, PhD in Plant Science, Professor at the Federal University of Acre, Rio Branco-Acre, Brazil. E-mail: selviro2000@yahoo.com.br (ORCID 0000-0002-1212-4989)

[3]Agronomist, PhD Student in Plant Production, Federal University of Acre, Rio Branco-Acre, Brazil. E-mail: gustavo_souza_fj@hotmail.com (ORCID 0000-0001-8855-5163)

[4]Agronomist, PhD in Plant Production, Senar-AC extensionist, Rio Branco-Acre, Brazil. E-mail: thays_uchoa@hotmail.com (ORCID 0000-0002-2176-8495)

[5]Agronomist, PhD in Plant Production, Acre Prosecutor Analyst, Rio Branco-Acre, Brazil. E-mail: wagnerdemoura@outlook.com (ORCID 0000-0001-9987-5891)

[6]Agronomist, PhD in Plant Science, Professor at the Federal University of Acre, Rio Branco-Acre, Brazil. E-mail: reginalff@yahoo.com.br (ORCID 0000-0003-2401-4995)

Introduction

Brazil is the largest yellow passion fruit producer and consumer worldwide (*Passiflora edulis* Sims), producing 690,360 tons in a harvested area of 46,436 hectares and achieving a mean yield of 14.9 t ha^{-1} (IBGE, 2021).

Passion fruit flowers and fructifies in mixed branches, showing continuous growth under adequate edaphoclimatic conditions (SOUZA et al., 2012). In tropical regions, e.g., Acre, Brazil, this species can produce fruits during most of the year with continuous growth and floral production under temperatures above 23 ºC and a photoperiod ≥ 11.8 h during nine months (UCHÔA et al., 2021b).

Despite the low yield obtained in the state of Acre (8.9 t ha^{-1}) (IBGE, 2021), passion fruit has significant social and economic importance since its cultivation is mainly performed by family farmers motivated by the rapid economic return, high profitability, and well-distributed income obtained with this crop throughout the year (SILVA et al., 2020; UCHÔA et al., 2021a).

In this scenario, yellow passion fruit is a self-incompatible plant that depends on cross-pollination for fructification (FALEIRO et al., 2019). Carpenter bees (*Xylocopa* spp.) are considered the effective natural pollinators of this crop due to their morphology and behavioral characteristics (LAGE et al., 2018; SILVEIRA et al., 2012).

Even with optimum environmental conditions for flowering, low natural pollination rates may still occur even if the production area is close to native vegetation, including organic cultivation systems (ARAÚJO NETO et al., 2014; FRANCISCO et al., 2020; GALVÃO et al., 2020; REZENDE et al., 2017; SILVA et al., 2019; UCHÔA et al., 2018 & 2021b). Therefore, artificial pollination is indispensable for passion fruit cultivation, especially in areas with large populations of *Trigona* bees (*Trigona* spp.), western honey bee (*Apis mellifera*), and other wild bees that harm flowers and/or steal pollen (JUNQUEIRA et al., 2013; MASCARELLO et al., 2019).

Another problem for passion fruit cultivation in Acre is the drought period from May to September (INMET, 2020). This period shows water deficit and causes a decline in passion fruit production under rainfed farming conditions (SILVA et al., 2019; UCHÔA et al., 2021b), even preventing the recovery from water stress, which compromises the next crop seasons (GALVÃO et al., 2020). However, under prolonged drought conditions, irrigation reduces the effects of water deficit and increases the yield and profitability of this crop (CAVALCANTE et al., 2020; UCHÔA et al., 2021a; UCHÔA et al., 2021b).

On the other hand, the intense rainfall during flowering peaks compromises pollination due to the absence of carpenter bees and the hygroscopic character of pollen grains, which may burst in high-moisture environments. Therefore, in order to minimize meteorological effects, fruit farming also employs technologies such as protected cultivation, protecting plants from direct solar radiation and excessive rainfall. As a result, in the case of passion fruit, the integrity of pollen grains is maintained, thus increasing fertilization and fruit production (KOETZ et al., 2010). After pollination, the stigmas should remain dry for at least two hours to allow fecundation (BRUCKNER; PICANÇO, 2001). Although artificial pollination, semi-protected cultivation, and irrigation increase production costs, these techniques can increase crop yield and profitability, as observed by Uchôa et al. (2021a) with irrigation and growing input levels.

