

RESEARCH

INFLUENCE OF DOUBLE CROPPING ON GROWTH AND YIELD OF DRY BEANS WITH COLORED PLASTIC MULCHES

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There are numerous studies of the use of plastic mulches in vegetable production, but there is little documentation of their use with dry beans (*Phaseolus vulgaris* L.) in single and double cropping. The objective of this study was to grow dry beans over two consecutive growing seasons using the same plastic mulch of different colors and examine the influence of soil temperature on growth and yield. The experiment was conducted in Saltillo, Coahuila, Mexico, in the spring and summer of 2008. The treatments included four colored plastic mulches: white-on-black, black, silver-on-black, aluminum-on-black, and bare soil as a control. The experimental design was a randomized complete block with four replicates. The percentage of photosynthetically active radiation (PAR) reflected from the plastic tended to be highest with the white-on-black mulch and lowest with the black mulch. Mean soil temperature under the plastic mulch decreased with the increasing percentage of reflected PAR. Mean soil temperature exhibited a relationship of 98% and 99% to yield in the first and second growing season, respectively. Photosynthetically active radiation had a relationship of 98% and 86% to yield in the first and second growing season, respectively. The effect of the colored plastic mulch on yield was significant ($p \leq 0.05$) in the first growing season but not in the second, where plastic mulch and bare soil treatments had similar yields, indicating that plastic mulches do not always increase yield.

Key words: *Phaseolus vulgaris*, soil temperature, photosynthesis, PAR, plasticulture.

Plastic mulching provides the opportunity to obtain double crops by using the same production system in two consecutive growing seasons. There is a possibility of increasing the cost-effectiveness of plastic mulching while reducing the negative impact on the environment by using the same plastic film for double cropping (Waterer *et al.*, 2007). Double cropping reduces the cost of plastic mulch and drip irrigation tapes and decreases plastic residues in the field (Hanna, 2000a; 2000b; Ngouajio and Ernest, 2005). In regions where a long growing season is possible, fall crops can be planted in the mulched plot once the spring crop has been removed (Hanna, 2000a). In regions with a short growing season, the second crop is planted in the spring of the following year, leaving the plastic film exposed for longer than 1 yr to obtain a second harvest. The success of the second crop depends on maintaining the physical, optical, and thermal properties of the polyethylene in good condition for the second

season (Ngouajio and Ernest, 2005; Waterer *et al.*, 2007).

Double cropping in the same year (Hanna, 2000a; 2000b) or different crops in different years (Ngouajio and Ernest, 2005) has been well documented. However, it is possible that the yield in the second season may be lower as consequence of the lost of properties of the plastic (polyethylene) caused by the prolonged exposition to radiation.

The common dry bean (*Phaseolus vulgaris* L.) is the world's most important legume for direct human consumption, especially in Latin America and in East and southern Africa. Twelve million metric tons are harvested annually worldwide, of which about 8 million tons are from Latin America and Africa. In Mexico, 1.07 million tons was produced in recent years (FAO, 2010).

Plastic mulching has been developed mainly for vegetable crops (Ibarra Jiménez y Rodríguez Piña, 1997; Lamont, 2005; Díaz-Pérez, 2010) and therefore there is very little information as to the effects of this technique on growth and yield in dry bean. A previous investigation in which dry bean was seeded on four different dates and mulched with a black plastic film indicated that this species responds positively by increasing yield, regardless of seeding dates. However, clear plastic films had a negative effect in three out of the four dates as seedlings collapsed due to excessive temperature stress, while plants mulched with a black plastic film exhibited

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reduced yield when seeding was conducted late in the season due to an excessive accumulation of heat in the soil (Ibarra Jiménez y Rodríguez Piña, 1997). Some farmers in northern Mexico use a production system in which plastic mulch and drip irrigation tape are used for double cropping of melon (melon after melon), with the potential benefit of obtaining higher profits.

The objective of the present study was to evaluate the possibility of obtaining two consecutive crops of dry beans on the same plastic mulch of different colors, and to examine the influence of soil temperature on growth and yield.

MATERIALS AND METHODS

Field studies were conducted at the Centro de Investigación en Química Aplicada, Saltillo, Coahuila, Mexico during 2008. Soil pH in the experimental site was 7.3 and the soil had a clayey texture (clay 47%, silt 32%, and sand 21%).

