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Peanut crop yield under full and deficit irrigation in the reproductive phase[1]

Produtividade da cultura do amendoim sob irrigação plena e deficitária na fase reprodutiva

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HIGHLIGHTS:
- *Optimal irrigation management increases peanut yield by 35% as compared to water-limited conditions.*
- *Deficit irrigation proved to be feasible for peanut in years under suitable temperatures.*
- *Suboptimal temperatures reduce peanut yield by up to 33%.*

ABSTRACT: Peanut cultivation has national and global significance in agriculture and industry. Under water-limited conditions, its yield decreases to the extent that it compromises the success of the exploitation. This study focused on evaluating peanut crop yield and production components under full and deficit irrigation applied in the reproductive phase, to determine the impact of water supply on the yield of peanuts grown in the off-season in the State of São Paulo, Brazil. The experiment was conducted for two years and followed a randomized blocks design with five irrigation levels distributed in strips, with four repetitions. The treatments consisted of crop evapotranspiration replenishments from 100 to 10%. In the first year, under suitable temperatures, the maximum yield reached 3,922 kg ha^{-1} with the application of 277 mm of irrigation depth and decreased up to 35% with the lowest irrigation depth (48 mm). In the second year, suboptimal temperatures caused a delay in the growing cycle and caused a 33% reduction in crop yields. Despite the potential benefits of deficit irrigation in increasing water productivity, low temperatures pose a risk to peanut yield, especially during the off-season crop in the region.

Key words: *Arachis hypogaea* L., water deficit, yield components

RESUMO: O cultivo do amendoim tem importância nacional e global na agricultura e na indústria. Em condições limitadas de água, sua produtividade diminui ao ponto de comprometer o sucesso da exploração. Este estudo teve como objetivo avaliar o rendimento da cultura do amendoim e seus componentes de produção sob irrigação plena e deficitária aplicada na fase reprodutiva, para determinar o impacto do fornecimento de água no rendimento do amendoim cultivado na segunda época no Estado de São Paulo, Brasil. O experimento foi conduzido durante dois anos e seguiu um delineamento de blocos ao acaso com cinco níveis de irrigação distribuídos em faixas, com quatro repetições. Os tratamentos consistiram na reposição da evapotranspiração da cultura de 100 a 10%. No primeiro ano, sob temperaturas adequadas, o rendimento máximo atingiu 3.922 kg ha^{-1} com a aplicação de uma lâmina de irrigação de 277 mm e diminuiu em até 35% com a menor lâmina (48 mm). No segundo ano, temperaturas subótimas causaram atraso no ciclo de crescimento e casou redução de 33% na produtividade da cultura. Apesar dos potenciais benefícios da irrigação deficitária no aumento da produtividade da água, as baixas temperaturas representam um risco para o rendimento do amendoim na segunda safra.

Palavras-chave: *Arachis hypogaea* L., déficit hídrico, componentes de produção

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Introduction

Peanut (*Arachis hypogaea* L.) is originally from South America and is one of the most produced oilseeds in the world (FAOSTAT, 2020). In the state of São Paulo, Brazil, peanuts are preferably cultivated during the rainy season, from October to February. Off-season cropping is an alternative for producers who engage in activities such as seed production. In several regions of Brazil, irrigation is necessary to supplement the lack of precipitation to obtain compensatory yields. To sustain irrigated agriculture, we need to maximize the production per unit of water consumed (Sezen et al., 2022).

One of the strategies for optimizing irrigated peanut cultivation is the adoption of deficit irrigation, in which net income increases as a result of the reduction of applied water (Capra et al., 2008). Deficit irrigation can be either imposed during the entire cycle or achieved by applying irrigation only in the most sensitive phenological stages, thus suppressing irrigation in the least sensitive stages.

