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Original article

Analysis of growth and yield of soybean cultivars in the dry season

Análisis del crecimiento y el rendimiento de cultivares de soya en la época poco lluviosa

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ABSTRACT: With the objective of analyzing the growth and yield of soybean cultivars in the cold season, this work was developed in areas of the Scientific and Technological Base Unit, Los Palacios, Pinar del Río, belonging to the National Institute of Agricultural Sciences. Soybean cultivars Incasoy-1, Incasoy-24, Incasoy-27, DT-20, DT-26 and D-2101 were used, which were sown on a Hydromorphic Gley Nodular Ferruginous Petroferric soil, on two different years (January 2016 and 2017), corresponding to the cold season. A randomized block experimental design with six treatments (the cultivars) and four replications was used, and the total dry weight of the aerial part (g) and the leaf area (m^2) were determined in each experimental plot. The growth dynamics of these variables was fitted to a second-degree polynomial exponential mathematical function, and the leaf area index (LAI) and the absolute growth rate (AGR) were calculated. Agricultural yield (t ha^{-1}) was also determined, performing a confidence interval from the standard deviation on the obtained means, with a probability of 95 % confidence. The results showed influence of the sowing date on the different growth indicators, both in the maximum value reached by the variable, and in the moments in which it was achieved, while it was possible to infer that the greater the accumulation of biomass, a higher yield was reached, highlighting the cultivars DT-20 and DT-26.

Key words: Glycine max, leaf surface, dry weight, development.

RESUMEN: Con el objetivo de analizar el crecimiento y el rendimiento de cultivares de soya nacionales y foráneos en la época poco lluviosa, se desarrolló el presente trabajo en áreas de la Unidad Científico Tecnológica de Base, Los Palacios, Pinar del Río, perteneciente al Instituto Nacional de Ciencias Agrícolas, para lo cual se utilizaron los cultivares Incasoy-1, Incasoy-24, Incasoy-27, DT-20, DT-26 y D-2101, sembrados sobre un suelo Hidromórfico Gley Nodular Ferruginoso Petroférrico, en dos años diferentes (enero 2016 y 2017), correspondientes a dicha época. Se empleó un diseño experimental de bloques al azar con seis tratamientos (los cultivares) y cuatro réplicas, y se determinaron la masa seca total de la parte aérea (g) y el área foliar (m^2) en cada parcela experimental. La dinámica de crecimiento de estas variables se ajustó a una función matemática exponencial polinómica de segundo grado, y se calculó el índice de área foliar (IAF) y la tasa absoluta de crecimiento (TAC). También se determinó el rendimiento agrícola (t ha^{-1}), realizándose a las medias obtenidas, un intervalo de confianza a partir de la desviación estándar, con una probabilidad del 95 % de confianza. Los resultados mostraron influencia de la fecha de siembra en los diferentes indicadores del crecimiento, tanto en el valor máximo alcanzado por la variable, como en los momentos en el que se logró el mismo, a la vez que se pudo inferir que a mayor acumulación de biomasa se alcanzó un mayor rendimiento, destacándose los cultivares DT-20 y DT-26.

Palabras Clave: Glycine max, superficie foliar, masa seca, desarrollo.

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INTRODUCTION

Plant growth is defined as an irreversible increase in the size of plants, determined by processes of morphogenesis and differentiation; the former is the development of the shape or model of the cell or organ, while the latter is the process, by which cells change structurally and biochemically to form or acquire specialized functions (1). On the other hand, plant growth analysis is a valuable tool for understanding biomass formation and accumulation. This analysis has developed in recent years as a discipline related to ecophysiology and agronomy, with its own concepts, terms and calculation tools (2).