The experimental unit for the two growing seasons consisted of individual beds (0.6 m wide, 7 m long) spaced 1.8 m apart. Beds were mulched with plastic films of four colors: white-on-black, black, silver-on-black, aluminum-on-black, and bare soil as control. All the polyethylene plastic mulches used were 0.03 mm thick and 1.2 m wide (Pliant, Chesterbrook, Pennsylvania, USA).

Throughout each growing season (approximately 60 d), the soil was fertilized through the irrigation system to a total of (kg ha⁻¹) 80 N, 40 P, 0 K, which is a rate similar to that used by bean farmers in different parts of Mexico. Only 27 kg N ha⁻¹ was applied to the second crop, with no P or K because it has been proven that with double cropping the quantity of fertilizers can be reduced in the second season (Mayfield *et al.*, 2002). Drip irrigation tape with emitters spaced 0.305 m apart was placed on the soil surface 5 cm apart at the center of the beds. Plants in all the mulching treatments received irrigation water as necessary. Seeding of the first crop was on 30 March 2008 by placing manually seeds of cv. Peruano on a raised bed, three rows per bed, with 0.1 m of space between plants. Once the first crop was completed, plant residues were removed from the field and seeds of the same cultivar were seeded on 7 July 2008 in the same holes of the plastic films already installed for the first crop.

Soil temperature was measured at a depth of 0.1 m (midpoint between plants), using copper-constantan thermocouples (0.6 mm diameter) connected to a data logger (CR23X; Campbell Scientific, Logan, Utah, USA) and a multiplexer (AM25T, Campbell Scientific). The data logger was programmed to record readings every 10 s and store daily values of maximum, minimum, and mean soil temperatures.

Photosynthetically active radiation (PAR) was measured with quantum sensors (Apogee Instruments, Logan, Utah, USA) for 60 d after seeding in both growing seasons. Reflected PAR (*rPAR*) was measured by placing

the quantum sensors 30 cm above the soil level and covering the width of the mulched bed; the sensors were placed facing the plastic mulch or the soil on non-mulched beds. The amount of PAR reflected by the mulches was expressed as a percentage of the incoming PAR. Radiation measurements were saved in the same data logger used to record the soil temperatures and at the same time interval.

The photosynthesis rate was measured using a portable photosynthesis meter (LI-6200, LI-COR, Lincoln, Nebraska, USA). Measurements were performed only on clear days between 11:00 and 13:00 h on the fourth youngest fully expanded leaf of three plants randomly selected in each plot. Dry plant biomass was determined on four sampling dates during the growing season from three plants for each experimental unit. Both crops were harvested at approximately about 80 das. Grain yield was measured as total yield per plot and transformed to t ha⁻¹.

The treatments were established in the field using a randomized complete block experimental design with four replicates. Data were analyzed using the Statistical Analysis System PROC GLM (SAS Institute, 2009) and the means were separated by LSD procedure ($P = 0.05$).

RESULTS AND DISCUSSION

Soil temperature

Averaged across plastic mulch treatments, maximum mean soil temperature was 24.3 °C during the first crop and 24.6 °C during the second, whereas minimum mean soil temperature was 20.6 and 20.4 °C for the first and second crop and soil mean soil temperature (MST) 22.6 and 22.4 °C, respectively (Table 1). In the first crop, mulch treatments recorded a higher MST ($p \leq 0.05$) compared to that of bare soil, except for aluminum plastic mulch. In the second crop, mulch treatments in white and aluminum plastic mulches showed a MST similar to that of the control (Table 1). The differential response between

Table 1. Mean, maximum, and minimum mulched soil temperature, and reflected photosynthetically active radiation (rPAR) on dry bean crop grown with colored plastic film during spring and summer of 2008.

Film color	T media	T max	T min	rPAR
				%
°C				
First crop				
Black	23.4a	25.2a	21.2a	7.4
Silver	22.9a	24.5ab	20.9a	9.4
White	22.5ab	23.9ab	20.7ab	12.4
Aluminum	22.8a	24.3ab	20.9a	10.6
Bare soil	21.5b	23.5b	19.3b	7.7
LSD	1.03	1.64	1.4	NA
Second crop				
Black	23.0a	25.9a	20.8ab	6.7
Silver	22.7ab	25.3ab	20.8ab	8.6
White	22.3bc	23.6c	20.5ab	11.8
Aluminum	22.2c	24.8bc	20.3ab	9.7
Bare soil	22.1c	23.6c	19.9b	5.8
LSD	0.57	1.35	1.42	NA

Means within each column followed by the same letter are not different at $p \leq 0.05$. LSD: least significant difference. NS: non significant. NA: Not available.

