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Use of the CSM-CROPGRO-peanut model in Argentina to estimate optimal sowing date and crop water productivity under different soil water content

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ABSTRACT

Almost 99% of Argentine peanut production is localized in Córdoba province, mainly under a rainfed regime. In this region, rainfall fluctuations can lead to droughts of varying severity. The peanut optimum sowing date can be determined using a crop growth model and historical climatic data, estimating the impact of drought on yields. This simulation aimed to identify optimum sowing dates of peanuts growing under three available water contents at seeding, in Córdoba. A secondary objective was to determine the responses of yield and dry matter to crop evapotranspiration and transpiration for the different treatments. CROPGRO-Peanut model seasonal analysis was carried out. For this, weather data from 1973 to 2019 at Manfredi Experimental Station, and crop coefficients of cultivar ASEM 485 INTA were used. The soil employed was a silty loam Typic Haplustoll. Treatments were: three available water contents up to 150 cm deep (30%, 60%, and 100%) at seeding, and two sowing dates (21/Oct. and 9/Dec.). The optimal planting date, determined by CSM-CROPGRO-peanut for Córdoba is influenced by the soil water content at sowing. In both sowing dates, a higher median seed yield and a smaller interquartile difference were determined when soil water content increased. In each soil moisture, the late sowing date presented lower median values but less variability. The number of bad years was 15 when the initial moisture content was 30%, regardless of the sowing date. The remaining planting date-initial water combinations did not determine bad years. Increases in early/late planting ranged from 19/12 36/31 and 46/42 good years when increasing moisture content. The highest water content at planting is associated with luxury consumption. Dry matter production/yield best fits a linear relationship when compared to transpiration rather than crop evapotranspiration. This behavior is accentuated in the early planting date.

Palavras-chave: ***Arachis hypogaea L.; Drought; Crop evapotranspiration; Crop transpiration.***

Uso do modelo CSM-CROPGRO-Peanut para estimar a época ideal de semeadura e produtividade da água da cultura sob diferentes teores de água no solo na Argentina

RESUMO

Cerca de 99% da produção de amendoim da Argentina está localizada na província de Córdoba, principalmente sob regime de sequeiro. Nesta região, as flutuações das chuvas podem levar a secas severas. A data ideal de semeadura do amendoim pode ser determinada usando um modelo de crescimento da cultura e dados climáticos históricos, estimando o impacto da seca na produtividade. Esta simulação teve como objetivo identificar as datas ideais de semeadura do amendoim cultivado sob três teores de água disponíveis na semeadura, em Córdoba. Outro objetivo, foi determinar as respostas da produtividade e da matéria seca à evapotranspiração e

transpiração da cultura para os diferentes tratamentos, sendo realizada análise sazonal do modelo CROPGRO-Peanut. Para isso, foram utilizados dados meteorológicos de 1973 a 2019 da Estação Experimental Manfredi, e coeficientes de cultivo da cultivar ASEM 485 INTA. O solo utilizado foi um Franco Siltoso Típico Haplustoll. Os tratamentos foram: três teores de água disponíveis até 150 cm de profundidade (30%, 60% e 100%) na semeadura e duas épocas de semeadura (21/out. e 9/dez.). A data ideal de plantio, determinada pelo CSM-CROPGRO-Peanut para Córdoba, é influenciada pelo teor de água do solo na semeadura. Em ambas as épocas de semeadura, observou-se maior produtividade média de sementes e menor diferença interquartílica quando o teor de água do solo aumentou. Em cada umidade do solo, a época de semeadura tardia apresentou valores medianos menores, mas com menor variabilidade. O número de anos ruins foi de 15 quando o teor de umidade inicial foi de 30%, independente da época de semeadura. As demais combinações de água no início do plantio não determinaram anos ruins. Os aumentos no plantio precoce/tardio variaram de 19/12, 36/31 e 46/42 anos bons ao aumentar o teor de umidade. O maior teor de água no plantio está associado ao consumo de luxo. A produção de matéria seca e produtividade se ajustaram melhor a uma relação linear, quando comparada à transpiração do que à evapotranspiração da cultura. Esse comportamento é acentuado na data de plantio.

