Article

Design and installation of an automatic shade mesh control system, case strawberry cultivation (*Fragaria* sp.)

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Abstract

At the national level, the application of electronic systems of automatic control in the processes of agricultural production is becoming more frequent. The development and application of automatic control systems allow the adaptation of cultivation techniques to environmental conditions, in order to achieve a more profitable and rational crop in small areas of the same agricultural exploitation. This work contemplates the development and evaluation of an automatic control system to control the opening or closing of a shadow mesh based on the incident radiation in the crop. An algorithm and program that automates the placement of the shadow mesh was developed with the help of a programmable logic controller (PLC Millenium III) for ease of implementation. The developed system was applied to the strawberry crop (*Fragaria* sp.). Tests and evaluation were carried out with three strawberry beds: open field, fixed mesh and mobile mesh controlled according to the radiation. The shadow mesh opens if the radiation is less than 400 W/m^2 or closes if the amount of radiation is greater than 600 W/m^2 when measured with a sensor, in addition it can be opened and closed manually to carry out the harvest and the maintenance. One of the results obtained is that the production in the bed under the mobile mesh is greater in 12.88% than in the fixed mesh and in 37.42% than in the open field.

Keywords: agriculture, automation, experiment, PLC, sensor.

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Introduction

At a global level, the improvement of agricultural production is increasingly frequent through the application of electronic systems of automatic control, which, in addition to the significant advantages in their performance, facilitate the operation, the adjustment, and the detection of faults, making it possible to carry out activities more suitable according to the agronomic requirements of the crop.

The development and application of automatic control systems allow the adaptation of cultivation techniques to environmental conditions, taking into account also the needs of the plants and the essential optimization of the use of inputs, to achieve a profitable and rational crop in small areas of the same agricultural exploitation (IDEA, 2010; Méndez, 2015).

But the application of automatic control systems (SCA) in agriculture is still in the first stage of its development and its poor adaptation is mainly due to the lack of economic resources, skills and competence (Pierpaoli *et al*., 2013). The best results of the application of the SCA are the saving of inputs and the increase of the production Bragachini *et al*. (2010).

As for the environmental control systems, for the crops there are different mechatronic systems to operate the different equipment under the roof of the facilities such as greenhouses (Ponce, 2015), dryers (Garduño, 2017). Research conducted by Hemming *et al*. (2006) and Zari (2011) explain the effect of shading meshes on greenhouses and their microclimate. Moaid and Hashing (2013), performed the control of the speed of two motors using closed loop control, for this they used microcontrollers. Irrigation system control was developed with selection of the elements, controllers, panels, motors of solar energy systems in agriculture (Martínez, 2015; Romantchik, 2013; Cebada, 2016).

For the automation and control of the system, a PLC (Programmer Logical Controler) was implemented since this intelligent controller is used mainly for the automatic control of different systems in all types of industries (Hernández, 2010). The PLC allows working in environments with adverse conditions, which makes it optimal for working in the agricultural field (Byron, 2005, Guzmán, 2015; Méndez, 2015) in order to control various types of machines or processes through sensors and motors (Bolton, 2009).

Solar radiation is one of the main environmental factors affecting life on our planet, since it controls the functioning of terrestrial ecosystems both through the control of photobiological processes (photosynthesis, photoperiod) and through its action on other environmental factors (temperature, humidity, etc.). Just as it is a fundamental part for biological processes such as photosynthesis, too much radiation can damage the plant by increasing the ambient temperature stressing the plant and can cause a rapid maturation and deformation and damage of the fruits (Bastida, 2008).

The use of shade mesh is a strategy used to protect plants from direct solar radiation, reduce the temperature and prevent the sunburn of the fruits (Ayala-Tafoya, 2011, 2015). The use of a fixed mesh decreases radiation on cloudy days, reducing the possibility of receiving adequate radiation these days. By using meshes, it can reduce between 10 to 95% of the total solar radiation. The amount of light that is allowed to enter the interior depends on the species that is in the crop and an ideal shade should be a selective filter that stops excess radiation without affecting the visible or useful part for photosynthesis (Juárez, 2011; Medina, 2012). With the meshes, the passage of rainwater is not avoided, they are also permeable to the wind, avoiding excess temperature. The automatic control to open and close the meshes cannot be done by using photo cells or phototransistors because they saturate so it is necessary to have a lighting sensor that measures 100 klux (Hahn, 2011).