The different indices that are contemplated within growth analysis are a good measure to compare the effect of environmental factors on crop growth, as well as the relationship between assimilatory apparatus and biomass production (3). Growth analysis uses direct measures such as plant dry mass (W), total leaf area (A) and time (t). Even derived measures that can be obtained from the direct measures, such as crop growth rate (CGR), which is an index of agricultural productivity and measures weight gain per unit of soil area per unit of time; the leaf area index (LAI). They represents the ratio between leaf area and soil area occupied by the crop, as well as the absolute growth rate (AGR), that refers to the increase in dry mass of the plant per unit of time (4).

On the other hand, the yield of a crop depends on its growth capacity and the production of assimilates, and what part of them is destined to the organs of economic interest. This is given, largely, by the use of sunlight in the manufacture of the constituent and functional components of the different organs of the plant (5). Different genotypic, environmental, and management conditions affect crop growth, and thus may help explain variations in yield response (6).

On the other hand, soybean (*Glycine max* (L.) Merrill) constitutes the main oilseed crop produced worldwide, mainly because of the high oil (20 %) and protein content of the grain (40 %) (7). In Cuba, in spite of the great demand of this crop, for the different forms of processing, it has not yet been possible to stabilize its production, nevertheless, in the last years, a genetic breeding program has been developed through which some cultivars have been obtained and others have been introduced, coming from Vietnam (8). All of them should be evaluated to know their behavior in the different planting seasons established for the crop in the country, which is why the objective of the present work was to analyze the growth and yield of national and foreign soybean cultivars in the low rainy season.

MATERIALS AND METHODS

The work was carried out in areas of the Basic Scientific and Technological Unit, Los Palacios (UCTB-LP, according its acronyms in Spanish), belonging to the National Institute of Agricultural Sciences (INCA, according its acronyms in Spanish), located in the southern plains of Pinar del Río Province. Six soybean cultivars were evaluated, three of them of national origin (IS-1, IS-24 and IS-27) and three from Vietnam (DT-20, DT-26 and D-2101), whose general characteristics are presented in Table 1 (8). They were sown in two years, January 2016 and 2017, corresponding to the little rainy season in Cuba, known as “cold season”, on a Ferruginous Petroferric Nodular Gleysol soil (9). Some chemical properties that characterize its fertility are presented in Table 2.

Direct sowing was used manually at a distance of 0.7 x 0.05 m, with a standard of 54 kg ha^{-1} of seeds, to ensure at least 28 plants per m^2. A randomized block experimental design with four replications and six treatments (cultivars) was used, and the experimental plots had an area of 42 m^2 (4.2 m x 10 m, 6 furrows per plot).

The phytotechnical work was carried out as recommended in the Technical Instructions for Soybean Cultivation (10). It was always ensured that there were no limitations for plants.

Table 1. Some characteristics* of the soybean cultivars evaluated

	Planting time	Growth habit	Yield (t ha^{-1})	Cycle (days)
IS-1	Cold Spring Summer	Determined	2.8	90
IS-24	Spring Summer	Determined	2.5	105
IS-27	Spring Summer	Determined	3.0	95
DT-20	Cold Summer	Semi-determined	2.5-3.0	90-95
DT-26	Cold Summer	Determined	2.5-3.5	92-96
D-2101	Cold Summer	Determined	2.0-3.0	90-95

*Taken from (8, 10)

Table 2. Chemical fertility and pH values of the arable layer (0-20 cm) of the soil where the experiments were carried out.

H_2O (pH)	Ca^{2+}	Mg^{2+}	Na^+	K^+	P_2O_5	OM
	(cmol kg^{-1} soil)				(mg 100 g^{-1} soil)	(%)
6.49	7.01	3.13	0.16	0.23	20.47	2.72

The values of the meteorological variables (global solar radiation, decennial average rainfall, maximum, minimum and average daily temperatures) for the period in which the experiments were carried out are shown in Figure 1, which were obtained from the Paso Real de San Diego Meteorological Station, in Los Palacios, approximately 3 km from the experimental area.