From this perspective, this study aimed to evaluate the effect of micro-sprinkler irrigation, semi-protected cultivation, and artificial pollination on the yield, the number of fruits, and the fruit mass of yellow passion fruit under organic cultivation.

Material and methods

The experiment was conducted at the Seridó Ecological Station in Rio Branco, Acre, located at the following coordinates: 9º 53' 16'' S and 67º 49' 11'' W, at an elevation of 170 m above sea level.

The soil of the area is classified as a Plinthic Lithic RED YELLOW ULTISOL without apparent erosion, slightly undulating topography, and moderate drainage. The chemical attributes of the soil layer from 0 cm to 20 cm are as follows: pH = 6.3; P = 1.0 mg.dm^{-3}; K = 1.1 mmolc.dm^{-3}; Ca = 24 mmolc.dm^{-3}; Mg = 11 mmolc.dm^{-3}; Al+H = 31 mmolc.dm^{-3}; M.O. = 17 g.dm^{-3}; SB = 36.1 mmolc.dm^{-3}; CEC = 67.1 mmolc.dm^{-3}; V = 53.8%; Ca/Mg = 2.18; and Mg/K = 10.0.

The climate is hot, humid, and classified as *Am* according to the Köppen classification, with mean annual temperatures around 24.5 ºC, relative air humidity of 84%, and annual rainfall ranging from 1,700 mm to 2,400 mm (INMET, 2020).). Local meteorological data for the experiment are shown in Figure 1.

The experimental design was in randomized blocks and set up in a factorial arrangement with split plots (2 x 2 x 2) corresponding to eight treatments and four replications, with four plants per experimental unit. Each plot consisted of irrigated or rainfed cultivation, in which the two other factors were distributed: cultivation environment (semi-protected or direct sunlight) and pollination (artificial or natural).

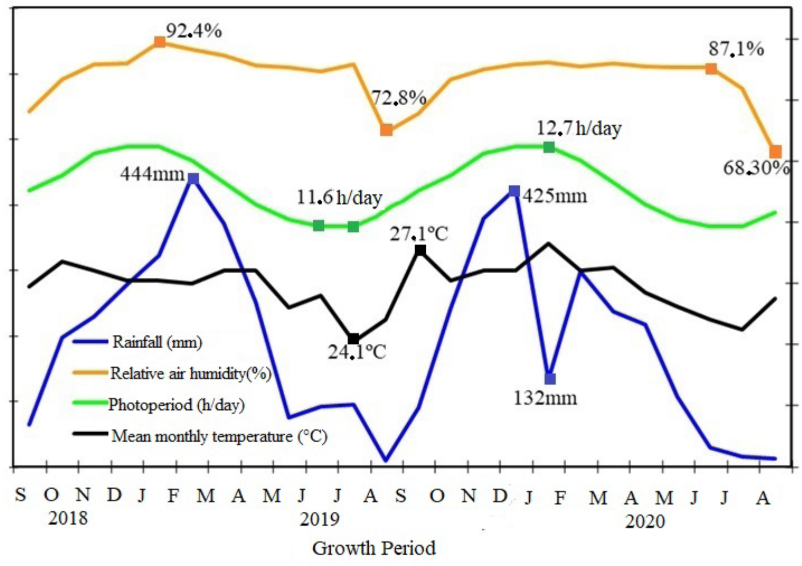

Figure 1. Rainfall (mm), relative air humidity (%), mean monthly temperature (°C), and photoperiod (h/day) during the experimental period. Rio Branco, AC, Brazil, 2018 to 2020. Source: Inmet (2020).