The area planted with strawberries nationwide reached 11 092 ha in 2016, of which 57% of the production is temporary, and the rest is irrigated by gravity, drip and sprinkler with a yield of 42.5 t ha^{-1} (4.25 kg/m^2) and 48% of production is for export. The system of production of strawberry in Mexico is open field or involves the use of plastic covers that serve to protect the fruits of the rots and limit the growth of weeds; however, plastic cover reduces the possibility of soil wetting caused by precipitation, so it is necessary for farmers to install irrigation systems.

The strawberry is a non- climacteric fruit, the process of its maturity and seasoning is a gradual but continuous process. It has a short shelf life. Strawberries contain around 15% solids and 85% water. They are very sensitive to the amount of light received during their growth. With a lot of radiation, the vaporization is increased and with low light it retards its growth. High temperatures cause vegetative growth and low temperatures induce flowering (Gruda, 2005).

The temperatures suitable for the strawberry are: temperatures lower than 6 °C the plant satisfies its own requirements of cold that needs to interrupt the dormancy or lethargy of the branches. During the vegetative phase, the optimum temperature is about 20 °C in the day and 12 °C at night, although the return of the cold is tolerated without damage. The thermal demands during the flowering and maturation phase that develop always optimally are at 25-26 °C (Bianchi, 2000).

The strawberry is the horticultural species that needs more nutritious requirements, that is why it demands the following formula of fertilization (Bianchi, 2000) nitrogen: 80-150, phosphoric anhydride: 50-100, potassium oxide: 100-200, calcium oxide: 60-80. In this research, an automatic system was designed built, programmed and evaluated that allows to control the opening and closing of the shade meshes. Based on direct radiation in the strawberry crop, as well as its irrigation.

Materials and methods

The work was carried out in the Postgraduate Course on Agricultural Engineering and Integral Use of Water (IAUIA, by its acronym in Spanish) of the Autonomous University of Chapingo (UACH) and the evaluations of the SCA were conducted in an experimental field of renewable energies located in Chapingo, State of Mexico, Mexico, at 19° 28' 40" north latitude and 99° 00' 45" west longitude and altitude 2 238 m above sea level. The soil of the site is of the chromic Vertisol type FAO (2007), dark gray in dry and gray when moistened, whose surface drainage is regular.

An SCA was developed for data processing, automatic management of shade mesh and irrigation. The SCA uses the following components, a PLC Milleniun III XD26, which has 16 digital inputs and 6 analogue 24 V, a light sensor LDR A106-300 Crouzet brand with a range of measurement of 1-3 000 lux, two sensors position, which indicates that the mesh is fully open or closed; as a system actuator, it uses the ERU-B motor of 24 V DC of 100W of power, with speed of 5.6 rpm and 80 Nm of torque.

In order to measure up to 90 000 lux during the day, a filter for the light sensor was developed, and the maximum and minimum ranges for the sensor were determined by adding a gain function to the PLC program, thus determining the maximum range of the sensor as 102 mV and the minimum range as 0. This means that when the sensor detects a value of 102, the incidence of solar radiation in the place will be the maximum and when it detects a value of 0, it will be the lowest possible incidence. Once the ranges were determined, a PCE-LED 20 luxometer was used to perform the sensor calibration, for which purpose the sensor with its filter was placed in different places at different values of solar radiation and the data was taken from both the sensor as of the luxometer in order to determine a feasible scale for the sensor.

The algorithm of operation with programming for PLC allows to open and close the mesh according to the requirements of a crop. The following values of solar radiation were used for the evaluation of the SCA: open with 600 $W*m^{-2}$ and close with 400 $W*m^{-1}$. The programming type is Functional Block Diagram (BDF), with Boolean logic functions, as well as numerical and comparative functions.

