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Does the use of cover crops optimize the use of mineral nitrogen in sweet pepper cultivation?

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ABSTRACT

The present study aimed to evaluate the effect of the combination between nitrogen rates and the management of straw mulches for the cultivation of peppers. The treatments comprised three managements of straw on the ground (no straw, *Urochloa ruziziensis,* and millet) and five nitrogen rates (0, 50, 100, 150, and 200% of the recommended dose of 120 kg ha^{-1}). Mulch presence results in better physiological activity in the plants, while the rates of N positively affect the physiological and biometric characteristics of the plants up to 127.50% and 181.21%, respectively. Rates up to 145.62% increased fruit length in the treatment composed of *U. ruziziensis* straw, while rates relative to 154.65%, 127.98%, and 138.55% for the control, *U. ruziziensis* and millet treatments provided productive gains of 202.52%, 267.44%, and 473.18%. We concluded that straw mulching improves the physiological condition of sweet pepper plants and the application of nitrogen fertilizer; using straw from millet plants, combined with the dose of 138.55% N, results in greater yield gains.

Keywords: Nitrogen fertilizers, Plant residues, Soil conditioning.

A utilização de plantas de cobertura otimiza o uso de nitrogênio mineral em cultivo de pimentão?

RESUMO

O presente trabalho teve como objetivo avaliar o efeito da combinação entre doses de nitrogênio e manejo de palhada para o cultivo de pimentão. Os tratamentos consistiram de três manejos de palha no solo (sem palha, *Urochloa ruziziensis* e milheto) e cinco doses de nitrogênio (0, 50, 100, 150 e 200% da dose recomendada de 120 kg ha^{-1}). A presença da cobertura morta resulta em melhor atividade fisiológica das plantas, enquanto as doses de N afetam positivamente as características fisiológicas e biométricas das plantas em até 127,50% e 181,21%, respectivamente. Doses de até 145,62% aumentaram o comprimento dos frutos no tratamento composto por palha de *U. ruziziensis*, enquanto doses relativas a 154,65%, 127,98% e 138,55% para o controle, *U. ruziziensis* e milheto proporcionaram ganhos produtivos de 202,52%, 267,44%, e 473,18%. Concluímos que a cobertura morta melhora a condição fisiológica das plantas de pimentão e a aplicação de fertilizantes nitrogenados; a utilização de palha de milheto, combinada com a dose de 138,55% de N, resulta em maiores ganhos de produtividade.

Palavras-chave: Fertilizantes nitrogenados, Resíduos vegetais, Condicionamento do solo.

1. Introduction

The sweet pepper (*Capsicum annuum* L.) has great prominence in the Brazilian horticultural scenario, being among the most produced and consumed vegetables by Brazilians. Ramos et al. (2017) state that fruit vegetable has high nutritional value, being a source of various vitamins (A, C, and E, for example) and a powerful antioxidant. For the success of the sweet pepper and other plants from the Solanaceae family, it is necessary to use the correct fertilization, which includes micronutrients and macronutrients, such as nitrogen. Nitrogen fertilization influences plant growth and fruit development, leading to greater development in a shorter period. Therefore, the deficiency of this nutrient causes a decrease in the growth and yellowing of the old leaves, and the young leaves also do not develop properly (Campos et al., 2008).

Nitrogen acts in plants in ways that make photosynthesis more efficient since it acts on chlorophyll, giving the plant a vivid green color. The synthesis of nitrogen generally begins with the reduction of nitrate to nitrite, and the latter reduces further to ammonium in the presence of relevant enzymes. This reaction occurs more rapidly in leaves in the presence of light (Mokhele et al., 2012). Besides the ideal levels of nitrogen in the soil and its synthesis by the plants, one must also take into account the levels of soil cover, especially with the use of plant materials, which are intrinsically linked to the final quality of the plants, as well as the soil, preserving its physical and chemical structure and its microbiota.

