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Original article

Variability of the yield in soybean cultivars (*Glycine max* L. Merrill). Part II. Springtime

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ABSTRACT

The research was developed in the areas of the Base Technological Science Unit, Los Palacios, Pinar del Río, belonging to the National Institute of Agricultural Sciences. The objective was to evaluate the variability of the yield in soybean cultivars (*Glycine max* (L.) Merrill) associated with meteorological variables according to the sowing date in the spring season. Four soybean cultivars were used (DV-5, DVN-6, DT-84, D-2101), which were sown on three different sowing dates (May 2012, April 2013 and May 2013), corresponding to the time of spring, on a Hydromorphic floor Gley Nodular Ferruginous Petroferric. An experimental design of random blocks with three replications was used, and agricultural performance and its main components were evaluated, as well as meteorological variables (temperatures, solar radiation, relative humidity), in different phenological stages of the crop (V_e-R_1, R_1-R_5, R_5-R_7). The results obtained indicated that the meteorological variables studied influenced the variability of the soybean yield in the spring season. Of the components studied, the one most associated with yield was the number of pods / plant for the three planting dates in general. The climatic variables evaluated that most influenced the duration of the stages were the temperatures and solar radiation in the R1-R5 stage, the accumulated degree-days and the relative humidity in the R5-R7 stage.

Key words: temperature, phenology, productivity, relative humidity, genotypes

INTRODUCTION

Globally, the cultivation of soybeans (*Glycine max* (L.) Merrill) is one of the most important due to the high oil and protein content of the grain [(1)]. Some studies show that the overall rate of yield increase in this crop will need to almost double to meet the population demands forecast for 2050, so various factors can influence yield gains over time [(2)].

It has recently been shown that the causes for soybean performance improvement are based on the inclusion of changes in management practices, genetic improvement, and environmental conditions [(3)], not to mention that the estimates of a high performance will often result in large gaps, with a considerable probability that it is not economical or sustainable [(4)].

In this sense, previous studies affirmed that meteorological variables such as temperature, solar radiation, rainfall and relative humidity, cause a direct effect on growth and yield in soybean cultivation [(5,6)]. The planting date has also been widely evaluated in different environments, considering it, one of the least expensive production decisions, while having a greater influence on yield than any other management practice [(7)].

On the other hand, the importance of yield has been described as the result of a process of agricultural activities carried out throughout the crop development cycle, so it is important to know its phenology, the possible duration of the different phases or stages and their potential problems and fundamental needs [(8)]. Some results have shown that the large seasonal change in environmental conditions can have considerable effects on yields, to which the response capacity of the plant's production processes is different depending on the stage of development [(1)].

These aspects demonstrate to some extent that the behavior and response of soybean cultivars to environmental conditions is different depending on the planting date and the time the crop is established, hence the analysis of meteorological variables may be adequate to detect the adaptation differences of soy in a given environment. Therefore, the present work was developed with the objective of evaluating the variability of the yield in four soybean cultivars (*Glycine max* (L.) Merrill), associated with meteorological variables (temperatures, solar radiation and relative humidity), according to date of sow in the springtime.

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MATERIALS AND METHODS

The experiments were carried out in the Base Technological Scientific Unit, Los Palacios (UCTB-LP), belonging to the National Institute of Agricultural Sciences, located in the southern plain of the Province of Pinar del Río, at 22° 44 'north latitude. and at 83° 45 'west latitude, at 60 m a.s.l, with an approximate slope of 1 %. Four soybean cultivars of Vietnamese origin (DVN-5, DVN-6, DT-84, D-2101) were evaluated, which were planted on three different planting dates; May 2012, April 2013 and May 2013, corresponding to the Spring season.

The soil of the experimental area is classified, according to the New Version of Genetic Classification of the Soils of Cuba [9], as Hydromorphic Gley Nodular Ferruginous Petroleum. As results of the soil sampling of the experimental area, some properties that characterize its fertility are shown (Table 1).