It used the bridge H consisting of 4 relays to connect the PLC to the motors, so that the PLC does not connect directly to the motors to avoid any possible damage to the PLC, since the motors, when forced for some reason, they can cause it. With the relays the PLC activates or deactivates the motor for opening and closing the mesh and the irrigation motor. A computer was used to elaborate the program with the Millenium III software and introduce it to the PLC.

A module of a photovoltaic panel and batteries was installed to power the system, making it more environmentally friendly to the system and reducing the energy demand of the crop where it is installed, in this case strawberry. The elements of the photovoltaic system were selected with the help of software (Romantchik, 2013). The experiment aims to verify if the SCA works correctly, according to the algorithm developed: the mesh is closed with radiation of 600 W/m^2 and opens with the 400 W/m^2, as well as with manual operation, and the irrigation control.

In order to have the possibility to evaluate the developed SCA and determine the effect of light and radiation on the growth of strawberry plants (*Fragaria* sp.) the Chandler variety, which is commonly rown in the state of Mexico, was chosen. Installed an experiment of three beds of 10 x 3 m: open field, with fixed mesh and automatically controlled mobile mesh. In each of these areas strawberry plants were placed so that they serve as part of the comparison. The solar radiation data was consulted with the UACH weather station on the experiment days and compared with the light sensor data. Strawberries of three beds were collected and measured every 7 days and compared for two and a half months.

As well as an automatic drip irrigation system controlled by the same PLC and consisting of a 300 liter tank, an AC motor of 0.25 kW that applies water and fertilizers every 20 min. Once the plants started germination, a mixture of high solubility commercial fertilizer (values in grams per kilogram of dry soil, g kg^{-1}) was applied to the soil of each bed, as follows: N-0.4; P2O5-0.03; K2O-0.05; CaO-0.0005; MgO-0.0013; S-0.00137; B-0.0002; Cu-0.00014; Fe-0.00012; Mn-0.0013; Mo-0.00005 and Zn-0.0002.

The reaction time of the program was evaluated, this is how long it takes to open and close the shadow mesh, as well as at what times of the day it is open and closed.

After having verified the correct functioning of the SCA, they were assigned on may 30 and 31 to supervise the entire day every hour from 8 in the morning until 7 at night, monitoring the amount of radiation that marks the sensor and was compared with that of the meteorological station of the UACH, in addition to checking the status of the mesh if it is open or closed and checked according to the radiation if it should be in that state.

Results and discussion

Development of the elements of the control system, algorithm and program

In the Figure 1 shows the automatic control system of the shadow mesh with its elements. The PLC has analog and digital inputs, of which two digital inputs were used to connect the two proximity sensors and an analog input was connected to the light sensor. In the two outputs, the motor of the shadow mesh was connected in such a way that one output is for the rotation of the motor in the clockwise direction and the other output will be for rotation in the counter-clockwise direction. Also, an output was destined for the connection with the irrigation motor through the relays. In addition, a circuit was placed (bridge H), which connects the PLC with the motors, which has the function of being a switch and also, protect the PLC from any overload due to the effort of the motors.

Figure 1. Scheme generating of the automatic control system: A) shadow mesh with motors; B) PLC; C) light sensor; D) position sensors; E) bridge H; F) batteries; G) laptop; I) solar panel; H) controller; and I) irrigation engine.

For loading the motors and the PLC itself, using the software, the solar photovoltaic panel, two deep discharge batteries and a regulator with the following characteristics were selected: panel-brand-solar one, model - HSL60P6-PB-4- 245, 24 V and 245 W power, the batteries are as follows - brand - Steren, model - BR-1212, with 12 V per unit, and 110 Ah capacity, of the voltage regulator that was used to correctly charge and discharge the batteries of the photovoltaic system, in addition to supplying the correct voltage to them, thus avoiding an overload - the brand was ENESOL, 24 V.

