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CROP PRODUCTION

Does organic hop cultivation in subtropical conditions promote physiological and productive changes?

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ABSTRACT: Hops are grown mainly for the brewing market due to the rich chemical composition that gives beer aroma and bitterness. Brazil is one of the largest beer producers and consumers in the world and one of the largest hop importers. There is growing demand and interest in producing hops for domestic supply; however, as this crop originates from a temperate climate and the Northern Hemisphere, it is important to carry out research that describes the development of hops in a tropical climate to provide information on its cultivation in Brazil, as well as to determine its behavior in organic cultivation. A randomized block design was adopted, the treatments consisted of two cropping systems, conventional and organic, for Hallertau Mittelfrueh variety cultivation, with four blocks and three plants per plot. Gas exchange analyzes of plants under both cultivation systems were performed to obtain measurements of *A*, g_s, *Ci*, *E*, *WUE* and *A/Ci*, morphometric and yield analyzes were also carried out. In comparison with the plants of the organic system, the plants of the conventional cultivation had greater photosynthetic efficiency; however, the practices adopted in the organic cultivation system provided the plants with greater productive capacity.
Key words: Cannabaceae, hops, photosynthetic measurements, productivity, tropicalization.

O cultivo orgânico de lúpulo em condições subtropicais promove mudanças fisiológicas e produtivas?

RESUMO: O lúpulo é cultivado principalmente para o mercado cervejeiro devido à rica composição química que confere aroma e amargor à cerveja. O Brasil é um dos maiores produtores e consumidores de cerveja do mundo e um dos maiores importadores de lúpulo. Há crescente demanda e interesse na produção de lúpulo para abastecimento interno; porém, como essa cultura é originária de clima temperado e do Hemisfério Norte, é importante a realização de pesquisas que descrevam o desenvolvimento do lúpulo em clima tropical para fornecer informações sobre seu cultivo no Brasil, bem como determinar seu comportamento em cultivo orgânico cultivo. Adotou-se o delineamento em blocos ao acaso, e os tratamentos consistiram em dois sistemas de cultivo, convencional e orgânico, para a variedade Hallertau Mittelfrueh, com quatro blocos e três plantas por parcela. Análises de trocas gasosas de plantas sob ambos os sistemas de cultivo foram realizadas para obter medidas de *A*, *gs*, *Ci*, *E*, *WUE* e *A/Ci*, análises morfométricas e de produção também foram realizadas. Em comparação com as plantas do sistema orgânico, as plantas do cultivo convencional apresentaram maior eficiência fotossintética. No entanto, as práticas adotadas no sistema de cultivo orgânico proporcionaram maior capacidade produtiva às plantas.
Palavras-chave: Cannabacea, lúpulo, medidas fotossintéticas, produtividade, tropicalização.

INTRODUCTION

Hop (*Humulus lupulus* L.) is a plant belonging to the Cannabaceae family, which includes the genus *Cannabis* (SPÓSITO et al., 2019). The species *H. lupulus* and *H. japonicus* are commercially cultivated because they have lupulin glands that confer commercial value to the plant (ALMAGUER et al., 2014). This crop originates from the Northern Hemisphere, but due to its wide commercial use, hop plants are grown worldwide (BOCQUET et al., 2018).

Hops are considered a short-day plant, as the lengthening of days into hours promotes the vegetative growth of plants and when the days begin to shorten, the increase in hours of darkness induces the change of plant stage from vegetative to reproductive, and thus, there is the formation of inflorescences

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that will develop into cones (JASTROMBEK et al., 2022), harvesting these is the main reason for interest in hop cultivation in the world.

In the Northern Hemisphere, the region originating from hops, flowering induction occurs when the length of the day is less than 16 hours of light (ISKRA et al., 2019), this length of days varies in relation to latitude and generally, the latitude that best induces good hop development is between 35° and 55° north or south of the equator (DODDS, 2017).