Keywords: *Arachis hypogaea L.; Seca; Evapotranspiração da cultura; Transpiração da cultura.*

Uso del modelo CSM-CROPGRO-peanut en Argentina para estimar la fecha óptima de siembra y la productividad del agua del cultivo bajo diferentes contenidos de agua en el suelo

RESUMEN

Casi el 99% de la producción argentina de maní se localiza en la provincia de Córdoba, principalmente en régimen de secano. En esta región, las fluctuaciones de las precipitaciones pueden provocar sequías de diversa gravedad. La fecha óptima de siembra del maní se puede determinar utilizando un modelo de cultivo y datos climáticos históricos para estimar el impacto de la sequía en los rendimientos. El objetivo de esta simulación fue identificar fechas óptimas de siembra de maní bajo tres contenidos de agua disponible en la siembra, en Córdoba. Un objetivo secundario fue analizar el comportamiento del rendimiento y la materia seca en respuesta a la evapotranspiración y transpiración del cultivo para los diferentes tratamientos. Se realizó un análisis estacional del modelo CROPGRO-Peanut utilizando datos meteorológicos de 1973 a 2019, de la Estación Experimental Manfredi (31° 49´S, 63° 46´O) y coeficientes de cultivo del cultivar ASEM 485 INTA. El suelo empleado fue franco limoso Haplustoll Typic . Los tratamientos fueron: tres contenidos de agua disponible hasta 150 cm de profundidad (30%, 60% y 100%) en la siembra y dos fechas de siembra (21/oct y 9/dic). La fecha óptima de siembra determinada por CSM-CROPGRO-peanut para Córdoba, está influenciada por el contenido de agua del suelo a la siembra. En ambas fechas de siembra se determinó una mayor mediana de rendimiento de semilla y una menor diferencia intercuartil cuando se incrementó el contenido de agua del suelo. En cada humedad del suelo, la fecha de siembra tardía presentó valores medianos más bajos pero menor variabilidad. El número de años malos fue de 15 cuando el contenido de humedad inicial fue del 30%, independientemente de la fecha de siembra. Las combinaciones restantes de fecha de siembra-agua inicial no determinaron años malos. Los aumentos en la siembra temprana/tardía oscilaron entre 19/12, 36/31 y 46/42 años buenos al aumentar el contenido de humedad. El mayor contenido de agua en la siembra está asociado al consumo de lujo. La producción/rendimiento de materia seca se ajusta mejor a una relación lineal cuando se compara con la transpiración en lugar de la evapotranspiración del cultivo. Este comportamiento se acentúa en la fecha de siembra temprana.

Palabras clave: *Arachis hypogaea L.; Sequía; Evapotranspiración del cultivo; Transpiración del cultivo.*

Introduction

Peanut is a commonly grown oil seed crop in Argentina. The average country yield was 2.7 t ha^{-1} for the last decade and 3.45 t ha $^{-1}$ for the last growing season (FAO, 2021). The main peanut region of the country covers 350000 ha in the temperate, central provinces of Córdoba (31º 49´S, 63º 46´W) and La Pampa (35º 01´S, 64º 15´W) (HARO et al., 2022), and 99% of Argentinean peanut production is localized in Córdoba province (NOVAS and CABRAL, 2002). Peanut yield in Argentina has increased over the decades, mainly since 1975, with the introduction of cultivars with procumbent growth habits (HARO *et al*., 2013). Nevertheless, yield gain rates have decreased in recent years; accordingly, new cultivars with greater potential should be bred and released and management strategies suitable for each production scenario should be developed.

Current peanut management practices involve a small number of cultivars, a temporal window for sowing during the first half of November, row spacing of 0.7 m and stand density of 14 plants m^{-2} (PEDELINI and MONETTI, 2018). Delay in sowing date (e.g., December) produces a fast emergence of plants, but exposes plants to decreased temperature and radiation levels during pod filling, with adverse consequences on yield. On the other hand, crops sown on earlier dates (e.g., October) are exposed to higher temperature and radiation levels during pod setting and growth; these conditions are beneficial for yield. Nevertheless, low temperatures at the onset of the season can delay germination, which can put plant emergence at risk (HARO *et al*., 2007).

Peanut production in Córdoba is mainly rainfed, with season rainfall being 595 mm (average of 80 years). In this region, summer rainfall variability (October to March) shows inter-annual to multi-decadal fluctuations (COMPAGNUCCI, AGOSTA and VARGAS, 2002), leading to droughts of varying duration and severity that reduce crop yields below the expected. The characterization of crop responses to different levels of drought is needed for the development of appropriate management strategies (DANGTHAISONG *et al*., 2006). In this sense, Noellemeyer, Fernández and

Quiroga (2013) showed that yields of soybean, sunflower, corn, and wheat, growing in Argentina, responds linearly to the available water contents at seeding plus the rainfall during the crop season.