After the selection of the SCA elements, an electrical system was developed, consisting of three main parts: power supply (a) bridge h and motors; (b) and the control with the entries; (c) as shown in Figure 2.

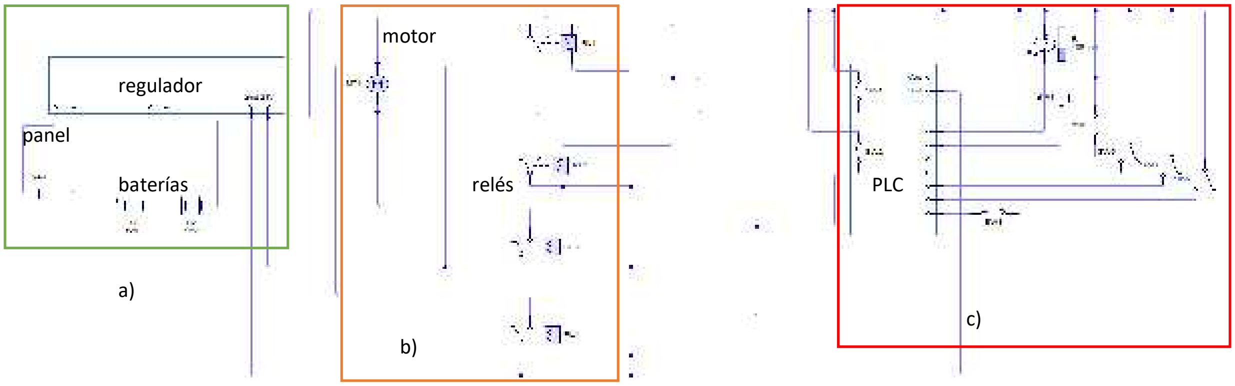

Figure 2. Electrical diagram. a) power supply system with panel and batteries; b) H bridge with relays and motor; and c) PLC with light sensor and final contacts.

The power system consists of three components: battery bank, solar panel and voltage regulator. The control was carried out with a Millenium PLC, receiving the signals from a radiation sensor (R1), and from two motor position sensors, in addition to a main switch, and two buttons for manually opening and closing the shadow mesh, connecting in the way shown in Figure 2 and sending signals to two outputs SW1 and SW2 for the mesh motor (the output for the motor or the irrigation is not shown). The main element of control is the algorithm of operation of the shadow mesh (Figure 3) that was made according to an operating logic that the program that was developed from it had to have.

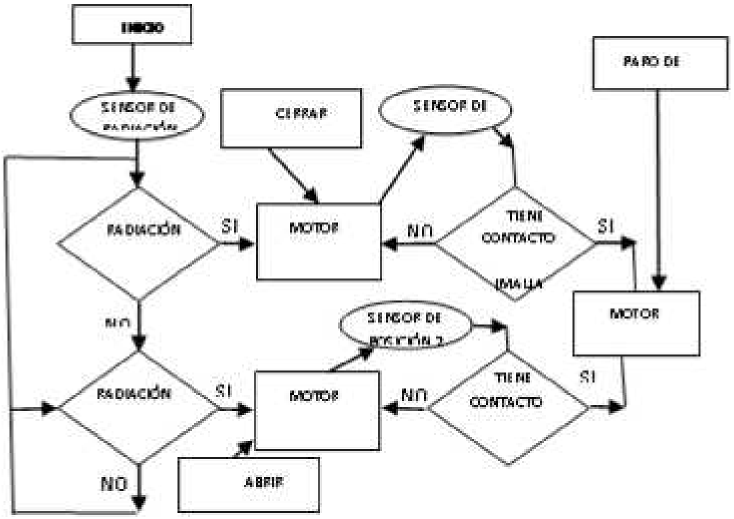

Figure 3. Algorithm of functioning of the SCA.

Subsequently, the program was developed in the MILLENIUM III software on a laptop, which would then be uploaded to the PLC. When carrying out the program, in addition to what the flow chart contained, an algorithm was added for the operation of the irrigation system to irrigate and fertilize the plants (Figure 4).