Despite what is known about the hop growing zone, several crops are currently observed growing in Brazil under subtropical conditions, especially in the southern and southeastern regions (GUIMARÃES, 2021). The city of Botucatu is located in the state of São Paulo in the southeastern region of the country and at latitude 22°50'S, where the photoperiod varies from approximately 10 hours on the shortest day of the year to 13 hours on the longest day of the year, not reaching the ideal photoperiod of 16 hours for crop development, thus promoting early floral induction (PEARSON et al., 2016; KOLENC et al., 2016), we soon noticed that there is a limiting factor for Brazilian production, the length of the day being less than 14 hours maximum, which has already led to many crops failing (LELES et al., 2023).

Hop plants are sensitive and susceptible to climate change, so this is one of the great challenges present in the cultivation of this crop (KORPELAINEN & PIETILAINEN, 2021). Thus, organic hop cultivation is a viable alternative because the practices used in organic management contribute to improvements in the biological and physical attributes of soil, such as the incorporation of organic matter, the use of beneficial microorganisms, and the use of legumes such as green manure (DANTAS et al., 2015; CARVALHO et al., 2020).

Crop development can be better analyzing by evaluating its physiological behaviors and productive capacity so that the existing environmental influences on the crop can be determined, so using this approach will help in understanding how hops develop in the southern central part of São Paulo.

Thus, the objective of this study was to evaluate the gas exchange of the hop variety Hallertau Mittelfrueh (HM) under organic and conventional management in subtropical climates and relate them to morphometric and productive parameters.

MATERIALS AND METHODS

Experimental conditions

The experiment was conducted in the experimental area of the Horticulture Sector, Department of Plant Production, on the Lageado Farm in Botucatu, São Paulo, belonging to the Faculty of Agronomic Sciences, of the São Paulo State University – FCA/UNESP, during the 2021 season in February (late summer). The region has a Cfa climate classification according to the Köppen method (KÖPPEN, 1948), and this classification corresponds to a humid hot (mesothermal) temperate climate, with an average annual rainfall of 1428.4 mm and an average annual temperature of 20.3 °C (DA CUNHA & MARTINS, 2009). The experimental area is located between 22°30' and 23°05'S, and 48°15' and 48°52'W and has an average altitude of 800 m.

Treatments and experimental design

A randomized block experimental design was adopted, and the treatments consisted of two cultivation systems (conventional and organic) of the HM variety, with four blocks and three useful plants per plot, totaling 24 experimental units.

The differentiation factors between the treatments (cropping systems) were related to fertilization and phytosanitary control, and fertilization for both cultivation systems was performed according to the fertilization needs identified by the soil analyses.

Crop characterization

Soil was collected in December 2020 for the soil analysis and fertilization recommendations for the cultivation systems (Table 1). Fertilization was performed based on soil analysis and adaptation of the recommendation established for the "Fertilizer Guide: Hops" (GINGRICH, 2000).

In the conventional cultivation system, nitrogen topdressing was performed with calcium nitrate and urea (51.38 kg.ha^{-1} and 16.79 kg.ha^{-1}, respectively), potassium with potassium chloride (30.52 kg.ha^{-1}) and Oligogreen® micronutrient mix (20 g to 20 L of water), zinc sulfate (5 kg.ha^{-1}) and borate acid fertilization with boric acid (4 kg.ha^{-1}). For phytosanitary control, applications of Abamex® (Abamectin) (20 mL to 20 L of water) for spotted mites and Dipel® (*Bacillus thuringiensis*) (500 g to 20 L of water in the entire culture) were applied when caterpillars occurred.

In the organic cultivation system, for nitrogen fertilization, bokashi (1.5 t.ha^{-1}), castor

Table 1 - Soil chemical analysis at depths of 0-20 cm and 20-40 cm for the organic and conventional Hallertau Mittelfrueh hop cultivation systems.