Water stress at any stage of the cycle reduces yield (Azevedo et al., 2014), but peanut plants are less sensitive to water stress from the period after seedling emergence until the start of floral organ formation. However, they become highly demanding during flowering and fruiting (Nakagawa & Rosolem, 2011). The fact that suppression of irrigation during the cycle or part of it reduces crop yield has resulted in little progress in the adoption of management in deficit irrigation (Capra et al., 2008).

Since there is a lack of information in the literature related to the magnitude of deficit and how much the peanut crop can withstand without significant reductions in yield, as well as how deficit irrigation affects water productivity, this study aims to evaluate peanut crop yield and production components under full and deficit irrigation applied in the reproductive phase, to determine the impact of water supply on the yield of peanut grown in the off-season in the state of São Paulo, Brazil.

Material and Methods

The experiments were carried out from March to August 2019 and 2020, at the São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal, SP, Brazil (latitude 21° 15' 22" S, longitude 48° 18' 58" W and altitude 570 m).

The climate in the region, according to Köppen's classification, is Aw, tropical (Alvares et al., 2013), with an average annual rainfall of 1,425 mm and an average annual temperature of 22.2 °C. The soil in the experimental area is an Oxisol (Soil Survey Staff, 2014), with a clayey to moderate texture, kaolinitic, and smooth wavy and wavy relief (Santos et al., 2018).

The peanut cultivar IAC 503, Virginia Runner type, has a growth cycle of 130-140 days. The seeds were provided by the Instituto Agronômico de Campinas (IAC), with a germination rate of 85%. Sowing was carried out mechanically, after plowing and harrowing the soil on March 6, 2019, and March 11, 2020, at a density of 25 seeds m^{-1} and spacing of 0.90 m between rows, with a final stand of 18 plants m^{-1}.

The experimental design was in randomized blocks in strips, with four replications and five treatments (L1, L2, L3, L4, and L5), corresponding to replacement of 100, 89, 56, 29, and 10% of crop evapotranspiration in 2019 and 2020. The irrigation levels were provided by a line-source sprinkler system, which allows obtaining a decreasing gradient of water depth perpendicular to the irrigation line, corresponding to the distribution factor, as established in the treatments (Hanks, 1986). In the vegetative period, irrigation was full (100% ETc) and in the reproductive period, the treatments of full and deficit irrigation were differentiated.

The irrigation system used was a sprinkler with a Christiansen uniformity coefficient of 91%, with irrigation applied after consumption of the readily available soil water (25.2 mm) calculated based on the soil water retention curve of the experiment ($\theta fc = 0.45\ cm^3\ cm^{-3}$ and $\theta pwp = 0.33\ cm^3\ cm^{-3}$), depletion fraction (p = 0.7) and root depth (30 cm) recommended by the FAO-56 method (Allen et al., 1998).

Soil water depletion was accounted for by crop evapotranspiration, calculated as the product of the crop coefficient (Kc) and reference evapotranspiration (ETo), estimated daily by the Penman-Monteith equation (Allen et al., 1998). The dimensions of the experimental plots were 2.4 × 6.3 m, totaling 15.2 m^2, containing seven rows, spaced 0.90 m apart. Of the seven rows, two were considered for growth assessment, disregarding one row on each side. For yield evaluation, two other rows were considered, also disregarding a row on each side.

The gradual distribution of precipitation was obtained by an in-line sprinkler system (Figure 1), in which the depth decreases as a function of the distance from the sprinkler line located in the center of the area (Hanks et al., 1976). Senninger sprinklers (Model 3023-2 with the double nozzle of 8 × 5 mm)