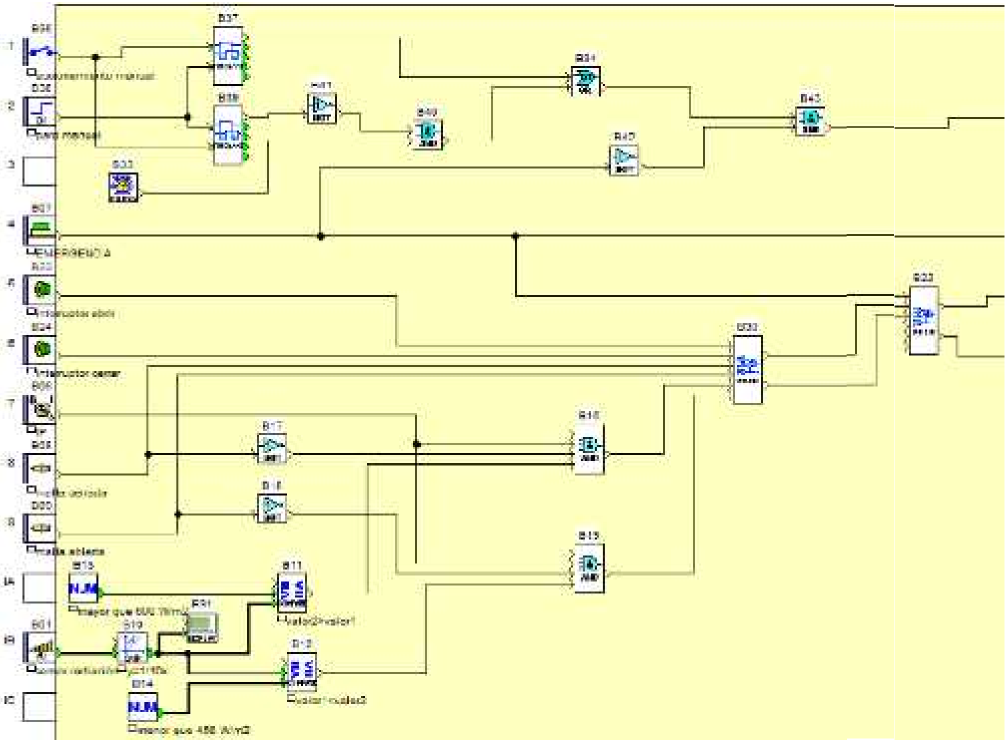

Figure 4. Program in Millenium III.

According to the methodology, the light sensor was calibrated. The data obtained are shown in the following table:

Table 1. Sensor calibration results.

Sensor	mV	9	12	19	35	51	54	65	75	80	102
Luxmeter	Lux	9430	10700	20100	40100	55400	51600	70800	77500	78400	88000

With these data the logarithmic curve was determined by numerical method, to use this function in the programming of the PLC (Figure 5).

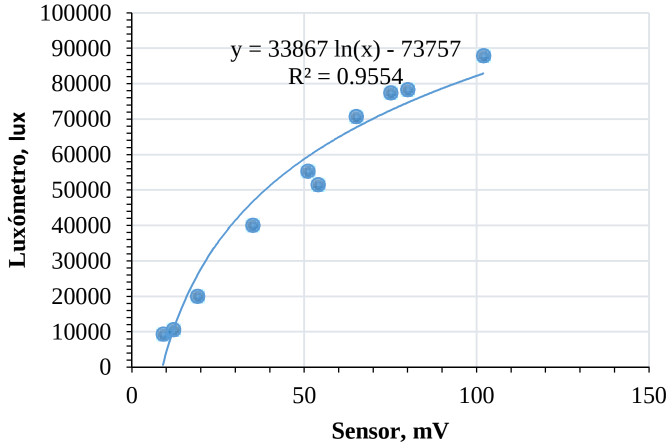

Figure 5. Calibration chart.