The passion fruit cultivar used in the experiment was an F4 variety of public domain formed by genotypes 2, 22, 23, 35, 37, 33, and 20 from Viçosa (MG, Brasil), the State University of Northern Rio de Janeiro (Campos dos Goytacazes, RJ, Brazil), and the municipalities of Brasiléia and Rio Branco (AC, Brasil) (NEGREIROS et al., 2008).

Seedling production occurred from May to September 2018 in a plant nursery covered with a 100 μm transparent plastic film and a 50% shading screen on the sides. The seeds were sown in 200-cell polystyrene trays and transplanted after emergence to 3-L plastic bags containing a substrate with the following composition: 33% soil, 33% organic compost, 33% ouricuri palm fiber (*Attalea phalerata*), 1.0 kg m^{-3} of dolomitic limestone, 1.5 kg m^{-3} of natural thermophosphate, and 1.0 kg m^{-3} of potassium sulfate.

The plants received irrigation twice a day, and the substrate was maintained within field capacity until the plants reached 1.5 m in height and had a mean base diameter of 4.76 mm, when they were then transplanted to the field in September 2018 at a spacing of 2.5 m between rows and 3.0 m between plants in the row, with evaluations until August 2020.

After the area was cleaned, planting holes 80 cm wide and 30 cm deep were opened with a motorized drill and fertilized with 20 L of organic compost, 500 g of limestone, and 200 g of thermophosphate.

After planting, the plants were conducted in a vertical trellis system using smooth wire no. 12 at the height of 2 m, whereas strings were used as trainers. The plants were monitored and thinned weekly to conduct them in a single stem (main branch). When exceeding 10 cm above the wire, the apex was cut so that the two shoots closest to the wire were conducted in opposite directions until they reached 1.5 m in length, the ideal condition for thinning. The tertiary branches that emerged from these were then conducted toward the soil and subsequently pruned at 20 cm from the ground to stimulate the emission of quaternary branches.

Two topdressing fertilization interventions were performed during crop formation: one 60 days after planting with 176.5 g $plant^{-1}$ of P_2O_5 and 88.2 g $plant^{-1}$ of K_2SO_4, and another 120 days after planting with 176.5 g $plant^{-1}$ of P_2O_5 and 88.2 g $plant^{-1}$ of K_2SO_4. In both applications, thermophosphate was used as the P source, whereas potassium sulfate was used as the K source.

Semi-protected cultivation was set up in the upper part of the trellis using a wooden structure and 100 m transparent plastic film (Figure 2).

Irrigation was performed using a micro-sprinkler system with one emitter per plant at a flow rate of 67.5 L h^{-1}. The moment of irrigation was defined by the soil water matric potential, measured with a tensiometer fixed at 0.15 m from the plant and at a depth of 0.20 m in the soil. When the value was close to 60 kPa, it indicated the moment when supplementary water had to be provided (DUTRA et al., 2018). The readings were performed daily using a digital reader.

Artificial pollination was performed daily between 1:00 p.m. and 5:00 p.m. with naked fingers. Before or during pollination, the plant anthers were collected so that the operator could pass the fingertips with pollen on the surface of the stigmas.

Source: Nilciléia Mendes da Silva

Figure 2. Plastic cover with the 100 µ transparent film. Seridó Ecological Station, Rio Branco, AC, Brazil, 2018-2020.

After topdressing fertilization, a mulch cover measuring 50 cm x 50 cm was laid at the base of the plants to prevent weeds and avoid constant hoeing and root cutting.

Passion fruit harvest was performed two to three times a week by collecting the fruits on the ground and the ripe fruits attached to the plants. All fruits that showed 55% of yellow peel color were considered ripe since, at this point, fruit quality is best preserved, and the shelf-life is extended (SANTOS et al., 2013).

The variables analyzed were the mean number of fruits per plant (NFP), obtained by the quotient between the total number of fruits in the plot and the number of plants; the mean fruit mass (MMF), determined by the quotient between the total fruit mass and the total number of harvested fruits; fruit yield, estimated for one hectare considering the fruit mass produced in the plot (30 m^2), with values estimated in kg ha^{-1} and considering the total and commercial yield after discarding the fruits without commercial standard. Cultivation continued for two years, and the first crop year occurred from January to August 2019, whereas the second crop year occurred from September 2019 to August 2020.