The optimum sowing date for the peanut region of Argentina can be determined by conducting field trials over several years. An alternative approach is the use of a validated crop growth model and historical climatic data to determine the impact of drought stress on plant growth and development, and crop yields (AMIRI, GOHARI and MIANABADI 2015). In this sense, peanut crop models have been developed (YOUNG *et al*., 1979; BOOTE *et al*., 1985, 1987, 1988) to simulate crop performance under different environmental conditions and management practices (SURIHARN *et al*., 2008).

CROPGRO-Peanut is a process-oriented model that is part of a suite of crop simulation models available in the software named Decision Support System for Agrotechnology Transfer (DSSAT) (BOOTE *et al*., 1998; JONES *et al*., 2003; HOOGENBOOM *et al*., 2019). The CROPGRO-Peanut simulates vegetative and reproductive development, growth and yield as a function of crop characteristics, weather and soil conditions and crop management scenarios. This model has been extensively used under multiple environmental conditions to assess crop yield, cultivars, cropping practices and genetic coefficient (BOOTE *et al*., 1985; SINGH *et al*., 1994 a and b). Accordingly, the validated model can be used to predict growth and yield responses to sowing dates, nutrient availability, row spacing and irrigation (HALDER *et al*., 2017), and is a useful tool to decide the best possible management options against available climatic variables along with soil and water inputs (YADAV *et al*., 2012).

The aim of this simulation was to identify optimum sowing dates for peanut crops growing under three available water contents at seeding, in the main peanut region of Argentina. A secondary objective was to analyze the dry matter production and yield in response to evapotranspiration and transpiration of the crop for the different treatments.

Material and methods

For this study, the CROPGRO-Peanut model was run under its ‘seasonal analysis’ mode. Forty-seven years of weather data (1973 - 2019), from the Manfredi Experimental Station of the National Institute for Agricultural Technology (INTA) (31° 49´S, 63° 46´W), provided forty-six growing seasons of simulation.

The crop coefficients of cultivar ASEM 485 INTA were used in this study. It is a runner cultivar of approximately 140 days of growth cycle that is currently used in most of the Argentine peanut growing area. In the simulation, rows spaced 0.7m apart and a stand density at emergence of 14 plants m^{-2} were used. The soil employed for the simulation is a silty loam Typic Haplustoll (USDA Soil Taxonomy) typical of the Córdoba central region, with 150 mm of plant available water per meter depth (DARDANELLI et al., 2003). Further details on crop and soil coefficient of CROPGRO-Peanut model applied in this paper can be found in Haro and Ovando (2016).

For the seasonal analysis, three available water contents up to 150 cm deep at seeding and two sowing dates were used. For the former, the treatments were (i) 30% of available water (SH1), (ii) 60% of available water (SH2), and (iii) 100% of available water (SH3) plus automatic irrigation, throughout the growing season, to keep soil water content near field capacity to 150 cm depth. For the latter; two sowing dates were considered: (a) early sowing on 21 October - Julian day 288 (SD1), and (b) late sowing on 9 December - Julian day 344 (SD2).

To carry out a comparative analysis, the relative yield was calculated with respect to the maximum yield of each year among the six treatments and they were classified as poor, normal or average, and good if their values are in the following intervals [0, 0.33), [0.33, 0.66) and [0.66, 1], respectively.

Results and discussion

Box plots were used to show the distribution of crop yields throughout combinations of sowing x water availability (**Figure 1**). Boxes represent the interquartile range (between the 25th and 75th percentiles of the distribution, respectively) and its line indicates the median. Bars extend down to the minimum value unless the distance to the minimum value is more than 1.5 times the IQR below the first quartile. In that case, the bar extends to 1.5 times in the IQR from the first quartile. A similar rule applies to the upper bar extending above the third quartile. The plotted black points represent the simulated yields in each of the 46 years for treatment.