Data in the column came from one reaping.

seasons in MST with white plastic may have been due to a deleterious effect on the plastic's optical properties associated with the longer exposition of the film to solar radiation by the time the second crop was established.

Colored plastic mulches significantly increased MST compared to the control; however, MST was similar during the first crop among all the plastic colors (Table 1). Results were different with the second crop because the color of the plastics significantly affected soil temperatures; MST in black plastic mulch was higher than that observed in white and aluminum films (Table 1).

A reduction in the optical properties of the plastic films by the second crop may explain the lesser difference in soil temperatures between mulched and non-mulched soils. It has been reported that white and aluminum-colored plastic mulches tend to lose short-wave radiation transmission to a greater extent than plastics of other colors. In general white mulches are more associated with lower soil temperatures than other colors (Lamont, 2005; Díaz-Pérez, 2009). The lower effect on soil temperature of the white plastic films observed in the second crop may be because they tended to lose their whiteness quickly due to the accumulation of dust and soil on the surface, turning the plastic yellow, which in turn led to a loss of optical properties after a given period (Summers *et al.*, 1995). In contrast to the results of the present experiment, Ngouajio and Ernest (2005) reported that in a double cropping of cucumber after tomato white plastics were among those with less loss of optical properties, and that they also exhibited less heat loss during the second crop, which was probably because the plastic film was of better quality, allowing only 10% loss of physical properties after exposure of over a year. The severity in the loss of properties in plastics varies according to their chemical composition and the duration of exposure to the environment. Aluminum-colored plastic is considered aphid repellent since it reflects significant PAR radiation (Csizinszky *et al.*, 1995). However, in the present study this effect was not observed because the incidence of pests was similar in all the treatments. The silverleaf whitefly (*Bemisia argentifolii*) was the most common pest observed in both growing seasons and was controlled by spraying conventional insecticides. A problem with aluminum mulch is that it loses shininess, thus in our study less radiation was reflected and a decrease in soil temperature was observed during the second crop. In the present study, as in others (Ham *et al.*, 1993), black films recorded the highest MST in both growing seasons and, in accordance with Ngouajio and Ernest (2005), there was less loss of heat accumulation properties during the second crop.

Vegetative growth

In general, the plant dry weight (DW) of the second crop was lower than that of the first (Table 2). Compared to the DW of plants in bare soil, plant DW was consistently

Table 2. Dry weight at 20, 30, 40, 50 days after seeding (das) of dry beans plants grown with colored plastic film mulches during spring and summer of 2008.

Film color	Plant dry weight			
	20 das	30 das	40 das	50 das
	g			
First crop				
Black	1.01a	4.06ab	12.11a	18.54ab
Silver	1.07ab	4.65a	11.93a	19.40ab
White	1.09ab	4.01ab	8.67ab	16.60ab
Aluminum	1.31a	4.44a	10.16ab	22.45a
Bare soil	0.80b	2.72b	6.46b	12.95b
LSD	0.32	1.64	4.97	7.04
Average	1.06	3.98	9.90	17.99
Second crop				
Black	1.09	3.34	8.86	10.36
Silver	1.02	3.88	7.32	10.89
White	0.99	2.99	8.59	11.22
Aluminum	1.03	3.43	8.00	11.72
Bare soil	1.08	2.95	7.88	11.03
LSD	NS	NS	NS	NS

Means within each column followed by the same letter are not different at $p \leq 0.05$. LSD: least significant difference. NS: non significant.

higher ($p \leq 0.05$) in the first crop when mulched with aluminum-colored plastic at 20, 30, and 50 das (Table 2). Similar tendencies were observed with black, silver, and aluminum plastic mulches when plant DW was averaged across the four sampling dates (Table 3). In the second crop, plant DW was not affected by plastic mulches during the growing season and the plants grown with plastic mulch had similar behavior to the plants on bare soil (Table 2).

Plant dry weight and grain yield

In the first crop there were differences ($p \leq 0.05$) among treatments in mean plant DW, pods per plant, 100-seed weight and grain yield (Table 3). However, this effect was not observed in the second crop since treatments with plastic mulch and bare soil had similar results in mean plant DW, seed weight and grain yield. In the second crop, there was only a difference among treatments in the

Table 3. Mean plant dry weight, pods per plant, weight of 100 seeds and yield of dry beans grown with colored plastic film mulches during spring and summer of 2008.