Samples	Depths (cm)	pH	OM	P_{resin}	K	Ca	Mg	CEC	V%
		$CaCl_2$	$g.dm^{-3}$	$mg.dm^{-3}$	------------------------mmol$_c$.dm^{-3}--------------------------				
Org.	0-20	5.3	21	54	4.6	36	13	83	65
Org.	20-40	4.0	19	38	3.8	20	10	103	32
Conv.	0-20	5.1	23	108	4.1	38	9	92	56
Conv.	20-40	4.2	19	96	3.2	38	9	106	47

Subtitle: Org.: organic; Conv.: conventional; OM: organic matter.

bean cake (1.4 $t.ha^{-1}$), sunn hemp biomass, radish and pigeon pea were used. Potassium fertilization was performed with potassium sulfate (39.17 $kg.ha^{-1}$), bone meal (1 $t.ha^{-1}$) was also provided, and phosphate fertilization was performed with potassium sulfate (46.64 $kg.ha^{-1}$) and boric acid (4 $kg.ha^{-1}$). Spraying was performed with Super Magro biofertilizer, and biological activation of the soil was performed with efficient microorganisms (EMs) (2 L of EM for 20 L of water).

Metarhizuium anisopliae and *Beauveria bassiana* applications were performed for preventive pest control. A calcium sulfide spray was also applied to the spotted mite. Ant management was performed with bioisca®, and spraying was performed with a mixture of raw milk and bordeaux mixture.

Agricultural practices

The young plants were acquired from a seedling nursery and planted with a 3.2 x 1.0 m spacing between plants in a "V" shape with four vigorous bines (PERAGINE, 2011) of approximately 40 cm in length.

The high trellis system was used to train the plants, for the assembly of this system the following materials were used, treated eucalyptus poles of 7.5 m and 2.5 m, and steel cables and wires used to guide the plants. The main posts of the system are 7.5 m long, in which 1.5 m were buried and thus 6 m of the post were used to define the height of the conduction, the 2.5 m posts were used as supports, being connected to the main posts by steel cables, functioning as anchors, 1.5 m of these were buried. Steel cables were used to connect the main poles and steel wires were used to fix the sisals, where the hop plants were led in a "V".

The drip irrigation system was set up, and two drip strips were used per planting row. The emitters were spaced 0.5 m apart, and the flow rate was 1.1 $L.h^{-1}$. Irrigation was automatically managed by the ASI, through a device that manages the tensiometry with a sensor installed below a seedling, at the depth where the effective roots of the hops are 20 cm.

The green manure was mowed at the time of floral initiation, and the biomass was placed as a cover in the rows. The control of weeds was performed, when necessary, mechanically through mowing, weeding and uprooting.

Physiological analyses

The gas exchange measurements were measured using an open photosynthesis system with a CO_2 analyzer and infrared radiation gas analyzer (IRGA, model LI-6400, Li-Cor). For the measurements taken during the day, analyses were performed on eight plants in the conventional cultivation system and eight in the organic cultivation system. For this purpose, the plants were previously selected and standardized using a fully expanded leaf from the middle third of the plant at 184 days after pruning.

The readings were performed every 2 h, from 8:00 am to 6:00 pm. For plants at the same developmental stage, the following variables were measured: CO_2 assimilation rate (A, µmol CO_2 $m^{-2}s^{-1}$); stomatal conductance (g_s, mol H_2O $m^{-2}s^{-1}$); internal concentration of carbon (Ci, µmol $m^{-2}s^{-1}$); transpiration (E, mol H_2O $m^{-2}s^{-1}$); water use efficiency (WUE, µmol CO_2 $m^{-2}s^{-1}$/mmol H_2O $m^{-2}s^{-1}$), determined by the relationship between A and E; and carboxylation efficiency (A/Ci, µmol CO_2 $m^{-2}s^{-1}$/µmol $m^{-2}s^{-1}$), determined by the relationship between A and Ci in the leaves, for A, g_s, E, and Ci, the IRGA data analysis program was used.

To ensure that the experimental conditions were consistent, the photosynthetic photo flux density (PPFD) was standardized using a light emitting diode coupled to the IRGA, according to the PPFD during each evaluation time (Table 2). The reference CO_2 concentration used during the evaluation was ambient, ranging from 380–400 µmol mol^{-1} of air.

Table 2 - Air temperature (°C), relative humidity of the air (%) and photosynthetic photon flux density (PPFD, µmol $m^{-2}s^{-1}$) from 8:00 am to 6:00 pm under field conditions.