Table 1. Some properties of the topsoil (0-20 cm) that characterize the fertility of the soil where the experiments were carried out

pH	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**P_2O_5**	**OM**
H_2O	**cmol kg^{-1} Soil**			**mg 100 g^{-1} of soil**	**%**
6.49	7.01	3.13	0.23	20.47	2.72

The main characteristics of the cultivars under study are presented in Table 2 [10], which were sown by direct sowing at a distance (manual), 0.70 m between rows and 0.07 m between plants, with a norm of 54 kg ha^{-1} of seeds. Phytotechnical work was carried out as recommended in the Technical Manual for Soybean Cultivation [11]. A randomized experimental block design with four treatments (DVN-5, DVN-6, DT-84, D-2101) and three replicates was used in each planting period. The experimental plots had a total area of 30 m^2.

Table 2. Main characteristics of the soy cultivars studied in the experiments

	DVN-5	**DVN-6**	**DT-84**	**D-2101**
Yield (t ha^{-1})	3,5-3,0	3,5-3,0	2,5-3,0	2,0-3,0
Number of pods /plant	61-51	60-53	23-47	25-55
Number of grains/plant	121-110	100-89	54-110	70-123
Mass 1000 grains (g)	170.0	173.0	170.0	180.0
Planting season	Spring-Summer	Spring-Summer	Winter-Spring	Winter-Summer

The values of maximum, minimum and daily average temperature (T max, T min, T mea), rainfall, global solar radiation (GSR) and relative humidity (Hr), for the period in which the experiments lasted, are shown in the Figure 1, which were obtained from the Paso Real de San Diego Weather Station in Los Palacios.

The accumulated temperature was determined from the calculation of the thermal sum or accumulated degrees days (GDA) using the following formula [12]:

$$\mathrm{GDA} = \sum^{n} (\mathrm{T\,max} + \mathrm{T\,min})/2) - \mathrm{T\,base}$$

Where in this case, the base temperature was selected at 10 °C [1] and n the number of days in the period considered.

In each experimental plot at the time of harvest, ten representative plants were taken at random in the effective area to neglect the edge effect, and the following variables were determined:

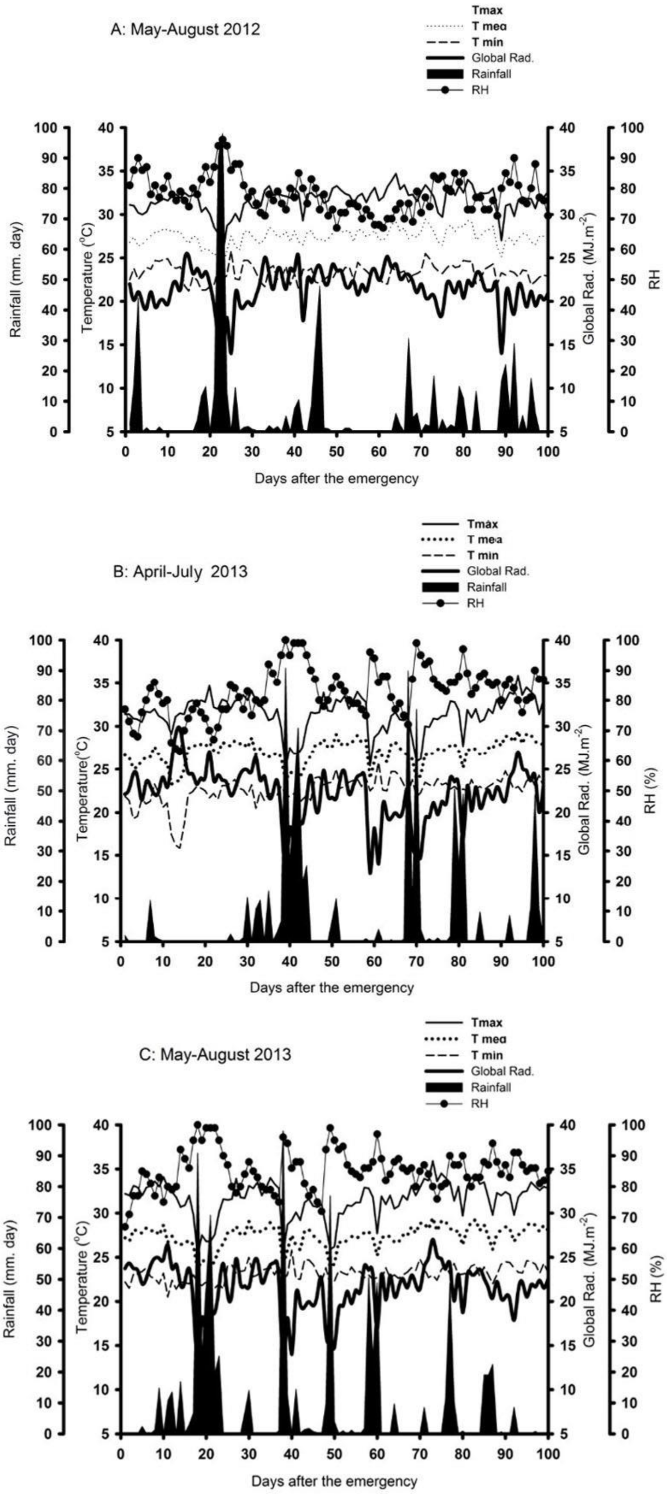
- Number of pods per plant (No pods)
- Number of grains per plant (No grains)
- Mass of a thousand grains (Mass 1000)