Statistical analysis was performed by checking the normality of errors by the Shapiro-Wilk test and the homogeneity of variances by the Bartlett test. Then, analysis of variance was performed, and the F-test was applied when differences were observed between two treatments ($p<0.05$). Finally, Pearson's linear correlation analysis was also performed.

Results and discussion

The total and commercial fruit yields in both crop years increased through artificial pollination and were not influenced by semi-protected cultivation and irrigation (Table 1).

The sum of the commercial yield values in the two crop years was 32.4 t ha^{-1} with artificial pollination but with a potential for 34.9 t ha^{-1} if considering the discarded fruits. The highest commercial yield in the second crop year was 24.2 t ha^{-1}, above the 2020 state and national means of 14.9 t ha^{-1} and 8.9 t ha^{-1}, respectively (IBGE, 2021). This value was also higher than the yield observed in two crop years under organic cultivation by Araújo Neto et al. (2014), Francisco et al. (2020), Silva et al. (2019), and Uchôa et al. (2021b), corresponding to 21.8 t ha^{-1}, 18.8 t ha^{-1}, 7.5 t ha^{-1}, and 17.4 t ha^{-1}, respectively.

The plants under artificial pollination produced 31% more commercial fruits than those that only received entomophilous pollination (Table 1), which was also confirmed by Krause et al. (2012) and Mascarello et al. (2019), who verified the effectiveness of artificial pollination in passion fruit. In this case, even with organic cultivation in a small passion fruit area with an adjacent forest and daily presence of carpenter bees, artificial pollination was more effective in increasing the yield.

Despite the lower yield obtained with natural pollination, this practice promoted high commercial fruit yields in the two crop years, with a mean value of 24.7 t ha^{-1} (Table 1). This result is attributed to the constant presence of carpenter bees in the cultivation environment (Figure 1). Furthermore, these species are considered efficient yellow passion fruit pollinators in Brazil (KRAUSE et al., 2012; LAGE et al., 2018; SILVEIRA et al., 2012). The increase in labor cost for artificial passion fruit pollination could be compensated by the increase in fruit mass and yield. Carvalho et al. (2010) recorded the maximum yield of 68,750 kg.ha^{-1} when using irrigation, protected cultivation, and artificial pollination. With organic cultivation, the minimum yield necessary to cover production costs is low, around 5.49 t ha^{-1}, including irrigation and artificial pollination (FRANCISCO et al., 2021), in addition to favoring job creation in the field and family income.

In this experiment, the constant presence of field pollinators is related to the preservation and conservation of the vegetation in the adjacent area, which is essential for organic production systems. According to Silveira et al. (2012), conserved natural landscapes can provide these pollinators with an adequate nidification environment and natural food sources during the absence of flowers.

Table 1. Commercial yield of the first and second crop years, total commercial yield, and total f passion fruit yield as a function of different cultivation arrangements. Seridó Ecologial Station, AC, Brazil, 2018 to 2020.

Pollination	Irrigated^{ns}		Rainfed^{ns}		
	Protected	Direct sunlight	Protected	Direct sunlight	Mean
Commercial yield 1st crop year (kg ha^{-1})					
Artificial	5.579	8.261	7.547	8.268	7.413 A
Natural	5.313	5.768	4.925	5.035	5.260 B
Irrigation C.V.: 48.9%; Experimental C.V.: 41.7%					
Commercial yield 2nd crop year (kg ha^{-1})					
Artificial	26.155	23.415	24.796	22.451	24.204 A
Natural	18.869	22.794	17.515	18.397	19.393B
Irrigation C.V.: 29.1%; Experimental C.V.:24.7%					
Total commercial yield (kg ha^{-1})					
Artificial	32.817	31.676	32.343	32.794	32.407A
Natural	24.182	28.562	22.441	23.432	24.654B
Irrigation C.V.: 33.29%; Experimental C.V.:15.4%					
Total yield (kg ha^{-1})					
Artificial	35.284	34.292	35.312	34.728	34.904A
Natural	26.171	30.298	24.604	25.417	26.622 B
Irrigation C.V.: 31.5%; Experimental C.V.:15.6%					

Means followed by different uppercase letters differ between artificial and natural pollination ($p<0.05$) by the F-test.