For Guilherme et al. (2022), changes in the vegetation cover of the soil modify the patterns of energy distribution, strongly impacting important variables such as temperature and relative humidity, concluding that regions with a high density of vegetation cover channel much of the energy to the evapotranspiration process, thus promoting a great hydrothermal regulatory effect on the environment.

This effect is highly beneficial, allowing the best use of natural resources and balancing the soil-plant-atmosphere relationship. Two of the most commonly used species for this purpose are the brachiaria grass (*Urochloa* sp.) and millet (*Pannisetum glaucum* L.), which have already demonstrated in various studies their benefits, conferring good soil coverage, with a short development cycle and ensuring the greater accumulation of dry plant mass (Timossi et al., 2007; Bellon et al., 2009; Forte et al., 2018).

These positive characteristics of the use of cover crops are also an opportunity for the preservation of nitrogen for longer in the soil; besides that, the plant residues themselves can act in the supply of the nutrient during the decomposition of their remains (Mancinelli et al., 2019). In addition, the instability of supply and the high costs related to the acquisition of nitrogen fertilizers requires the search for methodologies that assist in optimizing the use of this valuable resource (Schnitkey et al., 2022). Given the above, and under the hypothesis that sweet pepper plants are differentially affected by nitrogen fertilizer intensity and soil cover management, this research aimed to evaluate the effect of the combination between nitrogen rates and soil cover straw for sweet pepper cultivation.

2. Material and Methods

The experiment was conducted in a shaded covered greenhouse at the State University of Mato Grosso do Sul- UEMS, in the agronomy department of the University Unit of Cassilândia, MS (19º06'48" S, 51º44'03" W, and an average altitude of 510 m). The climate of the region is defined as rainy tropical (AW) with rainy summer and dry winter (winter precipitation less than 60 mm). The experimental environment is characterized by the dimensions of 18.0 x 8.0 m and a ceiling height of 3.5 m, containing black polyethylene screen on the sides and in the upper portion transparent plastic.

The soil used is classified as Neossolo Quartzarênico, composed of 12.5% clay, 7.5% silt, and 80% sand and with the following chemical characteristics: pH ($CaCl_2$) = 5.9, organic matter =19.0 g dm^{-3}, P (resin) = 14 mg dm^{-3}, K+ = 0.8 $mmol_c$ dm^{-3}, Ca^{2+} = 35 $mmol_c$ dm^{-3}, Mg^{2}+ = 7.0 $mmol_c$ dm^{-3}, H+Al = 13 $mmol_c$ dm^{-3}, Al^{3+} = 0.0 $mmol_c$ dm^{-3}, CEC = 56 $mmol_c$ dm^{-3}, sum of bases = 43 $mmol_c$ dm^{-3}, Cu = 0.1 mg dm^{-3}, Fe = 6.0 mg dm^{-3}, Mn = 2.3 mg dm^{-3}, B = 0.23 mg dm^{-3}, and base saturation = 77.0%.

A randomized block design with four repetitions was used. Each repetition was composed of an 11-liter pot with soil and one sweet pepper plant. The treatments were composed of a combination of three different soil cover management (no mulching, *U. ruziziensis*, and millet with 0, 0.39, and 0.36 kg m^{-2} of straw on the soil, respectively) and five proportions of recommended nitrogen dose (0, 50, 100, 150 and 200%), considering the recommended dose of 120 kg ha^{-1}, according to Filgueira (2008), which was applied in topdressing, divided into four applications.

The cover crops were sown in September 2020 and desiccated 39 days after planting. Soybeans were then grown until March 2021. After soybean cultivation, the residues of the treatments were kept on the soil, removing the spontaneous plants. Subsequently, sweet pepper seedlings cv. Ikeda, obtained from a certified nursery, were planted in the center of each pot when they had two leaves, two leaves, turning over the soil only where the seedling was placed.

