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Effect of artificial light on alfalfa (*Medicago sativa* L.) production

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ABSTRACT

Objective: To study the effects of different sources of artificial light on the growth of alfalfa plants (*Medicago sativa* L.).

Design/Methodology/Approach: The experiment was established on four shelves with a height of 2.50 m with three divisions each, each division 80×60 cm long and wide, respectively. The sun's rays were allowed to shine on three of the upper divisions, and in the remaining nine divisions three different sources of artificial light were placed (LED, incandescent and fluorescent), with three divisions for each light source at a density of four lamps per division. The energy expenditure per lamp, the intensity of photons, and the production of dry matter were quantified.

Results: The data indicated that the incandescent lamp had energy expenditure 8 times higher than the LED lamp and 3.5 times higher than the fluorescent, although the light intensity emitted is 3 and 2 times higher in the LED lamp *vs.* incandescent and fluorescent, respectively. The highest production of dry matter was found with sunlight, obtaining values of 391 g m^{-2}, and the lowest production of 17 g m^{-2} was seen with the incandescent lamp.

Study Limitations/Implications: It is necessary to continue conducting research work on fodder production with artificial light, to increase biomass yields.

Findings/Conclusions: With the data obtained, it is concluded that LED light can be a viable alternative in the future to produce food for animal consumption.

Keywords: Dry matter, LED, fluorescent, incandescent.

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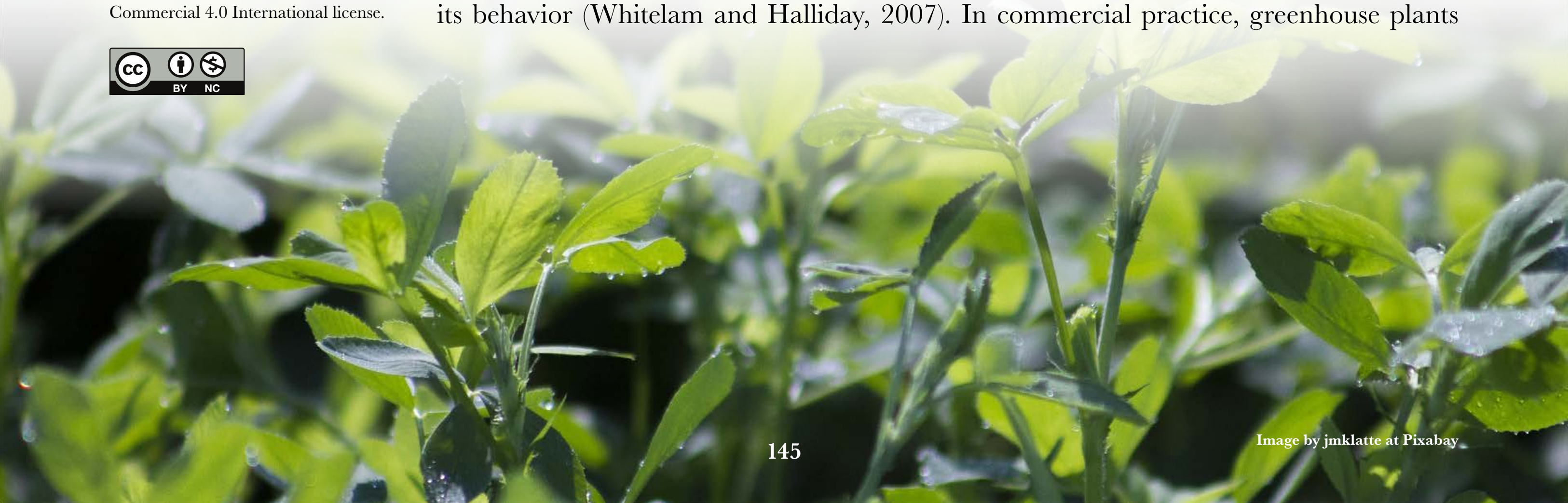
INTRODUCTION

Light plays a central role in plant physiology and ecology. Plants use light as a resource, through photosynthesis, and as a source of information (Bennie *et al.*, 2016), light is one of the most important environmental cues that affect the developing plant and regulate its behavior (Whitelam and Halliday, 2007). In commercial practice, greenhouse plants



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are supplied with supplemental light for a maximum of 16-20 h per day and the light intensity ranges between 100 and 200 μmol·m^{-2}·s^{-1} (Paradiso *et al.*, 2011), although lower levels are used for shade-adapted species. For example, according to Ouzounis *et al.* (2015) between 300-500 μmol·m^{-2}·s^{-1} is supplied for tomato (*Lycopersicum esculentum*) in commercial facilities in Scandinavia.