The leaf area and the total dry mass of the aerial part of the plants were determined, for which destructive sampling was carried out with a frequency between 10 and 15 days, from 10 days after emergence (dae) until harvest, taking 10 plants at random per experimental unit (the central furrows, without affecting the harvest sampling). In the laboratory, each plant organ was separated to quantify dry mass (g) of leaves, stems and fruits, and dried in a forced circulation oven (WiseVen) at 70 °C for 72 hours, until constant weight was reached. Leaf area was determined with a leaf area measuring device (YMJ-B), taking into account the correction factor of the scanner.

With the real data obtained the growth dynamics of the total dry mass of the aerial part and the leaf area index were established, which were adjusted to a Second Degree Polynomial Exponential mathematical function. Subsequently, the Absolute Growth Rate (AGR) of the total dry mass of the aerial part was calculated (11). To determine the agricultural yield (t ha^{-1}), 8 m^2 were harvested from the center in each experimental plot, the plants were threshed and the grains were dried to 14 % moisture.

The means of the evaluated variables obtained by cultivar and sowing date were subjected to a confidence interval based on the standard deviation, with a probability of 95 % confidence.

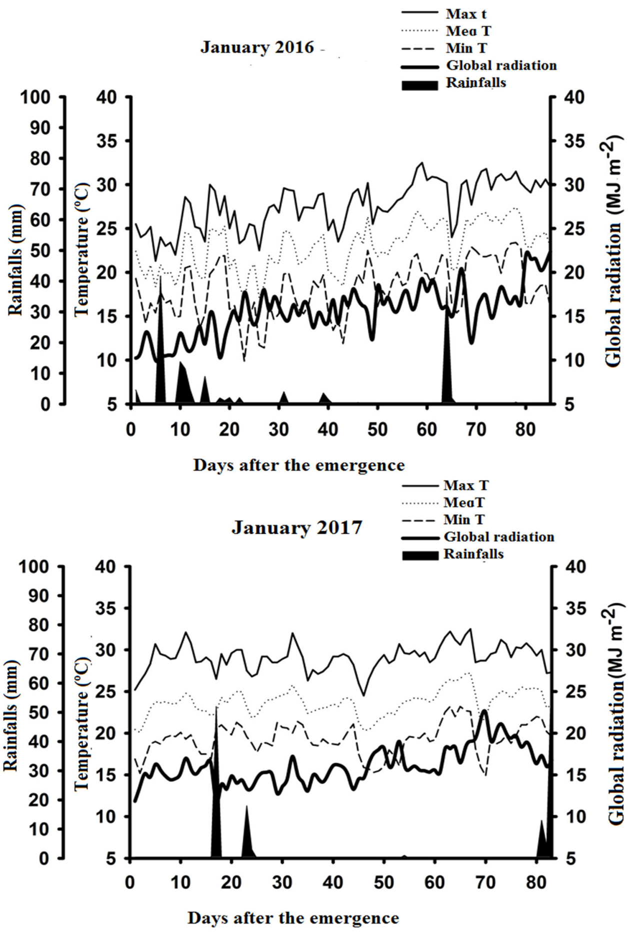


Figure 1. Temperatures (maximum, mean, minimum), global solar radiation and decadal average rainfall taken from the Paso Real de San Diego Agrometeorological Station, during the period of the experiments.