In both sowing dates, a higher median seed yield and a smaller difference between the Q3 and Q1 quartiles were determined when water content increased. In each soil moisture, the late sowing date presented lower median values but less variability (less value of interquartile range) than the early sowing date (**Figure 1**). Similar results were reported by Haro et al. (2022) when studied the ASEM 485 INTA´s performance during three years at Manfredi, Argentina. The late sowing exposed this cultivar to low temperature and solar radiation values during the seed filling-harvest period. Furthermore, Ijaz et al. (2021) indicated that peanut seed yield decreased 40% when sowing date was delayed 20 days in an arid and semi-arid subtropical region of Pakistan. On the other hand, the pronounced yield variability in the early sowing date results mainly from the irregular frequency of rainfall previous to sowing and during the early stages of crop development. This irregularity was attenuated when later sowing dates were used.

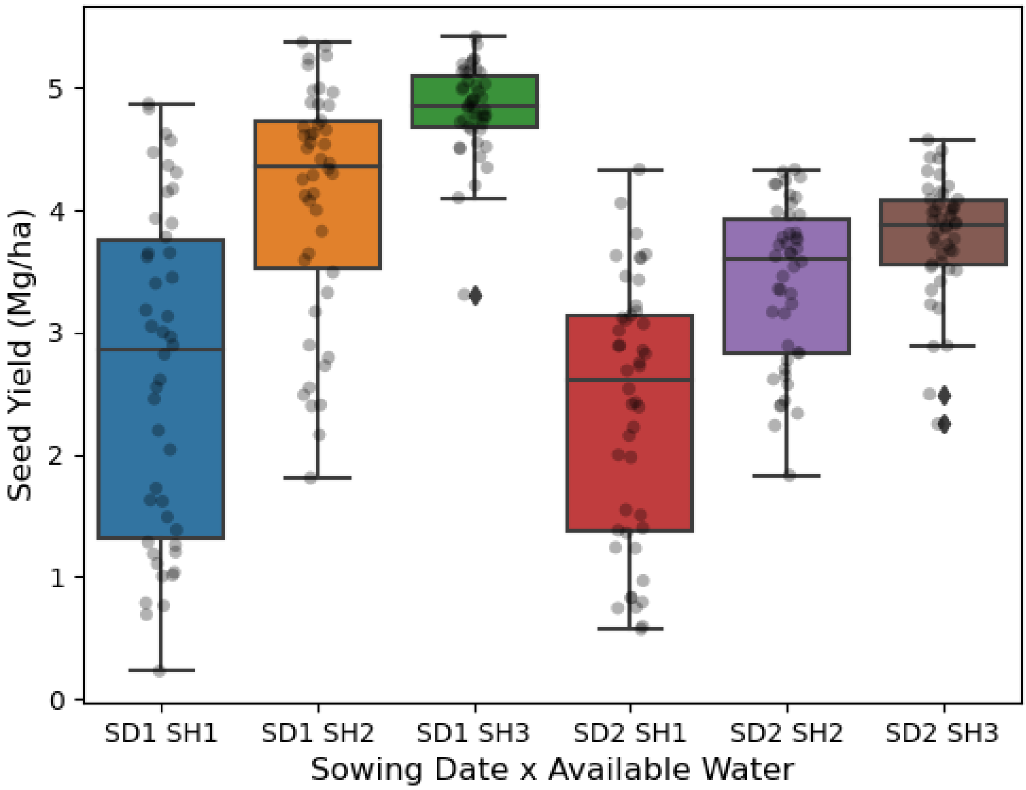

Figure 1. Response of seed yield to combinations of sowing dates and available water. SD1 for 288 julian day, SD2 for 344 julian day, SH1 for 30% of available water at seeding, SH2 for 60% of available water at seeding, and SH3 for 100% of available water at seeding and automatic irrigation to keep soil water content near field capacity to 150 cm depth throughout the growing season.

Figure 2 shows changes in relative peanut seed yield over time. The number of years classified as bad years was 15 and was only evident when the initial moisture content was 30%, regardless of the sowing date. The remaining planting date-initial water combinations did not determine bad years. These responses highlight the effects of initial water contents on the crop cycle and yield. An increase in initial soil water content leads to a higher number of good years and a lower number of bad years. Increases in early planting ranged from 19 to 36 and 46 good years when moisture contents were 30%, 60% and 100%, respectively. In late planting, the increases were 12, 31 and 42 good years when moisture contents were 30%, 60% and 100%, respectively.