Film color	Mean plant dry weight	Pods per plant	Weight 100 seeds	Yield
	g		g	t ha ⁻¹
First crop				
Black	8.93ab	22.25ab	41.35ab	4.13a
Silver	9.26ab	23.75a	40.41b	4.10a
White	7.64ab	19.75ab	40.10b	3.62ab
Aluminum	9.59a	20.50ab	41.03b	3.96a
Bare soil	5.73b	17.25b	43.28a	3.14b
LSD	1.90	5.20	2.22	0.95
Second crop				
Black	5.91	13.25ab	44.62ab	2.74
Silver	5.78	12.25ab	45.65b	2.83
White	5.95	14.00a	45.35a	2.87
Aluminum	6.04	12.50a	46.13ab	2.86
Bare soil	5.73	10.75b	46.05ab	2.71
LSD	NS	1.0	1.4	NS

Means within each column followed by the same letter are not different at $p \leq 0.05$. LSD: least significant difference. NS: non significant.

number of seeds per pod ($p \leq 0.05$), although this did not result in higher grain yield. In general, early seeding in spring produce higher dry bean yields than late seeding. Similar results have been reported with dry beans (Ibarra Jiménez and Rodríguez Piña, 1997) and tomato (Díaz-Pérez and Batal, 2002), suggesting that the use of plastic mulch is not necessarily associated with increased yields.

Reflected radiation, soil temperature and yield

Each plastic color has a different light reflection, which was confirmed in the present study since white, aluminum and silver plastic mulches reflected higher rPAR (Table 1). In both growing seasons black plastic mulch had the lowest reflected light, which was very similar to that of bare soil. In the first crop, soil temperature decreased as reflected light increased (Figure 1) and the same tendency occurred in the second crop (Figure 2).

In general, the higher reflectance of solar light with plastic mulch, the lower the absorbance (Ham *et al.*, 1993). It has been shown for instance that the radiation reflected from plastic mulch is associated with phenols, ascorbic acid and nutrient content in carrot (Antonious and Kasperbauer, 2002), leaf area in tomato (Decoteau, 2007), and positively associated with aroma, sugar content and higher yields in strawberry (Kasperbauer, 2000; Kasperbauer *et al.*, 2001). In the present study, during the

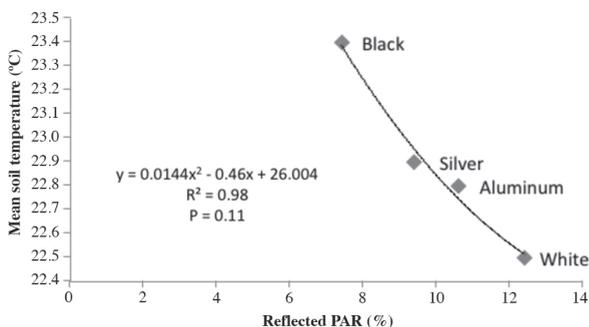


Figure 1. Relationship between mean soil temperature and photosynthetically active radiation (PAR) reflected by various colored plastic mulches during the first of two growing seasons of dry beans.

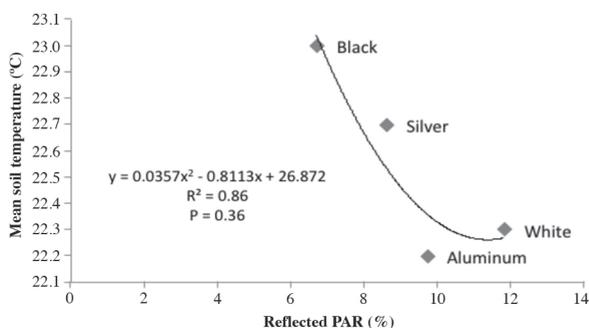


Figure 2. Relationship between mean soil temperature and photosynthetically active radiation (PAR) reflected by differentially colored plastic mulches, during the second of two growing seasons of dry beans.

first crop the radiation reflected was inversely correlated $R^2 = 0.99$ ($y = -0.0281x^2 + 0.4547x + 2.3075$) (Figure 3), and in the second crop was positively correlated $R^2 = 0.99$ ($y = -0.0069x^2 + 0.1527x + 2.0255$) (Figure 4) with yield. Therefore, we hypothesized that rPAR did not influence yield since the different mulch colors produced opposite behaviors over the two growing seasons. It is possible that incident PAR and/or air temperature were different in the two growing seasons, which could explain this behavior. Unfortunately, we did not measure these factors so no conclusions can be made.