RESULTS AND DISCUSSION

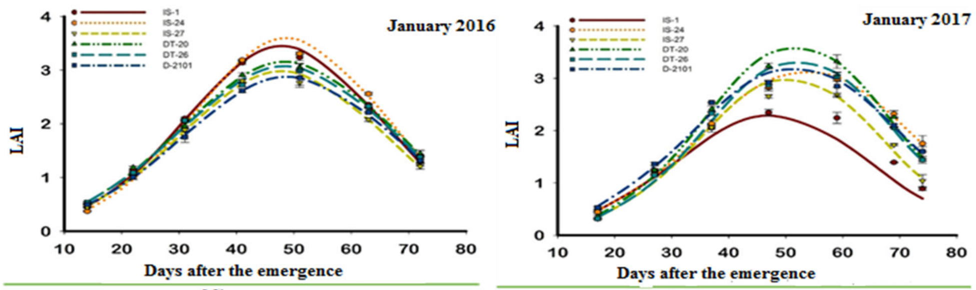
The results of the regression analysis for the description and interpretation of the growth of the cultivars studied, resulting from the adjustment of the leaf area index and the total dry mass of the aerial part, are presented in Table 3. As can be seen, in most of the treatments, the coefficients of determination (R^2) ranged between 0.98 and 0.99, which implies that a high percentage of the total variance was explained by the variance of the regression, and a satisfactory adjustment was achieved, both from a mathematical and biological point of view.

Figure 2 shows the dynamics of leaf area index (LAI) for each cultivar in the two planting years studied. In general, the behavior of the LAI showed a tendency to increase from the beginning of the cycle until it reached a maximum value and then decreased, because of the senescence of a large part of the foliage. On the other hand, the variation of the LAI with crop age was evidenced in the different sowing dates and the highest values (3.44 and 3.59) in January 2016 were obtained with the cultivars Incasoy-1 and Incasoy-24, at 48 and 49 days after emergence (dae), respectively. However, in the January 2017 date, cultivars DT-20 and DT-26 excelled with values of 3.63 and 3.36 at 52 and 53 dae. In this sense, it is known that leaf area is of great importance, since the interception of photosynthetically active radiation, necessary for biomass production and the corresponding contribution to yield, depends on its development (12). However, the LAI values obtained in this study are lower than those obtained by other authors who reported values higher than 4 (13).

The figure also highlights the variable response obtained by the cultivar Incasoy^{-1}, which despite reaching the maximum LAI at the same time (48 dae), in January 2016 obtained a high value of LAI, and in 2017 registered the lowest value of this variable. This result could be a consequence of a greater sensitivity of this cultivar to the behavior of temperatures, since, in January 2016, the average was above 25 ºC at the time the plants reached the maximum LAI and in January 2017, it was below, which could influence the foliar development of the plants. Some authors highlight the importance that should be given to temperature in soybean crop growth (14), while other studies emphasize on the complex phenomenon of crop response to various environmental conditions (15). Therefore, it is not necessary to define an absolute behavior pattern, especially when trying to explain physiological responses that depend, largely, on factors that cannot be managed under natural conditions, such as environmental variability. Therefore, in a general way it should be noted that in the January 2016 date the cultivars of national origin presented a higher LAI than the Vietnamese; however, this behavior was reversed in the January 2017 date.

Table 3. Equations and regression coefficients obtained in the adjustment of leaf area index and total dry mass of the aerial part of plants of six soybean cultivars in the two years studied.