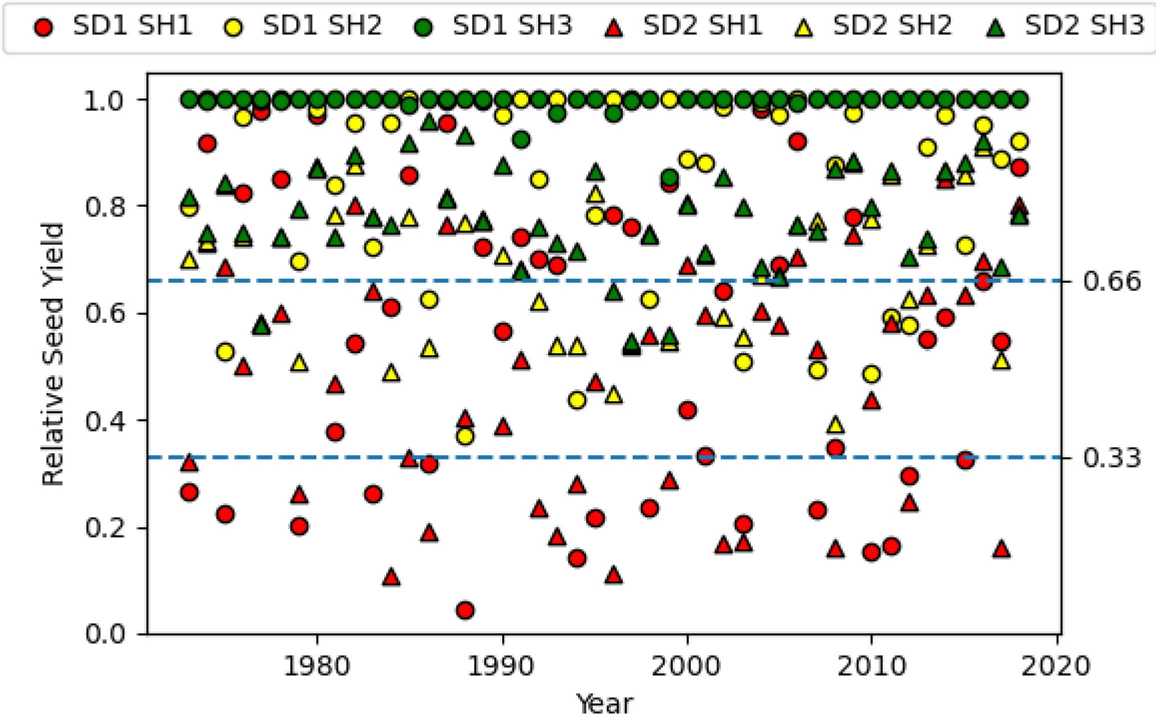

Figure 2. Relative peanut seed yield changes over time from 1973 to 2019 (n = 46) for different combinations sowing date-available water. SD1 for 288 julian day, SD2 for 344 julian day, SH1 for 30% of available water at seeding, SH2 for 60% of available water at seeding, and SH3 for 100% of available water at seeding and automatic irrigation to keep soil water content near field capacity to 150 cm depth throughout the growing season.

Dry matter production and yield in response to evapotranspiration and crop transpiration is presented in **Figure 3**.