Photosynthesis rate

Bean plants only showed a higher photosynthesis rate when mulched in the first sampling during the first crop (Table 4). In previous studies, Ibarra-Jiménez *et al.* (2011) reported a significant effect of the colors of plastic mulches on net photosynthesis, especially in the initial stages of plant growth. In the present study, the photosynthesis rate was measured on the fourth youngest leaf. However, measuring the entire plant canopy could be a better estimator of the plant photosynthesis rate, allowing for a more precise interpretation. In the first crop, the influence of plastic mulch on soil temperature seems to be more important in the production of plant DM and grain yield than in photosynthesis rate. Thus, it is not worthwhile

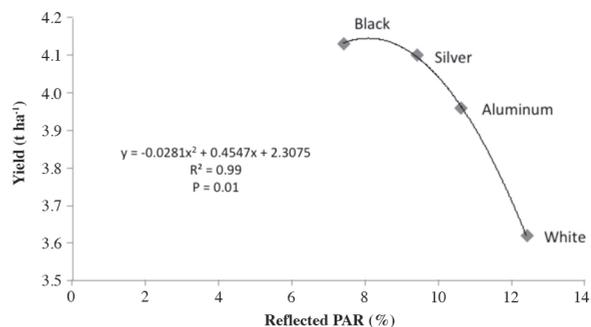


Figure 3. Relationship between photosynthetically active radiation (PAR), reflected by differentially colored plastic mulches, and yield of dry beans in the first of two growing seasons.

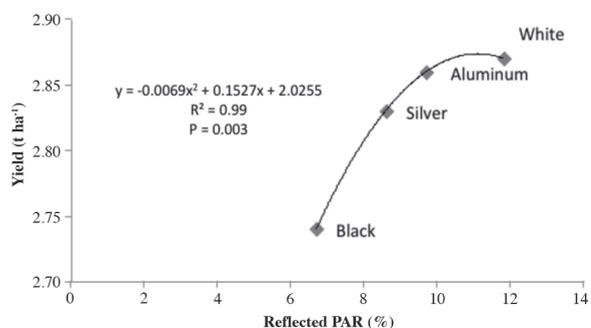


Figure 4. Relationship between photosynthetically active radiation (PAR) reflected by differentially colored plastic mulches, and yield of dry beans in the second of two growing seasons.

Table 4. Net photosynthesis rate at 20, 30, 40, and 50 days after seeding (das) of dry bean plants grown with colored plastic film mulches during spring and summer of 2008.

Treatment	Net photosynthesis rate			
	20 das	30 das	40 das	50 das
	μmol CO ₂ m ⁻² s ⁻¹			
First crop				
Black	4.77bc	4.86	6.33	8.54
Silver	4.06ab	4.46	4.33	8.42
White	3.74bc	4.71	4.20	8.47
Aluminum	5.14a	4.21	5.44	8.78
Bare soil	3.53c	6.39	7.29	7.98
LSD	1.05	NS	NS	NS
Second crop				
Black	13.55ab	8.00	8.27	7.64
Silver	13.58ab	6.67	6.83	7.88
White	16.12a	6.96	7.04	7.99
Aluminum	15.22ab	6.69	8.00	7.41
Bare soil	12.76ab	7.47	8.91	8.32
LSD	2.79	NS	NS	NS

Means within each column followed by the same letter are not significantly different at $p \leq 0.05$. LSD: least significant difference. NS: non significant.

to try to find differences in single-leaf photosynthesis measurements between mulched and non-mulched plants despite the difference in soil temperature. The increase in temperature was not sufficient to significantly affect the photosynthesis rate. The latter could be ascribed to environmental factors, such as PAR, air temperature, leaf temperature and ambient CO₂, which were very similar in mulched and non-mulched soils.