Day time	Air termperature (ºC)	Relative humidity (%)	PPFD (µmol $m^{-2}s^{-1}$)
8:00 am	23.2	60	780
10:00 am	25.8	63.1	1300
12:00 pm	30.7	46.4	2130
2:00 pm	32.1	50.1	1840
4:00 pm	30.4	48.5	1230
6:00 pm	27.6	50.37	450

The curve of the A (µmol CO_2 $m^{-2}s^{-1}$) in response to the PPFD (µmol $m^{-2}s^{-1}$) was obtained by decreasing the PPFD of 2000 µmol $m^{-2}s^{-1}$ to 0 µmol m^{-2} s^{-1} at intervals of 200 µmol m^{-2} s^{-1}, and then at intervals of 50 µmol $m^{-2}s^{-1}$ for greater accuracy of the slope of the curve. The temperature used during the evaluation was room temperature, at approximately 27 ± 3 °C.

The response curve was fitted to the hyperbolic function $A = a\,[(A\max{}^{*}\,\mathrm{PPFD})/(b + \mathrm{PPFD})]$ where A max is the maximum CO_2 assimilation and a and b are the parameters of the hyperbolic equation. From this function, respiration in the dark (parameter A of the equation) and light compensation (s, corresponding to the PPFD value where A is zero) were calculated. The light saturation point was determined by fitting a straight line (y = 1) to the highest points of the curve. The hyperbolic function was adjusted using the statistical program SAS 9.2.

Morphometric and Productive Analyses

To determine the ideal time to collect hop cones, samples were obtained for dry matter calculations, adopting 20-23% as established by MADDEN & DARBY (2012). After harvesting the plants in the field, they were taken to the Laboratory of Medicinal Plants at the FCA/UNESP for the analyses.

Hop plant morphometric and productive data, such as the length of the cones (cm), height of insertion of the first cone in the plant (cm), plant height (cm) and fresh weight of the cones (g), were collected. For the length of the cones, 30 random cones were selected, and they were measured. Then, the mean length was calculated.

The cone size classification methodology proposed by the American Society of Brewing Chemists (ASBC, 2021) was used. Based on this methodology, a large cone is equal to or greater than 5.1 cm, an average cone is between 3.2 and 5.1 cm, and a cone small is less than 3.2 cm.

The height of cone insertion in a plant was measured in the field before the plant was cut; for this characteristic, the cone originated in the lowest part of the plant was observed and measured based on the distance from it to the canopy of the plant, where the bine emerge starts, and the height of the plant was obtained by the sum of the distance between the internodes of the plants. These measurements are important because they are directly related to the productive capacity of plants.

The fresh weight of the cones was obtained as soon as the cones were harvested from the plants, and then, the cones were dried in a forced air oven at 35 °C until they reached a 10% moisture content, at which point they were removed from the oven and weighed.

The data were subjected to analysis of variance (F test), and the means were compared using the Tukey test at 5% probability using AgroEstat® software. To determine the homogeneity of the data, the statistical software SAS 9.2 and Levene's test were used.

RESULTS

Physiological measurements

The Hallertau Mittelfrueh hop plants in the conventional cultivation system had a higher A than that of the plants in the organic cultivation system. This difference was observed at most evaluation times, except at 12:00 pm and 6:00 pm (Figure 1). The A peaks of the plants in the conventional cultivation system occurred at 10:00 am and 2:00 pm, at 26.2 µmol $m^{-2}s^{-1}$ and 24.1 µmol $m^{-2}s^{-1}$, respectively. While the a of the plants in the organic cultivation system was stable between 8:00 am and 12:00 pm, at approximately 21.1 µmol $m^{-2}s^{-1}$, and the rate dropped to 17.7 µmol $m^{-2}s^{-1}$ from 2:00 pm to 6:00 pm.

With regard to g_s, plants in both cultivation systems had peak stomata openings at 10:00 am (Figure 1), when the relative air humidity was higher, at 63.1% (Table 2). However, g_s was higher in plants in the conventional cultivation than in those in the organic cultivation system at all times evaluated. The highest value of g_s in plants in the conventional cultivation system occurred at 10:00 am, which was consistent with the result for A, a behavior similar to that of the plants in the organic cultivation system that exhibited a stable g_s and A between 10:00 and 12:00 pm.