Once the SCA equipment was installed, the same tests as in the simulation with the computer, automatic opening and closing by means of the radiation sensor, as well as the manual opening and closing buttons, including the action of the button, were performed. emergency stop, which stopped all activity. The time it took to open and close the shadow mesh was 3.2 min for each operation.

To completely close the shadow mesh, an additional strip of this was applied to the axis where the shadow mesh is rolled (Figure 6). One end of the strip was placed in the structure and the other on the axis of the shadow grid, so this will be wound uniformly without obstructing the unwinding process or winding of the mesh and helping perfectly this spread and cover the area of culture.

a

Figure 6. Beds with strawberry (left), adaptation of the mesh to move (right).

The opening and closing tests of the mesh were carried out manually with the buttons of the control board. After testing with the sensor, this was done by plugging the sensor to detect less radiation and thus open the mesh until the end and drive the position sensor to stop the engine, then uncovered the sensor and activating the motor its closure and this was stopped at the end by the activation of the other position sensor.

Table 2. Radiation on day 30 and day 05/31/2017 [W/m^2].

30/05/2017						31/05/2017				
Hour	Sensor, mV	Station	Automatic mesh	Fixed mesh	Status of the mesh	Sensor, mV	Station	Automatic mesh	Fixed mesh	Status of the mesh
08:00	8	87	87	43.5	Open	4	34	34	17	Open
09:00	21	205	205	102	Open	15	140	140	70	Open
10:00	14	140	140	70	Open	14	138	138	69	Open
11:00	61	600	300	300	Closed	25	247	247	123.5	Open
12:00	73	728	364	364	Closed	71	709	354.5	354.5	Closed
13:00	20	198	198	99	Open	45	454	227	227	Closed
14:00	78	768	384	384	Closed	43	426	213	213	Closed
15:00	60	599	299	299	Closed	14	137	137	68.5	Open
16:00	62	611	305	305	Closed	11	100	100	50	Open
17:00	9	94	94	47	Open	7	66	66	33	Open
18:00	15	153	153	76.5	Open	3	26	26	13	Open
19:00	3	25	25	12.5	Open	1	5	5	2.5	Open
Total		4208	2554	2104			2482	1687.5	1241	
(%)		100	60	50			100	69	50	

On May 30 and 31, a record of the radiation measurements of the sensor was made to compare it with those of the UACH meteorological station and from there, to know the incident radiation in each bed, the data are shown in Table 2. With the radiation data two graphs were made (Figure 7), to compare the radiation in the three beds of the crop. It is observed that the solar radiations are different. If the solar radiation is taken as 100% in the open bed, in the bed with fixed mesh it is always 50%, but in the bed with mobile mesh is up to 70%, improving the reception of the radiation in the non-maximum times of radiation solar.

The bed plants with the fixed mesh have a deficiency of radiation that implies a lower yield per plant; On the other hand, the bed that does not have shade mesh receives too much radiation, which is why the temperature of the plant increases, generating a greater stress which also leads to a lower performance.