The phytosanitary management was performed as needed, following the recommendations for the crop, while the irrigation was performed in a semi-automated manner with a sprinkler irrigation system composed of a 1000 L reservoir, a 1-hp water pump, control head with disc filter, manometer, and gate valve, 32 mm PVC pipe in the main irrigation line and 24 mm PVC pipe in the lateral lines. The micro sprinklers were installed on the lateral lines with a spacing of 2 meters between sprinklers and 2 meters between lateral lines, located on the upper part of the structure of the protected environment in a longitudinal direction and tied with galvanized wires.

The sweet pepper plants were grown for 51 days when the physiological characteristics of net photosynthesis (*Pn*), stomatal conductance (*gS*), intracellular CO_2 concentration (*Ci*), and transpiration (E) were evaluated using a portable photosynthesis system (LCi, ADC Bioscientific, Hertfordshire, UK) on a leaf from the middle third of the plants. Also, instantaneous water use efficiency (*WUE*), intrinsic water use efficiency (*IWUE*), and instantaneous carboxylation efficiency (*EICI*) were calculated using the A/Ci ratio.

At the time when the characteristics that propitiated the harvest were observed (fruit commercialization point), the following characteristics were evaluated: fruit fresh mass (FW), obtained by weighing after harvesting; fruit diameter (FD), obtained with a pachymeter in the central portion of the fruit; fruit length (*FL*), obtained with a pachymeter; the number of fruits per plant (*NC*); and fruit yield (per plant) (*YLD*).

The data were submitted to the analysis of variance, and the means were grouped by the Scott-Knott clustering algorithm at a 5% probability level in case of significant effects of the F test ($p \leq 0.05$) for the straws. Polynomial regression analyses were also performed for significant effects of nitrogen fertilizer rates, using the statistical software Sisvar version 5.6 for Windows (Statistical Analysis Software, UFLA, Lavras, MG, BRA).

3. Results and Discussion

The different mulches interfered significantly only with the characteristics of intracellular CO_2 concentration (*Ci*), transpiration (*E*), instantaneous water use efficiency (*WUE*), and intrinsic water use efficiency (*IWUE*) (Figure 1). In this sense, it was found that the treatments containing *U. ruziziensis* and millet straw were superior to the control treatment by about 5% and 3% for Ci and 14% and 8% for *E*, respectively. On the other hand, higher values of *WUE* and *IWUE* were obtained for plants in the control treatment concerning the treatments with straw. For *WUE*, this superiority was 15% and 8%, and for *IWUE*, it was 24% and 14%, concerning the treatments containing *U. ruziziensis* and millet straw, respectively. For *Ci*, the effect of nitrogen rates was also observed, for which a quadratic and negative behavior occurred, with a minimum point of 112.82% (Figure 2A).