Regarding the number of grains and number of pods, the value of each variable was counted in the ten plants per plot. From all the grains of the 10 plants sampled, four random samples of 1000 grains per plot were taken. These were dried until the grains reached 14 % humidity and the samples were then weighed on an analytical balance (KERNPLJ e = 0.01 g) to obtain the value of the mass in grams.

To determine the agricultural yield (t ha^{-1}), 8 m^2 of the center were harvested in each experimental plot, the plants were threshed and the grains were dried until reaching 14 % humidity.

The means of the yield and its components to cultivate and date of sowing, were subjected to an analysis of variance (ANAVA), and the significant differences were determined with the Tukey test ($p < 0.05$); From the resulting experimental error, the confidence interval of the same was calculated.

Two data matrices were constructed; 1) cultivars, sowing dates, yield and their components; 2) cultivars, planting dates, duration (days) of three fundamental stages (V_e-R_1, pre-flowering stage and start of flowering (5-37 days after emergence). The R_1-R_5, early reproductive stage in which most fruits are established and start of seed filling (37-65 days after emergence), and stage R_5-R_7, seed filling period (65-92 days after emergence) [13], meteorological variables and degrees of day accumulated; which were processed by the multivariate technique of Principal Components, through the representation of a Biplot. The Statgraphics 5.0 statistical package [14] was used.



A: Planting period from May to August 2012, B: Planting period from April to July 2013, C: Planting period from May to August 2013

Figure 1. Daily temperatures (maximum, mean, minimum), rainfall, global solar radiation and relative humidity, taken from the Paso Real Agrometeorological Station in San Diego, during the period of the experiments

RESULTS AND DISCUSSION

Figure 2 shows the response of the agricultural performance of the cultivars at the different evaluated dates. In general, a variation of this variable is observed both between planting dates and between cultivars, demonstrating once again that a specific behavior pattern cannot be defined, taking into account the role that certain factors play in the process of yield training for a given cultivar.

In May 2012 the cultivars (DT-84, DVN-6, D-2101) reached the best response, with significant differences in the dates of April and May 2013. However, the cultivar DVN-5 showed an inverse response to the others cultivars studied, that is, the highest yield values were reached in the dates of April and May 2013, without significant differences between the two. The cultivar D-2101 reached the highest yields in the three sowing dates, especially in May 2012 with a value of 4.20 t ha^{-1}. On the other hand, the cultivar DVN-6 obtained the lowest yields, mainly in the dates of April and May 2013, with values of 2.88 and 2.87 t ha^{-1} respectively.