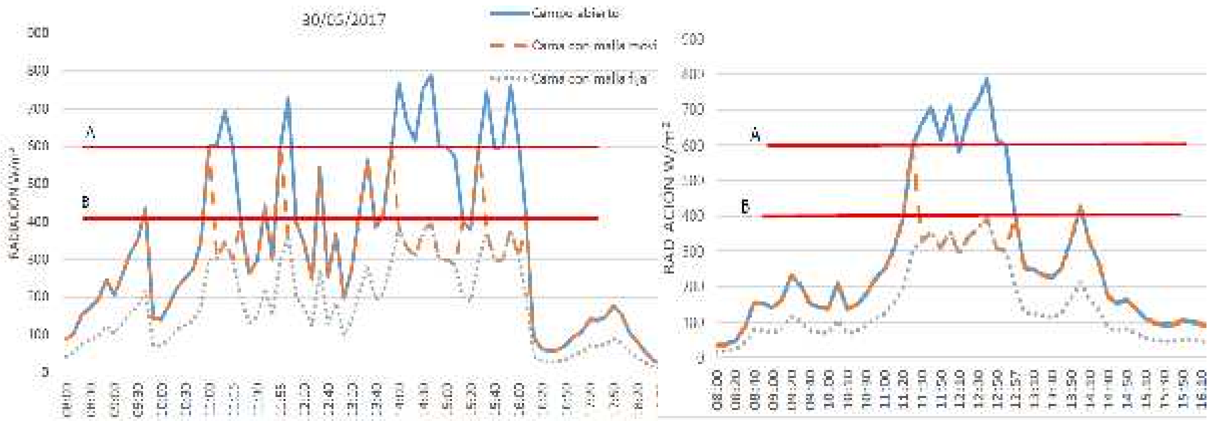

Figure 7. The change of solar radiation on the crop: left-30.05.2017, right - 05.31.2017.

Lines A and B are the limits of radiation control in the field with the mobile mesh, changing their values can increase or decrease the amount of radiation received by the drill.

The strawberries were planted on February 12, from 172 plants in each bed to May 30 are the plants shown in Table 3. As you can see the SCA helped us keep more plants alive (94.5%), since these present less stress by having the most optimal conditions for the plant. Doing so they produce, resulting in a production of 8.15 g per plant in the area where the automatic mesh is, 7.3 g per plant for the fixed mesh and 5.1 g per plant for which it has no mesh, this from the first cutting day that was on April 29 as shown in Table 4.

Table 3. Percentage of live plants (of 172 planted).

	Automatic mesh	Fixed mesh	Without mesh
Plants	162	156	132
Percentage	94%	90%	76%

Table 4. Performance per bed (g).

Day	Automatic mesh	Fixed mesh	Without mesh
29/04	100	70	25
06/05	130	100	80
13/05	180	150	120
20/05	240	180	200
28/05	770	720	270
Total	1 320	1 150	670

The results obtained were that the program acts in a concise manner as it was intended, opens and closes according to the radiation that the sensor measures, as well as allowing the mesh to be opened or closed manually. Open if required to perform any work to the plant such as weeding, harvesting and application of any agrochemical either for control of pests or weeds.

With the above, one of the objectives of the research is met, which was to control a shadow mesh based on the radiation and to control the radiation and temperature in the crop in the same way as it was evidenced: in the months in june and july the use of the meshes kept the temperature below 25 °C (Hahn, 2011). It has that under the area of the automatic mesh was obtained higher yield, in addition to better quality also checking what was said by Hahn (2011), which mentions that the fruits, in this case tomatoes, decreased their weight due to the increase in temperature in the air without mesh

With this it is affirmed that the control of the opening and closing of the shadow mesh has enough benefits since as can be seen in the results, better yields were also obtained in the area where the control of the shadow mesh was overcoming the performance by plant where there was no such system, which obtained less amount of fruit and the same way had a smaller size. In this way, the SCA of the shade mesh for strawberry decreased the loss of the plants by 25% compared to the open field and 15% compared to the fixed mesh.

The profit for the plant of 10.43% more than with the fixed mesh and of 37.42% in relation to the plant that does not have mesh, while the gain per bed is 12.88% greater than in the bed with fixed mesh and of 49.25% greater compared to the bed that does not have mesh. For all the above, we could infer that this automatic control system could not only be applied to strawberry crops, but also to a wide variety of horticultural species, since controlling the radiation and ambient temperature where they are developed provides an ideal means of it substantially improves the yield of the crop, which broadly translates into higher income for the producer.

Conclusions

A shade mesh SCA was designed that can control the incident radiation in any crop by opening and closing a shadow mesh by means of a DC motor, which is controlled by a PLC according to the signal obtained by a radiation sensor.

The SCA was powered by a solar photovoltaic system, which allows it to be sustainable.

It was proved that the use of the mobile mesh as a function of radiation improves strawberry production.

The SCA is available to optimize the incident radiation in the production of agricultural crops.

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