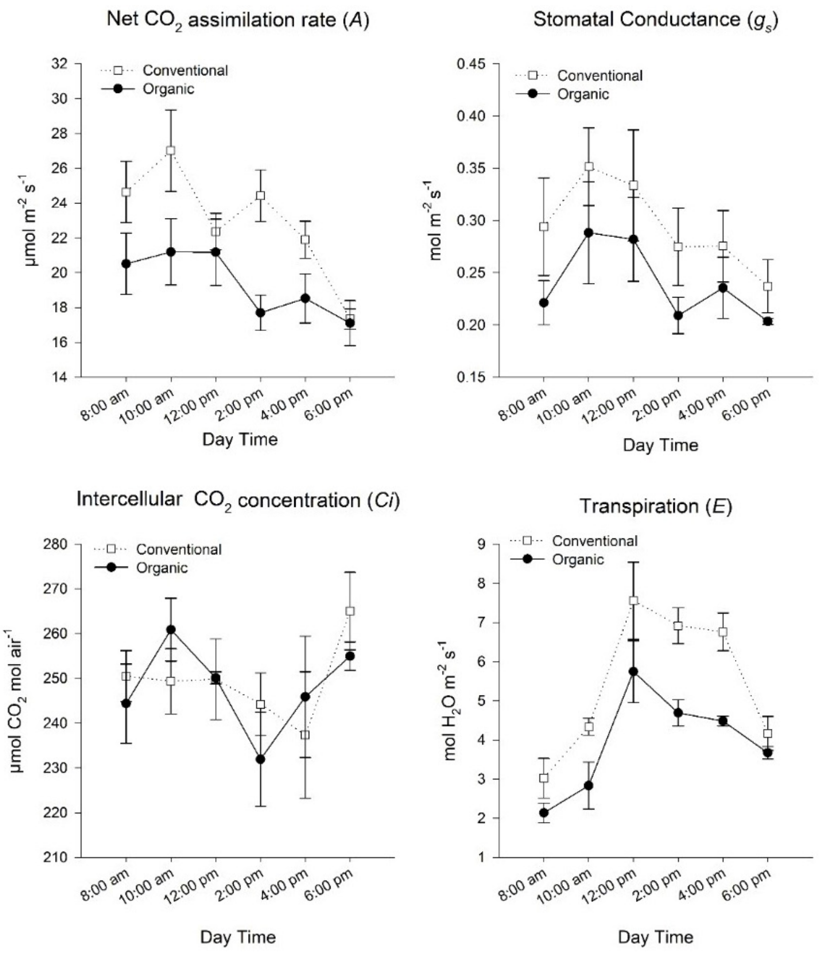

Figure 1 - Net CO_2 assimilation rate (*A*, μmol $m^{-2}s^{-1}$), stomatal conductance (g_s, mol $m^{-2}s^{-1}$), intercellular CO_2 concentration (*Ci*, μmol $m^{-2}s^{-1}$), and transpiration (*E*, mol H_2O $m^{-2}s^{-1}$) of Hallertau Mittelfrueh hop grown in conventional and organic cultivation systems.

There was a variation in the *Ci* values at the different evaluation times. The plants in the conventional cultivation system had stable *Ci* values of approximately 250 μmol CO_2 mol air^{-1} between 8:00 and 12:00 am, with the highest peak at 6:00 pm (Figure 1).

The *E* was higher in the plants in the conventional cultivation system than in those in the organic cultivation system at all times evaluated (Figure 1). The peak of *E* in both crops was at 12:00 pm and was influenced by the low relative humidity at that time (Table 2). The higher *E* values of the plants in the conventional cultivation system indicated greater water losses and were related to greater stomatal openings and *A* values.

For the gas exchange variables analyzed, in comparison to the conventional cultivation system, the organic cultivation system favored a higher hop plant *WUE* (Figure 2). This behavior occurred due to the lower *E* of these plants during the day when compared to that of the plants in the conventional cultivation system. For the hop plants, regardless of cultivation system, *WUE* decreased drastically starting at 12:00 pm due to higher temperatures and reduced relative humidity (Table 2).