Relationship between mean soil temperature and yield

Mean soil temperature was associated with bean yield in the first crop ($y = -1.1349x^2 + 52.667x - 606.84$; $R^2 = 0.98$) (Figure 5) and second crop ($y = -0.3047x^2 + 13.622x - 149.35$; $R^2 = 0.99$) (Figure 6). In general, in the first crop, yield increased as mean soil temperature increased, whereas in the second crop a temperature increase was associated with decreased yield. According to the estimated models, the optimum soil temperature for maximum bean yield was about 23 °C. It was not possible to obtain optimum soil temperature value for dry bean due to the lack of data, therefore it is not possible to determine if yield would have increased or decreased beyond what it did with the mean soil temperatures obtained in this study,

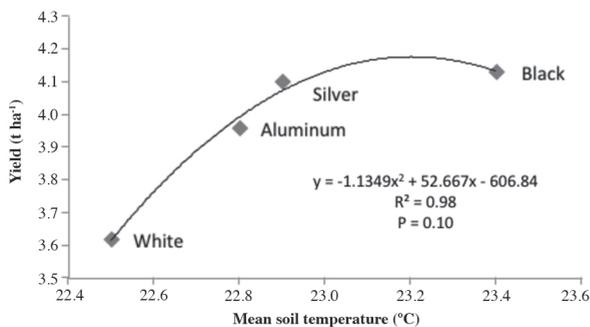


Figure 5. Relationship between mean soil temperature and yield of dry beans cultured with differentially colored plastic mulches in the first of two growing seasons.

but according to previous experiments dry bean yield is susceptible to seeding dates and can decay as spring advances (Ibarra Jiménez and Rodríguez Piña, 1997). The use of temperatures generated by different mulch colors allows a better comprehension of the response of dry bean plants to double cropping.

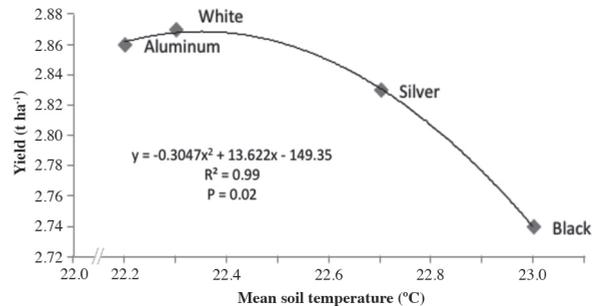


Figure 6. Relationship between mean soil temperature and yield of dry beans cultured with differentially colored plastic mulches in the second of two growing seasons.

CONCLUSIONS

Our findings support the premise that it is possible to obtain two growing seasons of dry bean in the same plastic mulched soil. The yield of dry bean crops responded favorably to early seeding dates using new plastic mulch in the first crop. The same response was not observed in late dates with plastic mulch used in the second crop. The mean soil temperature correlated with yield, but higher soil temperatures induced by plastic mulch were not the only the factor explaining higher yields, which was particularly true in the second crop.

Influencia del doble cultivo en el crecimiento y rendimiento de frijol con cubierta plástica de colores.

Existen numerosos estudios sobre el uso de cubierta plástica en la producción de hortalizas, sin embargo está muy poco documentado el cultivo simple o doble de frijol (*Phaseolus vulgaris* L.). El objetivo de este estudio fue cultivar frijol en dos estaciones de crecimiento consecutivas usando la misma cubierta plástica de diferentes colores y examinar la influencia de la temperatura del suelo en el crecimiento y rendimiento de frijol. El estudio fue conducido en Saltillo, Coahuila, México, en la primavera y verano de 2008. Se usaron cuatro colores de acolchado plástico: blanco-sobre-negro, negro, plata-sobre-negro, aluminio-sobre-negro, y control de suelo desnudo. El diseño experimental fue bloques completos al azar con cuatro repeticiones. El porcentaje de radiación fotosintéticamente activa (PAR) reflejada por las cubiertas tendió a ser mayor en el plástico blanco-sobre-negro y menor en cubierta negra. La temperatura media bajo la cubierta decreció con el incremento en el porcentaje de PAR reflejada. La temperatura media del suelo se relacionó con rendimiento

en 98% y 99% en la primera y segunda estación de crecimiento, respectivamente. La relación entre PAR y rendimiento fue 98% y 86% en la primera y segunda estación de crecimiento, respectivamente. El efecto de la cubierta de color sobre el rendimiento fue significativo ($p \leq 0,05$) en la primera estación de crecimiento, pero no en el segundo cultivo donde los tratamientos de cubierta y el control tuvieron un rendimiento similar, indicando que no siempre la cubierta aumenta el rendimiento.

Palabras clave: *Phaseolus vulgaris*, temperatura del suelo, fotosíntesis, radiación fotosintéticamente activa, plasticultura.

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