Irrigated cultivation did not result in higher yields compared to rainfed cultivation since the latter was favored by the rainfall events that occurred during the first four months after field planting (1,025.8 mm), higher than the minimum required for one passion fruit cycle, which, according to Silva & Klar (2002), is 954.98 mm. This phenomenon contributed to plant development in both crop years and allowed equivalent yield values for both water supplies.

Therefore, plants grown under rainfed conditions showed good establishment in the field and, after the subsequent drought period, maintained fruit production due to their high vigor. Furthermore, planting was performed using tall seedlings, a condition that favors early production and increased fruit yield and quality (SANTOS et al., 2017).

The mean number of fruits per plant in the first crop year ranged from 29.8 to 45.5, whereas this variable ranged from 98.5 to 146.3 in the second crop year, not differing statistically between production factors (Table 2).

Although there was no significant effect on the number of fruits, this parameter showed high values (Table 2) favored by organic cultivation, with the production of healthy and productive branches that, under favorable edaphoclimatic conditions, produced a larger number of flowers and showed more fruit establishment, thus directly influencing the yield (FRANCISCO et al., 2020; UCHÔA et al., 2021b).

There was a positive linear correlation between the number of commercial fruits per plant and the commercial yield in both crop years, with the yield value depending on the number of fruits producer per plant, estimated with a determination degree of $r= 0.91$ for the first crop year and $r= 0.99$ for the second (FIGURE 3). There was no correlation between the number of fruits and the mean fruit mass in the first ($r^2 = - 0.122$) and second crop years ($r^2 = - 0.068$) and between the mean fruit mass and the yield in the first ($r^2 = - 0.0799$) and second crop years ($r^2 = 0.148$).

Table 2. Mean number of fruits per plant as a function of production factors in the first and second crop years. Seridó Ecological Station, Rio Branco - AC, Brazil, 2019-2020.

Pollination	Irrigated		Rainfed	
	Protected	Direct sunlight	Protected	Direct sunlight
Number of fruits per plant in the 1st crop year ns				
Artificial	37.0	45.5	38.5	49.8
Natural	36.0	37.3	29.8	30.5
Irrigation C.V.: 57.7%; Experimental C.V.: 39.4%				
Number of fruits per plant in the 2nd crop year ns				
Artificial	146.3	130.3	123.0	128.8
Natural	123.0	143.0	98.5	108.3
Irrigation C.V.: 34.9%; Experimental C.V.: 33.34%				
Total number of fruits per plant ns				
Artificial	183.3	175.8	161.8	190.3
Natural	159.0	180.0	128.5	138.8
Irrigation C.V.: 38.0%; Experimental C.V.: 27.3%				

ns non-significant (p>0.05)