In comparison to those in the organic cultivation system, the hops in the conventional cultivation system showed higher *A/Ci* values (Figure 2), with higher values in the morning at 8:00 am and 10:00 am. These results are consistent with the *A* and *Ci* values. Plants in the organic cultivation system were stable at a *A/Ci* value of approximately 0.085 during the morning, with a decrease starting at 2:00 pm, and the lowest value occurred at 6:00 pm.

In addition, the type of cultivation system altered the light response curves of the hop plants (Figure 3; Table 3). Respiration in the dark did not differ

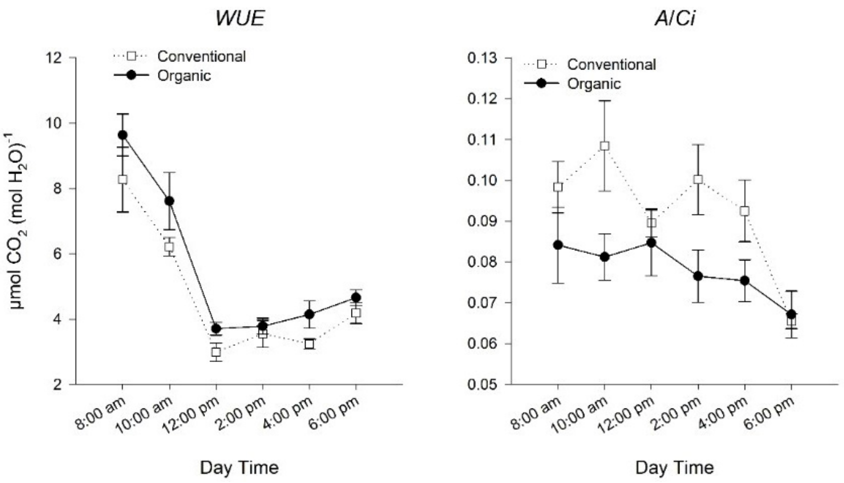

Figure 2 - Water use efficiency (*WUE*, μmol CO_2 $m^{-2}s^{-1}$/μmol $m^{-2}s^{-1}$) and carboxylation efficiency (*A/Ci*, μmol CO_2 $m^{-2}s^{-1}$/μmol $m^{-2}s^{-1}$) of Hallertau Mittelfrueh hop grown in the conventional and organic cultivation systems.

statistically between cultivation systems, while the light compensation point was higher in conventionally produced plants (51.60 μmol $m^{-2}s^{-1}$) than organically produced plants (36.83 μmol $m^{-2}s^{-1}$), which indicates that conventional and organic plants require different amounts of photosynthetic photons to assimilate CO_2.

In general, the plants in the conventional cultivation system assimilated more CO_2 than the plants in the organic cultivation system, and they reached a different saturation level. The hop plants in the conventional cultivation system reached photosynthesis saturation at a PPFD above 1822.75 μmol $m^{-2}s^{-1}$, while the saturation plateau occurred at 1539.01 μmol $m^{-2}s^{-1}$ for plants in the organic cultivation system.

Morphometric and Productive Data

For the morphometric characteristics (Table 4), we did not find significant differences for the

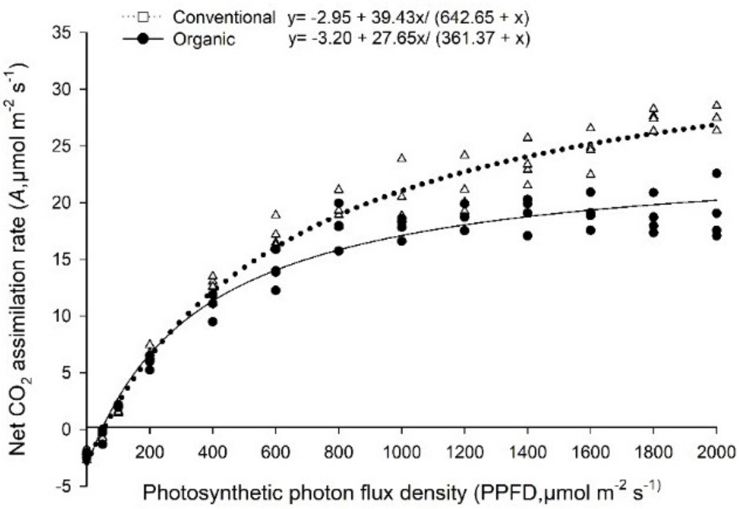

Figure 3 - Net CO_2 assimilation rate (*A*, μmol $m^{-2}s^{-1}$) as a function of photosynthetic photon flux density (PPFD, μmol $m^{-2}s^{-1}$) of Hallertau Mittelfrueh hop grown in the conventional and organic cultivation systems.