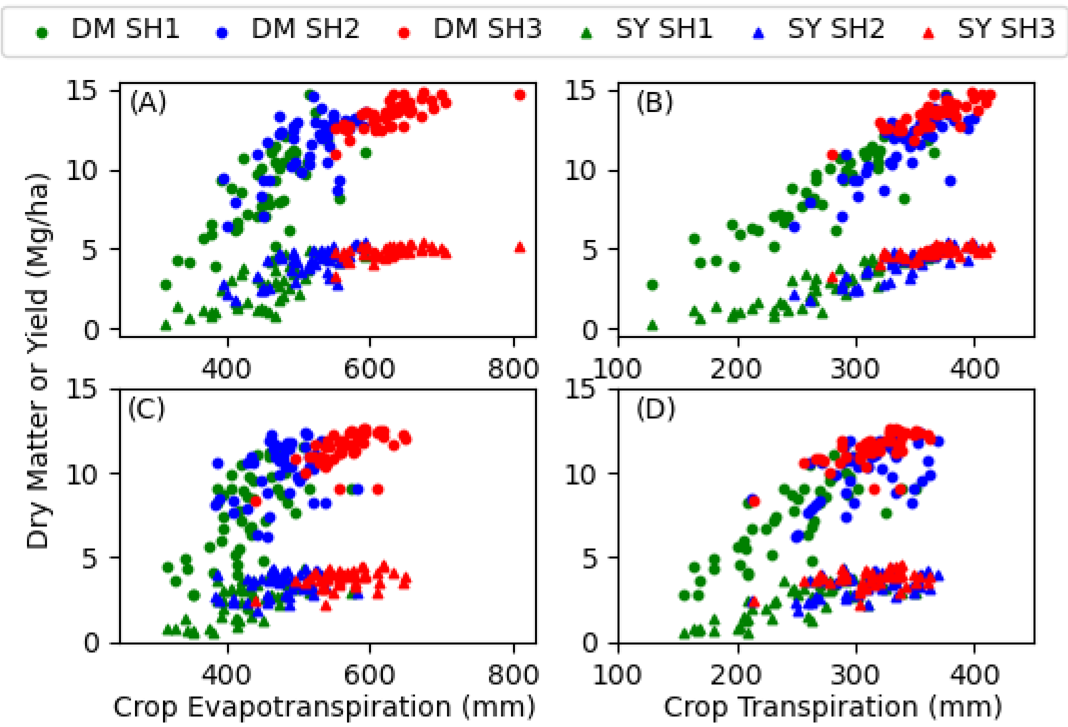

Figure 3. Response of dry matter (DM, circles) and seed yield (SY, triangles) to Crop Evapotranspiration (A and C) and Crop Transpiration (B and D) accumulated throughout the crop cycle. Early planting for 288 julian day (A and B), late planting for 344 julian day (C and D), SH1 for 30% of available water at seeding, SH2 for 60% of available water at seeding, and SH3 for 100% of available water at seeding and automatic irrigation to keep soil water content near field capacity to 150 cm depth throughout the growing season.

Comparisons between dry matter (total and seeds) versus evapotranspiration and, versus transpiration determined two responses (**Figure 3**) At first, a segmentation between 60% and 100% water availability treatments when dry matter and evapotranspiration were related (**Figure 3 A, C**). The second response shows the overlap between these treatments (60 and 100%) when the independent variable was transpiration (**Figure 3 B, D**). From the first response, it is also suggested that a proportion of water consumption is not translated into biomass production because it would correspond to the evaporative component. This is highlighted in the 100% treatment, where there is a marked increase in evapotranspiration that is not proportionally translated into biomass production. (**Figure 3 A, C**).

The relationships between dry matter production (total and seeds) versus evaporation and transpiration during the crop cycle fitted linear models (**Table 1**). Greater fits of the data to the linear model, i.e. less variability inferred by increases in R^2, were found when the independent variable was transpiration. Increases in R^2 were also found for early sowing dates, compared to those for late sowing.

Table 1: Values of regression coefficients and determination coefficient (R^2) in peanut dry matter (DM) or seed yield (SY) for all treatments from 1973 to 2019 (n = 46) as response to Crop Evapotranspiration (ETc. mm) or Crop Transpiration (CTr, mm) accumulated throughout the entire crop cycle, for early (SD1) or late (SD2) sowing dates.

Sowing Date	Independent Variable (mm)	Dependent Variable (Mg/ha)	Slope (Mg/ha.mm)	y intercept (Mg/ha)	R^2
SD1	ETc	DM	0.025	-2.141	0.675
		SY	0.011	-2.393	0.624
	CTr	DM	0.044	-3.183	0.850
		SY	0.021	-3.126	0.845
SD2	ETc	DM	0.024	-2.016	0.539
		SY	0.009	-1.222	0.455
	CTr	DM	0.040	-1.980	0.660
		SY	0.015	-1.258	0.570

Conclusions

The optimal sowing date determined by CSM-CROPGRO-peanut for Córdoba, Argentina is influenced by the soil water content at sowing. In both sowing dates, a higher median seed yield and a smaller interquartile difference were determined when soil water content increased. For each soil moisture, the late sowing has lower median values and interquartile range of yields. The bad years were observed when the initial moisture content was 30%, regardless of the sowing date. The remaining planting date-initial water combinations did not determine bad years. The highest water content at planting is associated with luxury consumption. Dry matter production/yield best fits a linear relationship when compared to transpiration rather than crop evapotranspiration. This behavior is accentuated in the early planting date.

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