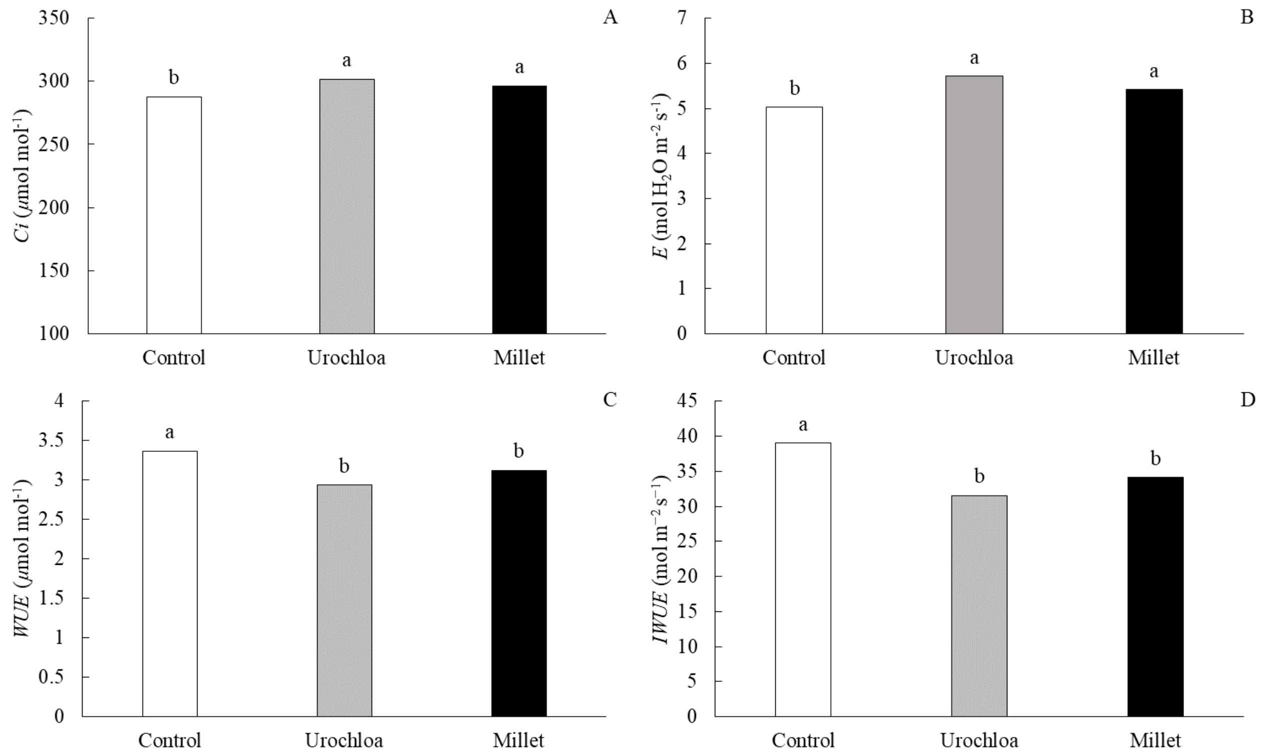

Figure 1. Intracellular CO_2 concentration (A), transpiration (B), water use efficiency (C), and intrinsic water use efficiency (D) of sweet pepper plants grown on different soil mulches. Equal letters on the bars indicate the means belong to the same group ($P < 0.05$). Bars represent the mean values (n = 4).