Cultivar	Leaf Area Index	R^2	Dry mass of the aerial part	R^2
		January 2016		
INCASoy-1	$Y=e^{\left(12.79+0.14\,x-0.001*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-4.44+0.22\,x-0.0018*10^{-3}x^2\right)}$	0.99
INCASoy-24	$Y=e^{\left(0.98+0.17\,x-0.002*10^{-3}x^2\right)}$	0.98	$Y=e^{\left(-3.14+0.17\,x-0.0013*10^{-3}x^2\right)}$	0.99
INCASoy-27	$Y=e^{\left(-2.75+0.14\,x-0.001*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-3.99+0.19\,x-0.0015*10^{-3}x^2\right)}$	0.99
DT-20	$Y=e^{\left(-1.82+0.11\,x-0.001*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-3.56+0.19\,x-0.0015*10^{-3}x^2\right)}$	0.99
DT-26	$Y=e^{\left(-2.09+0.12\,x-0.001*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-3.01+0.15\,x-0.0010*10^{-3}x^2\right)}$	0.98
D-2101	$Y=e^{\left(-2.55+0.14\,x-0.001*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-4.01+0.19\,x-0.0014*10^{-3}x^2\right)}$	0.99
		January 2017		
Cultivar	**Leaf Area Index**	**R^2**	**Dry mass of the aerial part**	**R^2**
INCASoy-1	$Y=e^{\left(-3.02+0.16\,x-0.0016*10^{-3}x^2\right)}$	0.98	$Y=e^{\left(-3.14+0.16\,x-0.0010*10^{-3}x^2\right)}$	0.99
INCASoy-24	$Y=e^{\left(2.83+0.14\,x-0.0008*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-2.83+0.14\,x-0.0008*10^{-3}x^2\right)}$	0.99
INCASoy-27	$Y=e^{\left(-3.81+0.19\,x-0.0019*10^{-3}x^2\right)}$	0.98	$Y=e^{\left(-4.75+0.20\,x-0.0014*10^{-3}x^2\right)}$	0.98
DT-20	$Y=e^{\left(-3.71+0.19\,x-0.0018*10^{-3}x^2\right)}$	0.99	$Y=e^{\left(-3.70+0.18\,x-0.0012*10^{-3}x^2\right)}$	0.99
DT-26	$Y=e^{\left(-3.79+0.19\,x-0.0081*10^{-3}x^2\right)}$	0.98	$Y=e^{\left(-4.33+0.21\,x-0.0016*10^{-3}x^2\right)}$	0.99
D-2101	$Y=e^{\left(-2.73+0.15\,x-0.0014*10^{-3}x^2\right)}$	0.98	$Y=e^{\left(-2.73+0.16\,x-0.0011*10^{-3}x^2\right)}$	0.98



Cultivars	Max LAI T (days)	Max LAI
IS-1	48	3,44
IS-24	49	3,59
IS-27	48	2,97
DT-20	49	3.15
DT-26	49	3.06
D-2101	49	2,87

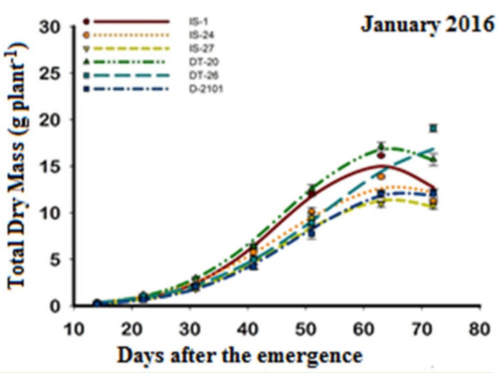
Cultivars	Max LAI T (days)	Max LAI
IS-1	48	2.29
IS-24	54	3.16
IS-27	51	3.01
DT-20	52	3,63
DT-26	53	3,36
D-2101	52	3,21

MaxLAI T: time in which the maximum value of LAI is reached; Max LAI: maximum value of LAI

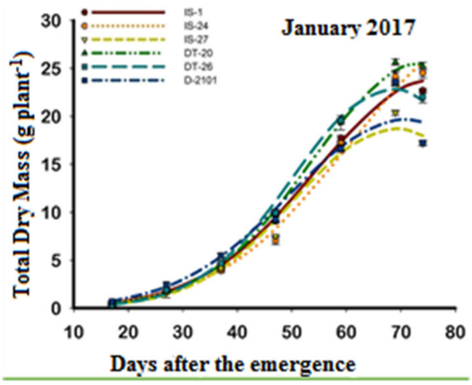
Figure 2. Estimated dynamics of leaf area index (LAI) of soybean (*Glicine max* (L.) Merrill) cultivars plants in two years of planting in the low rainy season.

For the two planting years evaluated, the growth dynamics of the total dry mass of the aerial part of soybean plants (Figure 3) showed a sigmoidal behavior with crop age, and generally, a decrease in values appeared at the end of organ development. In January 2016, cultivars reached the maximum value between 63 and 76 dae, while, at the January 2017 date, the highest dry mass accumulation ranged between 71 and 85 dae. On the other hand, the highest values were obtained by the cultivars in January 2017, which ranged between 18.7 and 28.4 g plant^{-1}.