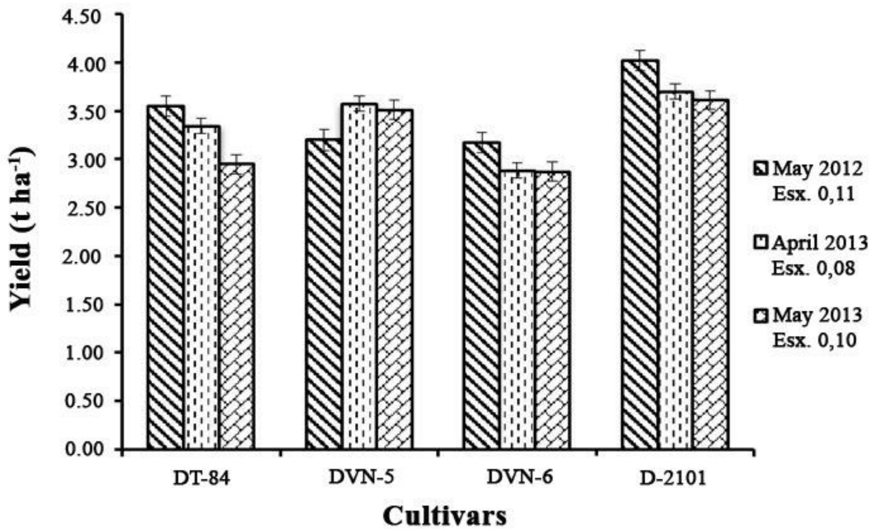


Figure 2. Agricultural yield (t ha^{-1}) at 14 % of grain moisture of soybean cultivars on the three planting dates

Results related to the effect of the sowing date show that the variations in the yield are fundamentally due to the influence that the meteorological variables exert in the formation of the same [7,15]. Therefore, when analyzing the behavior of meteorological variables during the time that the experiments lasted, it was observed that the highest values of temperature and solar radiation (Figure 1) coincide with the planting date where the cultivars reached the highest yields. (May 2012). Some authors reported that the soybean crop yield was strongly correlated with the maximum daily temperature (≤30 ºC) during the grain filling stage (R_5-R_7), that is, high temperatures are generally associated with a longer duration of the period, leading to increased availability of incident radiation [5,16]. This direct effect allows increasing the efficiency of the use of radiation for performance, in fact, some results show that the spatial distribution of the pods in a greater number of knots, could improve this efficiency by reducing competition within the nodes [17].

The low yields reached by the cultivar DVN-6 in the dates of April and May 2013, have a certain relationship with the period where the highest values of precipitation and relative humidity were recorded, as well as temperatures and the availability of solar radiation they were relatively lower compared to their performance on the highest yield date. Other authors reported similar results, where they show that the reduction of incident radiation through shading applied from R_3 onwards decreased the number of pods and grains, given the strong relationship that exists between both components and growth during the critical period in soybean [18].

The possibility of increasing profitability in soybean cultivation in tropical regions has been raised, especially in the spring season, where environmental conditions may have an ideal behavior for the growth of the crop [19]. In Cuba, previous studies affirm that the highest yields in soybean cultivation are obtained in the spring season, because it is the period of the year when the plant reaches a higher height, increasing the number of reproductive structures per unit area of soil [20].

This variability in yield between planting dates and between cultivars was even more evident when analyzing the behavior of its main numerical components (Table 3), so the influence that these components exert during the yield formation process can be explained, if the conditions under which the experiments were carried out are taken into account. For the number of pods, the best performance was achieved by the cultivars on the date where the highest yield values were obtained, and although various authors define this variable as an indirect component [21], it apparently had an influence on the determination of the same. Adverse weather conditions during this stage cause a drop in the number of pods, and consequently, a decrease in the number of grains, which leads to low yields [15]. Several authors maintain the theory that yield is positively correlated with pods per node, and although this variable was not determined in this study, the role-played by the number of nodes in fixing reproductive structures that start must be recognized to the yield formation process, especially in the number of pods [15,17,22].