Table 3 - Light compensation point (µmol $m^{-2}s^{-1}$), light saturation point (µmol $m^{-2}s^{-1}$) and respiration in the dark (µmol $m^{-2}s^{-1}$) for Hallertau Mittelfrueh hop grown in conventional and organic cultivation systems.

	Light compensation point	Light saturation point	Respiration in the dark
Conventional	51.50	1822.75	2.95
Organic	36.83	1539.01	3.05
F^*	26.79^*	20.75^*	2.28^{ns}
CV (%)	8.78	12.11	6.10

Subtitle: ^{ns} not significant (P > 0.05) *significant at 5% probability (P < 0.05).

analyzed variables. Plants in the organic management system produced cones that were heavier (61.43 g) than those of the plants in the conventional system (53.30 g). Regarding the length of the cones, according to the ASBC Hops - 2, the plants in the two managements had cones classified as small at 2.83 cm, on average.

The highest insertion height of the first cone at 179.75 cm was observed in the plants in the organic cultivation system, and the insertion height was lowest in the plants in the conventional cultivation systems (137 cm). Finally, the plants in the organic cultivation system had a higher average height of 675.33 cm, while the mean height for the plants in the conventional cultivation system was 632.33 cm.

DISCUSSION

The analysis of gas exchange during the day showed that in comparison to those in the organic cultivation system, the hop plants in the conventional cultivation system had higher *A* values, as well as higher *E* and g_s values and lower *WUE* values.

The *A* values in the plants in both cultivation systems were high. Under controlled cultivation conditions in the USA, the Cascade, Centennial and Chinook hop varieties showed *A* values of 12.5, 17.3 and 18.7 µmol $m^{-2}s^{-1}$ (BAUERLE, 2021), respectively, which are lower than those observed in this study. Thus, the two cultivation systems favored *A* and translocated assimilated carbon for cone cultivation, and in the organic cultivation system, the plants were more efficient because they assimilated less CO_2 and produced cones with the same mass as those of the plants in the conventional cultivation system.

Conventional chemical fertilizers have high salt levels when compared to those used in organic cultivation systems (MANTOVANI et al., 2017), and possible salt stress can reduce g_s (OLIVEIRA et al., 2014), affecting *A*, *E* and *WUE* (PRAZERES et al., 2015). Thus, based on the fertilization performed in the conventional cultivation system, good and efficient development of the plants occurred because high rates of g_s occurred and consequently higher hop plant *A* and *E* values.

The hop plants had high daily water consumption (GRAF et al., 2019), and as evidenced in this experiment, in comparison to the conventionally produced plants, the organically produced plants showed greater efficiency when using water in photosynthesis, presenting less losses and an efficient use of water.

Although the study compared the physiology of hop plants in two different cultivation systems, it also showed the physiological behaviors of the HM variety under subtropical conditions, as this is a plant originating from temperate regions of the Northern Hemisphere (GARGANI et al., 2017). This characterization allows the understanding of hop plant physiology to guide the management of this crop under subtropical conditions.

This variety appears to be adapted to subtropical and tropical conditions, as it maintains high g_s and *E* values even under conditions of high temperatures and low relative humidity. This relationship among the environment, g_s, and *E* was also observed in nongrafted cucumber; these plants seem to be more sensitive to environmental conditions because they have decreased g_s as a result of an increase in temperature and a reduction in relative humidity (AMARO et al., 2014).

It was also observed that the HM variety is demanding regarding photosynthetically active

Table 4 - Morphometric data of Hallertau Mittelfrueh hop under organic and conventional management.