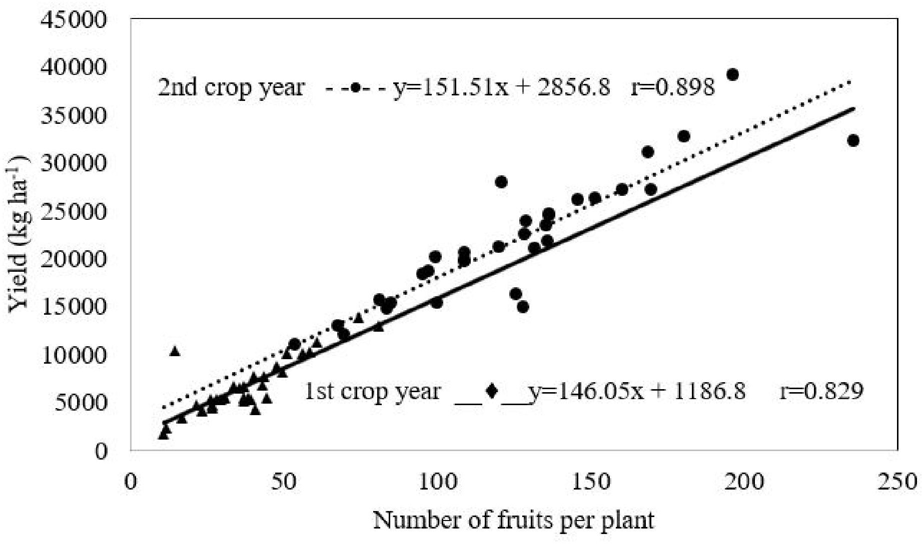

Figure 3. Linear correlation between the number of fruits per plant and the yield of yellow passion fruit. Seridó Ecological Station, Rio Branco - AC, Brazil, 2020.

The production factors (pollination, semi-protected cultivation, and irrigation) interacted and influenced the mean commercial fruit mass in the two crop years (Table 3), with a higher influence on the plants under semi-protected cultivation, rainfed cultivation, and artificial pollination in both crop years.

Under rainfed conditions, passion fruit uses adaptative strategies to increase the photosynthesis efficiency and decrease the respiratory rate in order to maintain production (CAVALCANTE et al., 2020).

However, the supply of 80% of the crop water requirement is sufficient to maintain physiological processes without limiting the stomatal inflow of carbon dioxide and carbon assimilation during the photosynthetic processes (SOUZA; RIBEIRO, 2016), thus turning the implantation of irrigation into a safety measure for long drought periods, in which the plant population may decline (SILVA et al., 2019; UCHÔA et al., 2021b) and even result in no fruit production (GALVÃO et al., 2020).

Artificial pollination, plastic covers, and rainfed cultivation were isolated factors that contributed significantly to increasing the mean fruit mass (Table 3). Since, in passion fruit, the number of seeds is intimately related to the amount of pollen deposited on the stigmas, the fruit biomass is expected to increase with the number of pollinated stigmas (SILVEIRA et al., 2012).

Allied to artificial pollination, the plastic cover offered protection for the pollen deposited on the flower stigmas. According to Lage et al. (2018), climatic factors such as relative air humidity and temperature can influence the viability of the pollen grain.

Table 3. Mean commercial fruit mass of passion fruit as a function of cultivation arrangements. Seridó Ecological Station, Rio Branco - AC, Brazil, 2019-2020.

Pollination	Irrigated		Rainfed	
	Protected	Direct sunlight	Protected	Direct sunlight
	Mean commercial fruit mass – 1st crop year			
Artificial	140.8Baα*	137.8Aaα	150.5Aaα	121.3Bbβ
Natural	128.8Abβ	136.3Aaα	127.3Aaβ	132.8Aaα
Irrigation C.V.: 14.08%; Experimental C.V.: 3.58%				
	Mean commercial fruit mass - 2nd crop year			
Artificial	140.5Baα	136.0Aaβ	151.8Aaα	124.0Bbβ
Natural	131.0Abβ	142.8Aaα	135.8Aaβ	139.3Aaα
Irrigation C.V.: 13.95%; Experimental C.V.: 3.13%				

*Means followed by different uppercase letters between alternate columns differ for irrigation, whereas means followed by different lowercase letters in the row differ for cover, and means followed by different Greek letters differ between artificial and natural pollination by the F-test at 5%.

Conclusions

Micro-sprinkler irrigation and semi-protected cultivation did not affect the yield per hectare and the number of fruits per plant.

Artificial pollination increased the passion fruit yield by up to 31% under organic cultivation.

The fruit mass is favored by combining a semi-protected environment, rainfed cultivation, and artificial pollination or by direct sunlight with natural pollination regardless of irrigation.

Irrigation and pollination increase the mean fruit mass under direct sunlight conditions.

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