The cultivar Incasoy-1 presented, on this date, one of the highest values of dry mass; however, it reached the lowest value of LAI, which shows the efficiency when taking advantage of photosynthetically active radiation and converting it into dry mass, with little leaf area and a shorter time of duration of the same, compared to the rest of the cultivars.



Cultivars	Max TDM T (days)	Max TDM (g plant-1)
IS-1	63	15,0
IS-24	66	12,8
IS-27	65	11,4
DT-20	65	16,9
DT-26	76	17,1
D-2101	68	12,2



Cultivars	Max TDM T (days)	Max TDM (g plant-1)
IS-1	76	23,8
IS-24	85	28,4
IS-27	69	18,7
DT-20	74	25,5
DT-26	68	22,9
D-2101	71	19,7

Max TDM T: time at which the maximum value of TDM is reached; TDM max: maximum value of TDM

Figure 3. Estimated dynamics of total aerial dry mass (g plant^{-1}) of plants of soybean cultivars (*Glicine max* (L.) Merrill) in two years of planting in the low rainy season.

The maximum magnitude of dry mass is reached in the soybean crop, which indicates the cessation of growth, and generally occurs in the R_5-R_6 phase (grain filling stage) (16), an aspect that coincides with the results obtained in this study, so that in the case of Incasoy-1, the weight of the grains positively influenced the high values of dry mass.

Other studies with soybean cultivars of different vegetative cycles, show values of dry mass between 12 and 18 g plant^{-1} (17) and the authors refer that the differential performance of cultivars in relation to the production of this variable, in each growth stage, could be associated with their genetic composition. Other authors state that the accumulation of dry mass in plants is a process that, in addition to internal factors, governed in this specific case by the balance of photosynthesis and respiration depend largely on external factors, mainly the environment (18).

The result obtained in this study shows a common characteristic of the cultivars, based on a slow accumulation of dry mass during the first 30 dae, followed by a rapid increase after flowering, which coincides with the results obtained in several works (19).

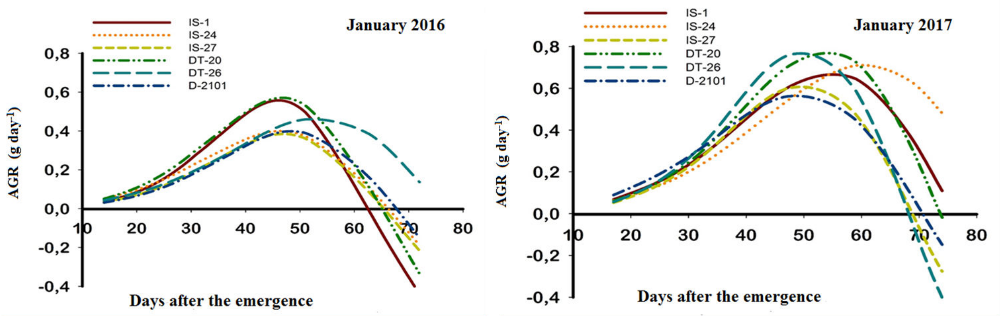
The maximum absolute growth rate (AGR) of dry mass of the soybean cultivars studied is shown in Figure 4, where the differences between cultivars are evident, both for the same sowing date and among them.

In general, in January 2016, the cultivars showed an earlier growth, reaching their maximum growth rate between 46 and 54 dae, while in January 2017; it prevailed between 50 and 61 dae. However, it is important to highlight the growth retardation shown by cultivars DT-26 on the January 2016 date, and Incasoy-24 in January 2017, where their maximum growth velocities were at 54 and 61 dae, respectively.