Table 3. Response of the main yield components of soybean cultivars at the different planting dates studied

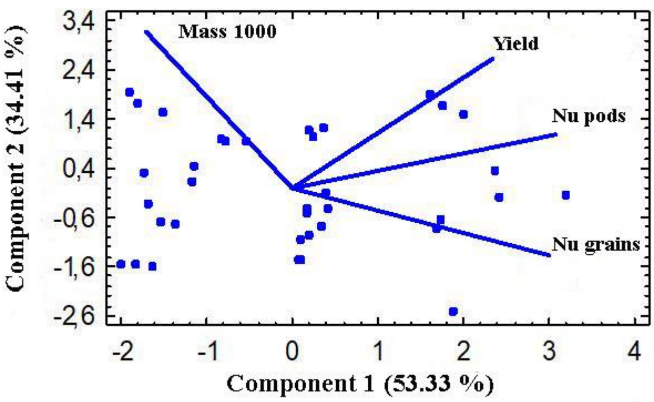
	May 2012		
Cultivars	**Nu. pods**	**Nu. grains**	**Mass 1000**
DT-84	74,9-81,7	108,9-119,7	234,9-252,5
DVN-5	68,4-75,2	109,6-120,4	245,8-263,4
DVN-6	66,7-73,5	102,1-112,9	246,9-264,5
D-2101	81,0-87,8	126,4-137,2	246,5-264,1
Esx.	1,76	2,77	4,47
	April 2013		
DT-84	67,1-76,1	115,2-128,2	194,5-131,1
DVN-5	61,3-70,3	121,1-134,1	150,8-187,4
DVN-6	54,1-63,1	102,3-115,3	222,0-258,6
D-2101	74,4-83,4	130,1-143,1	169,4-206,0
Esx.	2,28	3,33	9,36
	May 2013		
DT-84	67,3-74,9	115,9-123,5	167,5-208,7
DVN-5	62,0-69,6	107,3-114,9	250,6-291,8
DVN-6	58,6-66,2	99,3-106,9	190,0-231,2
D-2101	75,1-82,7	113,5-121,1	240,8-282,0
Esx.	1,92	1,94	10,51

The 95 % confidence interval calculated from the mean, taking into account the experimental error of the analysis of variance

Regarding the number of grains, the highest values were reached by the cultivars on the date of April 2013, in which low yields were obtained compared to those obtained on the best-performing sowing date (May 2012). However, it should be underlined that the date of May 2013 again coincides with the lowest values reached by cultivars. In previous results, it was confirmed that the physiological processes that explain the variations in the yield, are commonly associated with the determination of the number of grains per unit area of soil, since this is the main numerical component of the yield (23). On the other hand, when the cultivars were analyzed independently, the cultivar D-2101 was confirmed as the one with the best response on the three planting dates. This is highly successful to the point that it is possible for different genotypes to have similar or different yields in the same environment, and for a genotype to have different yields in different environments (24). In experiments carried out under controlled environmental conditions with genotypes of different development cycles, variations in the number of grains were obtained, which brought about a decrease in yield (22). Hence, subsequent studies by these same authors, show that the yield is positively correlated with the number of grains, however, they highlight the importance that the number of pods plays during the critical period of the crop (period in which the plant is with greater sensitivity), especially when filling the grains (17).

On the other hand, the mass of the grains had a similar response to the number of pods, so it must have been an important element in the formation of the yield. However, it should be noted that this variable achieved a behavior contrary to the number of grains, that is, on the sowing date where the cultivars obtained a low value in the mass of the grains, it was where they reached the highest number of them. In this regard, some results have concluded that the increase in yield can be attributed to the considerable increase in the number of pods per plant and the weight of the grains [(5)]. In other words, each component is affected with different intensity by the environment at each stage of development and within certain limits, but there is the ability to compensate for reductions in one component by increasing the subsequent one [(21)], although in a wide range of agronomic conditions. , the number of grains as the main component of the yield, can only be compensated by their mass [(25)].

From the previous results and when analyzing the degree of association of agricultural yield and its main components, it was resolved that the most influential variable on the expression of yield was the number of pods/plant, generally seen for the three dates of sowing studied. This is demonstrated in the principal component analysis, where components 1 and 2 explained 87.74 % of the total variability (Figure 3).