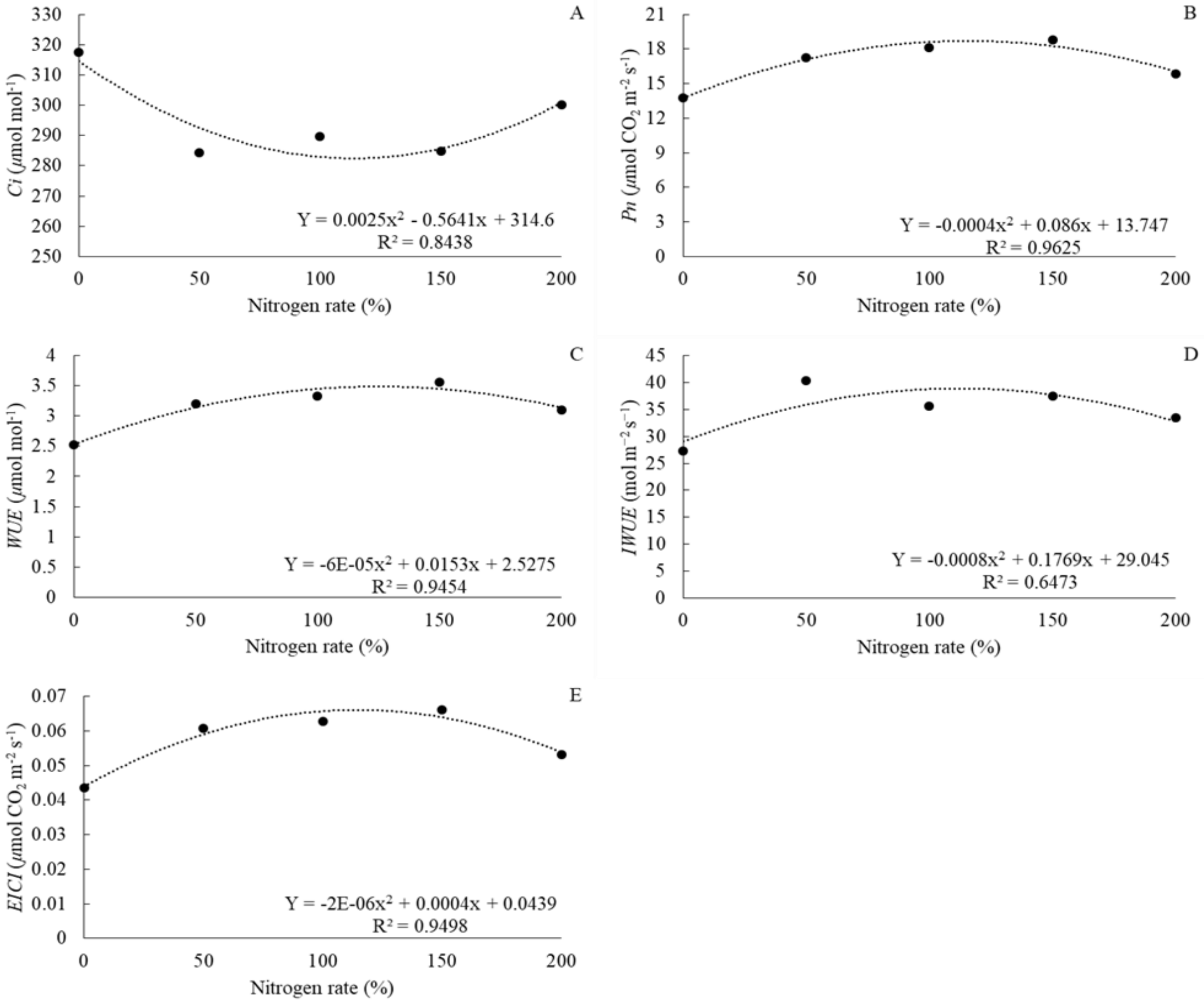

Figure 2. Intracellular CO2 concentration (A), net photosynthesis (B), water use efficiency (C), intrinsic water use efficiency (D), and carboxylation efficiency of sweet pepper plants according to the nitrogen rates.

On the other hand, for net photosynthesis (*Pn*), *WUE*, *IWUE*, and instantaneous carboxylation rate (*EICI*), there were quadratic and positive responses with increases up to rates of 107.50%, 127.50%, 110.56%, and 100%, respectively. The number of fruits per plant (*NC*), the fruit fresh mass (*FW*), and the fruit diameter (*DF*) had their values increased until the maximum calculated rates of 122.78%, 181.21%, and 162%, respectively, with a subsequent decrease (Figure 3). At these rates, the gain concerning the absence of nitrogen application was 122.06%, 108.10%, and 39.39%, respectively.

For the fruit length (*FL*), the effect of nitrogen fertilizer rates was verified only for plants grown on *U. ruziziensis* mulch (Figure 4 A). In this condition, there was an increase of *FL* up to a rate of 145.62%. Nitrogen rates had a different influence on fruit yield (*YLD*) depending on the mulching type (Figure 4B). Yield gains were observed up to rates of 154.65%, 127.98%, and 138.55% for the control, *U. ruziziensis*, and millet treatments, respectively, which provided gains of 202.52%, 267.44%, and 473.18%, concerning the absence of nitrogen. The management of soil cover affected the fruit yield only when the rates of 100% were used, with superiority of the treatments composed of both straws, and 150%, in which there was the superiority of the treatment containing the millet straw (Figure 4B).

The Pearson linear correlation revealed a negative correlation between *Ci* and most other variables, especially fruit yield. In contrast, except for *E* and *gS*, there was a positive correlation between physiological variables and yield (Table 1). The concentration of intracellular CO_2 in plants, according to Taiz et al. (2015), is an important variable since the fruit yield can be analyzed as the product of intercepted solar energy and fixed CO_2 over a given period.