The photosynthesis process can be generated by artificial light sources including incandescent lamps (IL), fluorescent lamps (FL) and light emitting diodes (LED) (Massa *et al.*, 2008). However, the different types of artificial light sources have different light qualities for plant growth. For example, ILs are used mainly to extend the lighting time during seasons with a short daylight period. These convert only 15% of the electrical energy used into light for plant photosynthesis, while the remaining 85% is converted into heat that is not useful and can be harmful to plants (Massa *et al.*, 2008).

LED technology has not yet been fully integrated into the greenhouse control system and must be optimized in terms of light output and distribution, while the cost of LED lamps must be reduced to achieve sustainable and economically viable production (Morrow, 2008).

Light from FLs has been commercially applied in vegetable cultivation, uses less electricity and provides better plant growth than ILs (Shoji *et al.*, 2013). In Japan, about 60% of industrial plant farms use FLs as a light source (Shoji *et al.*, 2013). Many studies revealed that different types of LEDs could affect plant growth in terms of quantity and quality (Ruangrak and Khummueng, 2019); however, no study was found indicating the effect of artificial light on fodder production intended for animal consumption.

Therefore, this study aimed to research the effects of LED, incandescent and fluorescent artificial light sources on the growth of alfalfa (*Medicago sativa* L.) plants.

MATERIALS AND METHODS

The research work was carried out in the experimental greenhouse 3 ALA-2 SEC-2 of the Botany area of Colegio de Postgraduados, Montecillo, Texcoco, Estado de México, located at 19° 29' latitude North, 98° 53' longitude West, and 2240 masl.

The experiment was established on four shelves with a height of 2.50 m with three divisions, each division with dimensions of 80 cm long by 60 cm wide. On each division, a wood base with 20 cm height was placed where 70% sandy loam soil was added, with pH 8.2 and 4.1% of organic matter extracted from the experimental area known as new plot and 30% of compost of sheep and goat feces extracted from the CCIT experimental field of Colegio de Postgraduados. Seeds of the Jupiter variety were sown in all divisions at a density of 8 g m^{-2}, which were previously treated at 50%, generating an actual density of 4 g m^{-2}.

The sun's rays were allowed to shine on three of the upper divisions, and three different sources of artificial light (LED, incandescent and fluorescent) were placed on the remaining nine divisions, three divisions for each light source, at a density of four lamps per division, which were distributed at a height of 10 cm, with respect to the first leaf of the plant. They were provided with 18 h of artificial light per day and the shelves were covered with a black cloth that prevented sunlight from entering.

After planting, potable water was supplied every third day and continuous weeding was carried out every third day to prevent weed growth until day 150 when the first sampling was made. After 150 days, a ground level cutting was carried out to determine yield, then regrowth was allowed and a cutting was done at 28 days for three continuous periods. The mean of the four cuts represents the values reported as dry matter yield.

Dry matter yield

The dry matter (DM) yield of the aerial part was obtained by cutting the fodder at ground level. The biomass of each replicate was deposited in Ziploc plastic bags that were previously labeled, to later determine the partial moisture at the fodder laboratory of Colegio de Postgraduados, Montecillo Campus, as well as the residual moisture at the Animal Nutrition Laboratory of the Zootechnics Department of Universidad Autónoma Chapingo.