Mass 1000: mass of a thousand grains (g). Yield: Agricultural yield (t ha^{-1}). No grains: Number of grains per plant. No pods: Number of pods per plant

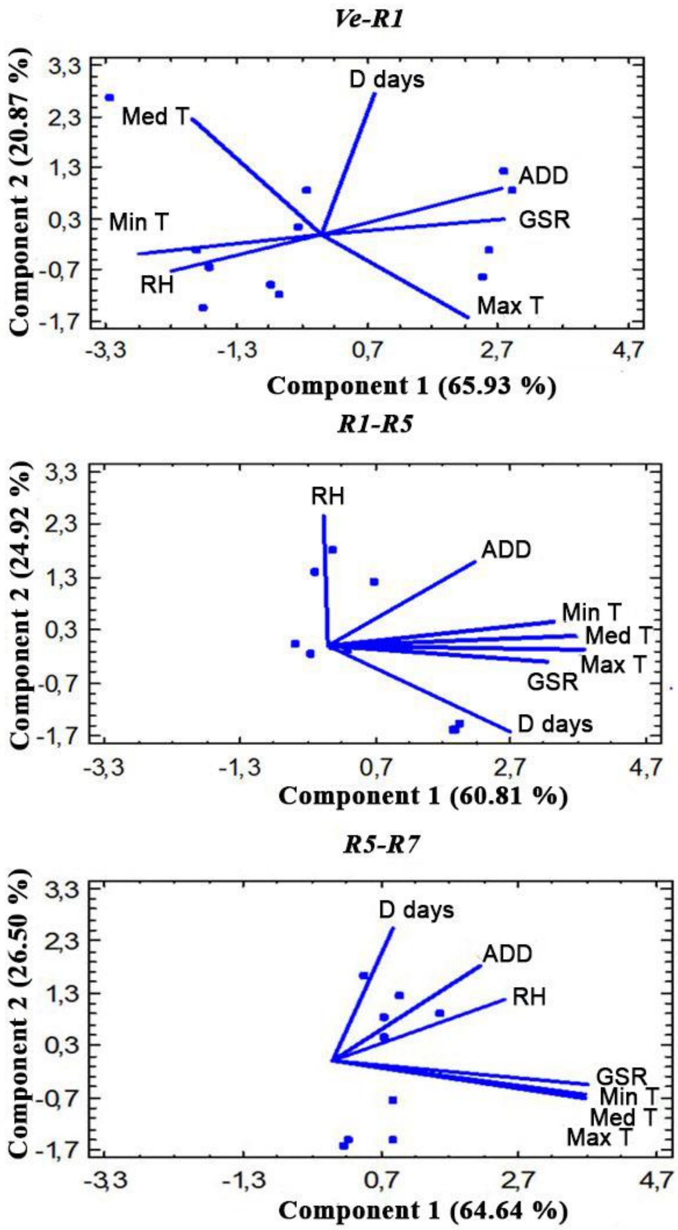
Figure 3. Association of the agricultural yield of soybean cultivars with the variables obtained on the first and second component in the three sowing dates studied

The mass of the grains obtained a high angular separation with respect to the number of pods, the number of grains and the yield. This indicates that under these conditions as the number of grains, the number of pods increases, their mass decreases, and vice versa, which once again demonstrates the compensatory level between these variables.

Similar results were obtained in tropical conditions with soybean cultivars of different maturity groups, where the increase in yield is attributed to the considerable increase in the number of pods per plant and the number of grains [5]. Other studies related to this result, allowed us to establish that the general response found is that the number of grains per m² is the component most associated with variations in yield in soybean cultivation, however, there are situations where yield is explained by variations in unit weight and/or by joint variations [21,25].

Another important aspect is the influence of meteorological variables as one of the main driving forces to define the different phenological stages through which the crop passes, therefore, the duration of each of these stages partially explains the generation and variation of the morphological components of performance. Hence, when analyzing the degree of association between these variables and the duration in days in each of the stages studied for the three planting dates in general, the differences between them were evident (Figure 4).