Under adequate light conditions and in the absence of stress, such as water deficit, for example, higher concentrations of carbon dioxide sustain high photosynthetic rates, while at very low intercellular CO_2 concentrations, photosynthesis is limited. For *E*, it is understood that as the soil water availability decreases, the transpiration rate decreases as a result of the closing of the stomas. One of the main responses of the plants to water deficit is the closing of the stomas and, with this, the decrease of CO_2 to the leaf mesophyll, which causes a drop in photosynthesis (Jadoski et al., 2005).

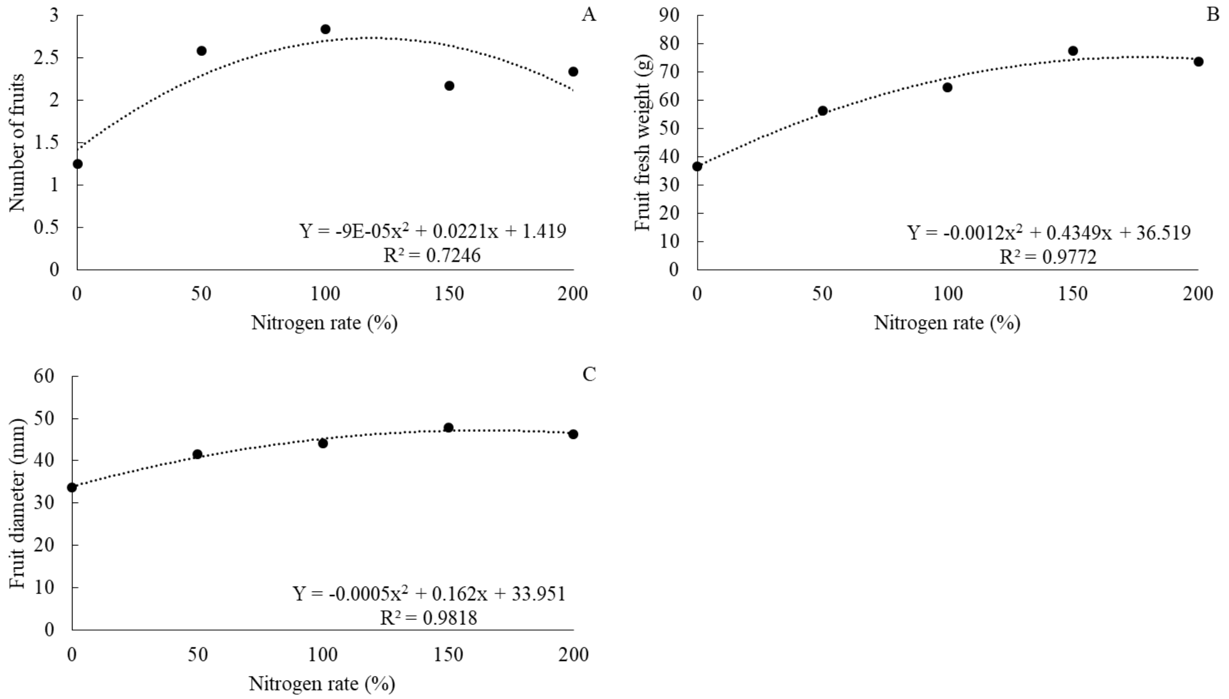

Figure 3. Number of fruits (A), fruit fresh mass (B), and fruit diameter (C) of sweet pepper plants according to the nitrogen rates