	CFM	CL	HCI	PH
Organic	61.43	2.83	179.75	675.33
Conventional	53.30	2.83	137.00	632.33
F^*	0.92^{ns}	0.00^{ns}	2.76^{ns}	5.34^{ns}
CV (%)	20.84	14.97	36.36	4.02

Subtitle: ^{ns} not significant (P > 0.05). Legend: CFM: cone fresh mass (g), CL: cone length (cm); HCI: height of first cone insertion; PH: plant height (cm).

radiation (PAR), at approximately 1500 µmol $m^{-2}s^{-1}$, which allows it to be cultivated in regions of high solar radiation and light intensity. As Brazil has begun to cultivate hops recently, varieties are currently being adapted to the prevailing tropical climate of the country (GUIMARÃES et al., 2021). The data from this study show the suitability of HM for subtropical and tropical climates.

ERIKSEN et al. (2020) conducted experiments evaluating the *A* at different temperatures in the varieties Cascade, Centennial, Chinook, Pride of Ringwood, Willamette, and Southern Brewer and found no significant differences attributed only to the different temperatures. Thus, we observed the influence that an adopted cultivation system can have on the development of hop plants.

Plants in the organic cultivation system showed a propensity to saturate photosynthesis with lower PPFD values than those of the plants in conventional cultivation system, thus indicating that this type of management favors the best use of incident light. Thus, plants in the organic cultivation system were more susceptible to variations in environmental conditions. Under intense radiation, there is no significant increase in photosynthesis; however, photosynthesis is saturated, which limits *A*. The morphometric and productive analysis showed that the plants did not differ in relation to the agricultural cultivation system used and showed similar performances in terms of vegetative and productive development.

In a study by SOLARSKA et al. (2013) with the Magnum and Marynka varieties, there was an increase in the yield of the cones when an organic cultivation system, with horse manure enriched with microorganisms and rock powder, was used under the environmental conditions of a temperate climate. Notably, diversified fertilization with enrichment and activation of soil microorganisms can promote good responses regarding plant productivity and growth. Thus, diversified fertilization is beneficial because it affects soil organisms (OSZUT et al., 2014).

The morphometric and productive characteristics evaluated did not have significant differences between production management, however, it is possible to compare the size of the cones and the height of the plants with other Brazilian research evaluating the Hallertau Mittelfrueh variety, thus creating more reference for research with Brazilian hops.

LELES et al. (2023) evaluated in the same year that this research was carried out (2021) some characteristics of Hallertau Mittelfrueh, among them, the length of the cones and the results found were similar, they obtained 2.5 cm cones and in this research we obtained 2.83 cm, thus, in both studies, the cones are considered small.

Another characteristic that can be compared is the height of the plants, this is important because it shows us the potential for vegetative development of plants according to management and their physiological performance, thus, plants that have a satisfactory vegetative development stage are more prone to have greater productions in relation to the release of side arms and floral curls.

NEVES et al. (2023) evaluated Hallertau Mittelfrueh plants in the autumn and winter harvest of 2020 in the interior of São Paulo, Brazil, at this time the length of days varies from 10 to 11 hours, which directly affects the development of the plants, and evaluating the height of the plants obtained 152.48 cm, which contrasts with what was obtained in this work, 632.33 cm in conventional management and 675.33 cm in organic management.

The main difference between these two works is the period of the year of execution, in Brazil there is a great difference in the length of days during the seasons of the year, therefore, the photoperiod becomes a more limiting factor for autumn and winter cultivation than for of spring and summer, in these last two seasons the plants can make better use of the lengthening of the days until December when the summer solstice occurs, generally after this date the first inflorescences and floral clusters are formed.

Therefore, we note the importance of carrying out research evaluating the behavior of hops in different seasons and investigating how to manage the photoperiod to enable production in the country in different regions and in different harvests, maintaining production standards in quantity and quality.

CONCLUSION

The two cultivation systems provided Hallertau Mittelfrueh hop plants with efficient physiological conditions because their vegetative and productive development was satisfactory. The conventional cultivation system resulted in its plants having higher g_s, *A* and *E* values and lower *WUE* values. The conventional cultivation system also favored plants that could better use light in photosynthesis. The plants in the organic cultivation system were more susceptible to environmental conditions.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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