In the phenological stage V_e-R_1, there was no association with the analyzed variables (temperature, solar radiation, relative humidity), so in this case it is not possible to define a behavior pattern that allows explaining their influence in view to the phenological changes of the plant. It should be noted that the literature points to temperature as the variable that most influences the rate of crop development, from emergence to harvest, which means that all crops and all stages of development are sensitive to itself [18]. Also, like the temperature, reference is made to the effect that the length of the day causes on the growth of the soybean crop, mainly from the stage where the first trifoliate leaf appears (V_1) until the beginning of flowering (R_1) [17,18], although this variable was not analyzed in the present study.



D days: Duration in days (days). GDA: Accumulated degrees days (°C). GSR: Global Solar Radiation (MJ m^{-2}). T min: Minimum temperature (°C). T mea: Average temperature (°C). T max: Maximum temperature (°C). Hr: Relative humidity (%)

Figure 4. Association of the main meteorological variables with the duration in days of soybean cultivars in each of the phenological stages studied for the three planting dates in general

However, in the phenological stage R_1-R_5, solar radiation and temperatures gave the clearest association with the duration in days. This can be linked in some way to variations in yield and its main components, since the associated variables are related to changes in the availability of assimilates after the beginning of flowering [18]. It is important to highlight that some authors suggest optimum temperatures for soybean development. It could be the range of 16-28 °C during the entire period of cultivation, of 15-22 °C, 20-22 °C and 15- 22 °C as optimum temperatures for the emergence, flowering and maturity stages respectively, or a maximum of 27 °C for the period of filling of the grains [1]. In this study, the average temperature on the date of May 2012 (Figure 1), when the filling of the grains began (65 days after emergence), registered a value around 29.0 °C, which justifies the low number of grains reached by cultivars on this date, if the maximum temperature is taken into account for their development according to the literature. Studies carried out with high temperatures, showed that these had a significant negative effect on the yield and the biomass produced, due to the slower growth rate obtained by the crop, at the same time that the size of the grains decreased and the wrinkling increased thereof [26]. On the other hand, on the sowing date (May 2013), where the lowest yield values were recorded, it coincided with a low availability of solar radiation throughout this stage. It has become evident in different results that the reduction of incident radiation through the shading applied from R_3 onwards decreased the number of pods and grains [18,22]. This was a result to be expected, given the strong relationship that exists between yield components and growth during the critical period of the crop. Therefore, a physiological mechanism that is commonly associated with a higher soybean yield is to extend all or part of the duration of reproductive growth, while there is a greater interception of solar radiation and an increase in the daily photosynthesis of the crop, and in this way, a greater availability of photoassimilates is guaranteed [18].

On the other hand, in the phenological stage R_5-R_7, the greatest influence was exerted by the accumulated degrees days and the relative humidity. Thermal time is generally used to include the effects of temperature and describe the timing of the biological processes of the plant, that is, it can be defined as the number of degrees days required to complete a certain development process or phenological phase [8]. Therefore, in this study, thermal time must have had a certain impact on the duration of the stage, so that it could respond to variations in the number of grains, that is, there is a direct relationship in the duration of the stage, incident radiation and determination of the number of grains. In the case of relative humidity, this association is evident due to the rainfall that occurred during this stage on all planting dates. Studies show that the decrease in seed vigor is a response to the deterioration caused by several factors, mainly the high relative humidity due to rains during the period near maturity, and therefore, these seeds tend to produce weak seedlings with reduced performance potential [27].

CONCLUSIONS

- The results obtained indicated that the highest values of agricultural yield were found on the date of May 2012, while the cultivar D-2101 was the one with the best response on all the sowing dates studied.

- The number of pods/plant behaved as the variable that most influenced the expression of yield.
- In the phenological stage V_e-R_1 there was no association with the meteorological variables studied, while in the stage R_1-R_5 temperatures and solar radiation proved to be the most influential.
- The accumulated degrees and relative humidity were the variables that were most associated with the duration of the phenological stage R_5-R_7.

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