To quantify partial dry matter (pDM), the fresh sample was placed in a #8 paper bag and placed in a forced air furnace for 72 h at 55 °C. Once the time was over, the bags were removed from the oven and subsequently weighed on a Dibatec scale with a capacity of 600 g, and the pDM was calculated with the following formula.

$$\%pDM = (dry\ matter\ weight\ /\ fresh\ matter\ weight) * 100$$

To determine the total dry matter (tDM), the partially dried samples were placed in a furnace at 105 °C for 12 h (method 7.003, AOAC, 1980), using the following equation:

$$\%\ of\ tDM = (\%\ DM\ at\ 55\ °C) * (\%\ of\ DM\ at\ 105\ °C)\ /100$$

Intensity of light emitted and power consumption

To quantify the intensity of light emitted, a linear ceptometer, model LP-80 (DECAGON DEVICES INC.) manufactured in the United States of America, was used, in which an adapter was used to measure μmol of photons $m^{-2}\ s^{-1}$ at a specific site.

Commercial lamps were used and the energy consumption was obtained from the specifications of these lamps.

Photosynthetic rate

Twenty alfalfa plants of the Jupiter variety were grown in black perforated plastic bags measuring 20×20 cm, and their net photosynthesis rate (μmol CO_2 $m^{-2}\ s^{-1}$) was measured 100 days after sowing at the fodder laboratory of Colegio de Postgraduados.

Readings were taken with a previously calibrated portable photosynthesis meter system IRGA (Infra Red Gases Analyzer, USA), placing 5 leaves per repetition to make the measurement, which allowed to deduce the photosynthesis in alfalfa plants with different light sources. The photosynthesis rate (μmol CO_2 $m^{-2}\ s^{-1}$) was measured by placing a fully expanded leaf inside the assimilation chamber of the IRGA, where measurements are based on the differences in CO_2 concentration entering and exiting a closed chamber where the exposed leaf is found.

Statistical analysis

An analysis of variance was performed using the PROC GLM procedure of the SAS 9.0 statistical software (Statistical Analysis System version 2002), with a completely randomized design, in order to evaluate the relationship between the variables studied in the experiment. The means comparison was performed using Tukey's adjusted test (P=0.05).

RESULTS AND DISCUSSION

Intensity of light emitted and electricity expenditure per artificial light source

Table 1 shows the watts h^{-1} expenditure of the different artificial light sources; the energy expenditure was 8 times higher with the IL than with the LED and 3.5 times higher than with the FL. The intensity of the light emitted is 3 and 2 times higher in LED *vs.* IL and FL respectively. According to Ouzounis *et al.*, (2015) the use of LED lamps has the potential to generate significant energy savings for greenhouse producers who use artificial light sources because of the low energy expenditure. Nelson and Bugbee (2014) state that there are economic benefits when using LEDs, primarily produced in the United States, compared against other light sources.

In addition, there is a negative relationship between the distance from the artificial light source and the intensity, this trend agrees with that reported by Bennie *et al.* (2016), who mention that the greater the distance from the source, the lower the light intensity on a surface as it is scattered over a larger area.

With these results it can be inferred that in order to generate a high photosynthesis rate with an artificial light source, it is necessary to have a shorter distance with respect to the plant, otherwise the light intensity will not be sufficient to allow the photosynthesis process (Bennie *et al.*, 2016).

Table 1 shows the efficiency of the lamps, in which the LED artificial light emits more μmol m^{-2} s $watt^{-1}$ consumed, with values of 120 *vs.* 26.61 and 6.95 of the FL and IL, respectively. The efficiency data do not agree with those published by Ouzounis *et al.* (2015) who reported values close to 2 μmol m^{-2} s $watt^{-1}$, this difference with respect to the 120 μmol m^{-2} s $watt^{-1}$ found in this study may be due to the distance of the lamps with regards to the leaves, since the lamps were placed at a greater distance in the study by Ouzounis *et al.* (2015). Similarly, Van Leperen and Trouwborst (2008) report efficiencies of 1.9 μmol-m^{-2}-$watt^{-1}$ in high-pressure sodium lamps.

Likewise, the low efficiency of the IL to produce μmol m^{-2} s is related to the heat production it generates. According to Massa *et al.* (2008) and Etae *et al.* (2020) IL provides only 15% of illumination and 85% of the remaining energy is transformed into heat, which

Table 1. Consumption, intensity, and efficiency of artificial light sources.