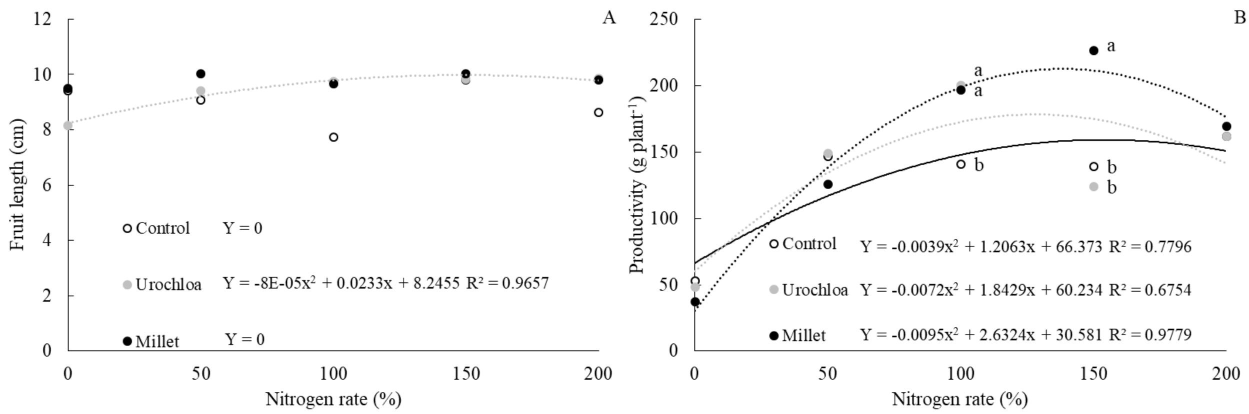

Figure 4. Fruit length (A) and fruit yield (B) of sweet pepper plants grown on different soil mulches and nitrogen rates

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In our study, it is possible that the millet and *U. ruziziensis* mulches kept the substrate at adequate moisture levels, preventing water deficit and consequently maintaining ideal CO_2 levels for the photosynthesis of sweet pepper plants, as well as transpiration levels, in line with the information above. On the other hand, the reductions in WUE and IWUE may have occurred due to decreased water availability in the plant due to the composition of the vegetation cover alone (*U. ruziziensis* or millet) compared to the treatment without the use of a straw.

Perin et al. (2015) noted that the speed of decomposition of mulch, when desiccated, varies depending on its composition, the climate, and the activity of living organisms in the soil, allowing their residues to remain for more or less time on the soil surface. The absence of straw in the control treatment increases the values of these two variables since there is a decrease in stomatal functionality as a result of increased water loss through the soil, resulting in water stress, especially during the early stages of plant development, when there is a concentration of the roots near the surface (Grasso et al., 2020; Ramos et al., 2022).

Unlike the effects observed for the straw treatments, the increase in *WUE* and *IWUE* in response to the increase in nitrogen rates results from the increase in net photosynthesis since there were no significant effects on transpiration and stomatal conductance. Also, the prominent increase in carboxylation efficiency results from the increased photosynthetic rate and use of intracellular CO_2 as a substrate for the fixation of atmospheric carbon.

Table 1. Pearson linear correlation coefficient between the characteristics of sweet pepper plants grown on different soil mulches and nitrogen rates.

	ci	*E*	*gs*	*A*	*WUE*	*IWUE*	*EICI*	RCI	NL	FM	FL	FD	YLD
ci		0.34	0.58	-0.78	-0.90	-0.94	-0.87	-0.73	-0.67	-0.59	-0.31	-0.53	-0.67
E			0.69	0.14	-0.41	-0.46	0.02	-0.28	0.05	-0.28	-0.40	-0.03	-0.05
gs				0.01	-0.34	-0.76	-0.14	-0.30	-0.21	-0.05	-0.05	0.09	-0.10
A					0.84	0.57	0.99	0.64	0.68	0.67	0.32	0.71	0.76
WUE						0.76	0.90	0.74	0.59	0.77	0.51	0.68	0.72
IWUE							0.69	0.62	0.59	0.45	0.29	0.36	0.54
EICI								0.69	0.70	0.67	0.34	0.69	0.76
RCI									0.78	0.80	0.19	0.79	0.87
NL										0.47	0.09	0.53	0.90
FM											0.55	0.96	0.78
FL												0.42	0.33
FD													0.81
YLD													
			**		*			ns		*		**	

ci = intracellular CO_2 concentration; *E* = transpiration; *gs* = stomata conductance; *A* = net photosynthesis; *WUE* = water use efficiency; *IWUE* = intrinsic water use efficiency; *EICI* = instantaneous carboxylation efficiency; RCI = relative chlorophyll index; NL = number of leaves; FW = fruit fresh mass; FL = fruit length; FD = fruit diameter; YLD = fruit yield; *, ** and ns = significant at 1%, 5% and not significant by the t-test.