The highest AGR values were obtained in January 2017, which ranged between 0.57 and 0.78 g day^{-1}, standing out in this regard, with the highest values, cultivars DT-20 and DT-26. In this regard, some works attribute certain importance to the AGR study, especially when the capacity of a certain crop to produce dry mass is taken into account, based on the different prevailing environmental conditions (11), while others have used it to compare the efficiency of the application of certain foliar bioproducts (4).

In turn, the increase or decrease of the growth period caused by variations in the behavior of environmental conditions, depending on the sowing date, can affect the yield (15). Reaching maximum yields will be in direct relation with a maximum photosynthesis and that this occurs in a quite prolonged time, so a greater foliar area and duration of the same in the reproductive stage could lead to a higher yield (5,7). In addition, the relationship between the accumulation of total biomass and grain production has been demonstrated in different studies in general, and in the absence of limitations for the crop, the higher the biomass, the higher the yield (19). All of the above is shown in Figure 5, where it is generally observed that the highest yield values of the soybean cultivars studied coincide with the highest values of LAI and dry mass on both planting dates.

At the sowing date of January 2016 the DT-26 cultivar obtained the highest value of yield (2.98 t ha^{-1}), although without significant differences with respect to the DT-20 and D-2101 cultivars. While in January 2017 the cultivar DT-20 showed a higher value (3.16 t ha^{-1}) than the rest of the cultivars without significant differences with the cultivar D-2101, which evidenced in both sowing dates, its capacity and efficiency when taking advantage of the resources with a lower leaf area and low values of dry mass.



Cultivars	Max AGR T (days)	Max AGR (g day-1)	Cultivars	Max AGR T (days)	Max AGR (g day-1)
IS-1	46	0.55	IS-1	55	0.67
IS-24	47	0.40	IS-24	61	0.71
IS-27	47	0.38	IS-27	51	0,62
DT-20	47	0.56	DT-20	54	0.78
DT-26	54	0.47	DT-26	51	0.78
D-2101	49	0.39	D-2101	50	0.57

Max $_{AGR\ T}$: time in which the maximum value of AGR is reached; Max AGR: maximum value of AGR

Figure 4. Absolute growth rate (AGR) of total aerial dry mass accumulation (g day^{-1}) of plants of soybean cultivars (*Glicine max* (L.) Merrill) in two years of planting in the low rainy season.

On the other hand, the cultivar Incasoy-1 obtained the lowest yield value on both sowing dates, 1.49 and 1.90 t ha^{-1} respectively, although on the date where it obtained the highest dry mass values, it reached a higher yield. Therefore, these results are consistent with those obtained by other studies, which once again showed that soybean yield depends on the production of leaf area and dry mass (5).

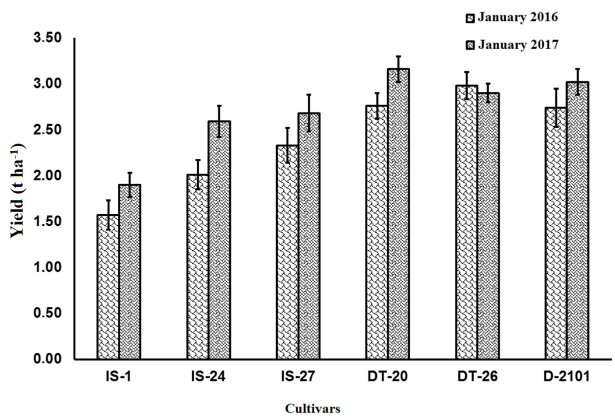


Figure 5. Agricultural yield behavior (t ha^{-1}) at 14 % grain moisture of soybean cultivars (*Glicine max* (L.) Merrill), in different planting years during the cold season.

CONCLUSIONS

The results obtained indicated that the influence of the year of sowing was found in the different growth indicators studied, both in the maximum value reached by the variable, as well as in the moments in which it was achieved, obtaining the best response of the soybean cultivars, in general, in 2017. The highest yield values were reached by the foreign cultivars, with the DT-26 and DT-20 cultivars standing out in January 2016 and 2017, respectively.

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