Sources	Consumption watts/ lamp	Intensity μmol m^{-2} s^{-1} a 1 cm	Intensity μmol m^{-2} s^{-1} a 10 cm	Intensity μmol m^{-2} s^{-1} a 20 cm	Efficiency μmol m^{-2} s^{-1} $watt^{-1}$ a 10 cm
Incandescent light	60	417 [c]	97 [c]	27 [b]	6.95
Fluorescent light	23	612 [b]	149 [b]	22 [b]	26.61
LED ligth	10	1200 [a]	420 [a]	127 [a]	120.00

Different literals in the same column represent a significant difference with P<0.05.

justifies the high temperature presented by the ILs when they are illuminating, this being a negative effect of this source because they reached temperatures above 60 °C, when the room temperature fluctuated at 21 °C, which can cause negative effects on the crop if the ILs are near, contrary to what happened with LED and FL, which increased 1 °C with respect to the room temperature.

Table 2 shows alfalfa DM production with different photon sources; the highest production was observed with sunlight with values of 391 g m^{-2}, while the lowest production resulted from IL with 17 g m^{-2} ($P<0.05$). These results compared with those reported by Rivas et al. (2020), who observed production yields with open sunlit environment of 489 g m^{-2} DM for the winter season and 976 g m^{-2} for the summer season, data that are higher than those found in this study. With the above, it can be concluded that there is still much research to be done in alfalfa production in closed systems with artificial light sources.

On the other hand, the result of the division between dry matter production and intensity of light emitted can predict the efficiency of each light source to produce DM. According to the results, the light coming from LED is the most efficient with a value of 0.5 and the least efficient is from IL; however, it is important to emphasize that the value of sunlight intensity was the highest only throughout the day and sunlight intensity is not constant, so that the value of sunlight efficiency is overestimated.

The photosynthetic rate was determined by using the potted alfalfa plants. The highest value was observed with sunlight, presenting 28 μmol CO_2 m^{-2} s^{-1}, while with IL the value was the lowest at a distance of 1 cm (Table 3); however, it can be seen that as the plant is furthest from the light source the photosynthesis rate will be lower. The photosynthetic rate data of plants that received LED lighting at 10 cm 21 (μmol CO_2 m^{-2} s^{-1}) are statistically lower than those found with solar illumination at 13:00 hours of the day, when there was greater light intensity; however, the sunlight intensity is not constant and therefore this value is not permanent throughout the hours of sunlight. Thus, the values presented with LED lighting generate some expectation in the use of lamps in the future. Luna *et al.* (2020) reported values of photosynthetic rate of alfalfa lower than 20 μmol CO_2 m^{-2} s^{-1}, a value similar to that found in this study with the use of LED lighting.

The photosynthesis rate decreased as the distance between the light source and the plant increased, which may be attributed to the fact that the farther away the light source, the lower the photon intensity per surface area (Table 1).

Table 2. Dry matter production of alfalfa under different artificial light sources.

Light source	**μmol m^{-2} s^{-1} 10 cm**	**Production of MS g m^{-2}**	**Production in g de MS μmol m^{-2} s^{-1}**
Incandescent light	97 [c]	17 [d]	0.18
Fluorescent light	149 [c]	63 [c]	0.42
Led light	420 [b]	211 [b]	0.50
Sunlight	1680 [a]	391 [a]	0.23

The dry matter data are the average of four cutting periods, the first at 150 days after planting and three subsequent cuts from the sprouts with a rest of 28 days between cuts. Different literals in the same column represent a significant difference with $P<0.05$.

Table 3. Photosynthetic rate of alfalfa with different light source.

Light source	Photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) to 1 cm	Photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) to 10 cm	Photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) to 20 cm
Incandescent light	13 [d]	4 [c]	2 [b]
Fluorescent light	17 [c]	5 [c]	2 [b]
Led light	24 [b]	21 [b]	4 [b]
Sunlight	28 [a]	28 [a]	28 [a]

Different literals in the same column represent a significant difference with $P<0.05$.

CONCLUSIONS

LED light can be a viable alternative in the future to produce food destined for animal consumption, despite having a lower biomass production compared to sunlight; it is more efficient compared to other artificial sources.

It is necessary to continue research work on fodder production with artificial light to obtain higher yields, which will allow us to prepare for an uncertain future.

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