The results found in this study agree with the statement of Taiz et al. (2015) regarding nitrogen fertilization. The authors state that an adequate supply of nitrogen impacts the growth and development of plants, especially the physiological aspects, since it directly interferes with the photosynthetic process, both in the photochemical and carboxylation stages. Nitrogen, a constituent of chlorophylls, is indispensable in the photosynthetic process. Even though it is indispensable, the results showed that for the variables analyzed, exceeding the recommended N dose impairs the development of the plant, leading to a decrease in the values related to its photosynthetic activity and the efficiency of converting chemical energy into production, increasing the growth and plant development of the sweet pepper fruits, which are the part of commercial interest. The correlation between morpho-physiological characteristics (Table 1) is also related to the prominent effect of nitrogen fertilization on the physiological characteristics of plants, increasing the photosynthetic capacity and, consequently, helping for efficient use of available resources, such as water and atmospheric carbon

The data found in this study agree with the observations made in a study by Campos et al. (2008), where nitrogen fertilization rates were assessed on the sweet pepper crop (cv. All Big). The authors state that the increase in the number of fruits per plant indicates that during the growth and development of the plants, the nitrogen applied efficiently supplied the nutritional demands of the crop, with the positive effect of the N rates responsible for the number of fruits and maximum fruit yield per plant, related to the supply of nutrients in an equalized manner. The inhibition of fruit growth characteristics (fruits per plant, fresh mass, and diameter) may have occurred due to the toxic effects of excess absorbed nitrogen or the low osmotic adjustment capacity of the crop (Carvalho et al., 2013).

We observed in our study that N supplementation above the recommended dose (100%) affects the development characteristics of the sweet pepper, and this may be due to the toxic effect that ammonium exerts on the plant, as well as the low rate of nitrification, causing the plant to reduce the uptake of other cations, such as Ca^{++} and Mg^{++}, for example (Carnicelli et al., 2000). Equivalent results were found in other studies, with the use of nitrogen fertilizer in the sweet pepper crop, showing that the increase in rates does not present, in general, a great influence on crops (Aragão et al., 2013; Silva et al., 1999), although there is divergence in the literature in this respect.

The use of higher nitrogen rates is related to the soil and climate conditions of this study, mainly related to soil composition. In this sense, other studies corroborate the results obtained since the presence of plant residues increases the organic matter content of the soil, increasing the amount and time of nitrogen availability for plants. In addition, the decomposing material partially supplies the demand for the nutrient since there is the availability and release of nitrogen present in the plant tissues of the cover plants (Mancinelli et al., 2019).

The results presented are in line with an important global demand related to the difficulty of acquisition and the increase in the value of nitrogen fertilizers (Schnitkey et al., 2022). Thus, the use of cover crops can be explored as an alternative for reducing the input of this nutrient in cropping systems through the better use obtained by modifying the edaphic environment.

4. Conclusions

Soil mulching with straw improves the physiological condition of sweet pepper plants, as does the application of nitrogen fertilization, which increases the characteristics related to gas exchange activity up to a dose equivalent to 100% of the recommended fertilization.

Authors' Contribution

João Flávio Floriano Borges Gomides, Eduardo Pradi Vendruscolo and Murilo Battistuzzi Martins: conceptualization, data curation and writing-original draft. Fernanda Espíndola Assumpção Bastos and Tassila Aparecida do Nascimento Araújo: writing-review and formal analysis. Thaise Dantas and Cássio de Castro Seron: writing review and editing.

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