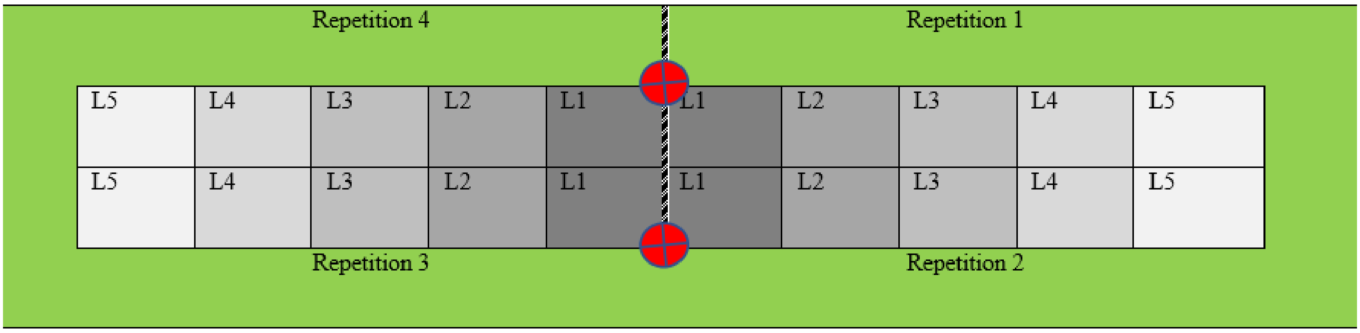


Figure 1. Schematic of the experimental area with sprinkler system in lines, irrigation depth treatments and repetitions. The circle in red represents a sprinkler

were used, operated with a pressure of 300 kPa, and at a spacing of 6 m, producing a radius of reach of 12 m and application intensity of 13 mm h^{-1}.

Collectors spaced 1 m apart were used to determine the spatial distribution of the irrigation depth and the amounts applied in each treatment, calculated by averaging the values collected before and during the irrigation application. From this field test, the sprinkler precipitation distribution fractions, used to define the applied water depths, corresponding to the experimental treatments, were also defined (Figure 2).

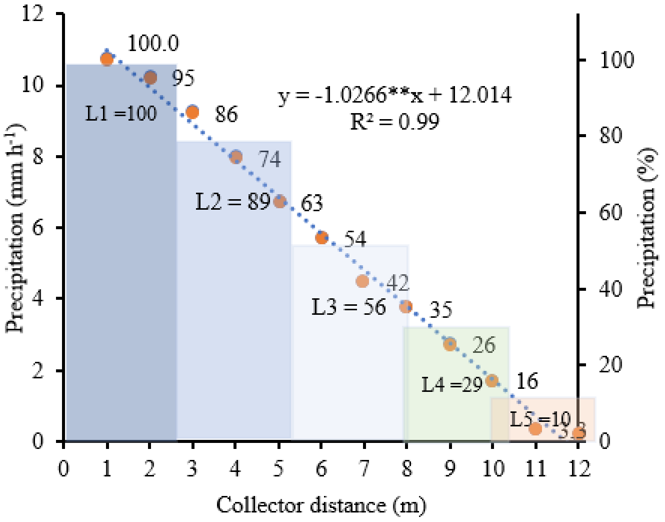
Irrigation management was carried out based on the crop water demand, using the FAO 56 method, with climatic data obtained daily at the Unesp Agrometeorological Station. Reference evapotranspiration (ETo) was estimated daily by the Penman-Monteith equation (Allen et al., 1998). Peanut crop evapotranspiration (ETc) was calculated as the product of ETo with tabulated values of crop coefficients (Kc) (Allen et al., 1998).

During the experiments, the temperature was within the ideal range of cultivation for peanuts (10 to 33 °C) (Prela & Ribeiro, 2000), with decreasing values from the beginning to the end of the cultivation cycle. During the 2020 experiment, minimum temperature values were lower than in the 2019 experiment, mainly between the flowering (R1) and early seed formation (R5) stages (Figure 3). Lower temperature between these stages is harmful to the peanut crop, as it can affect its production components and, consequently, its yield.

Precipitation in 2019 (104 mm - Figure 4 A) and 2020 (65 mm - Figure 4B) was more concentrated at the beginning of the experiment, from sowing to flowering (stage R1).

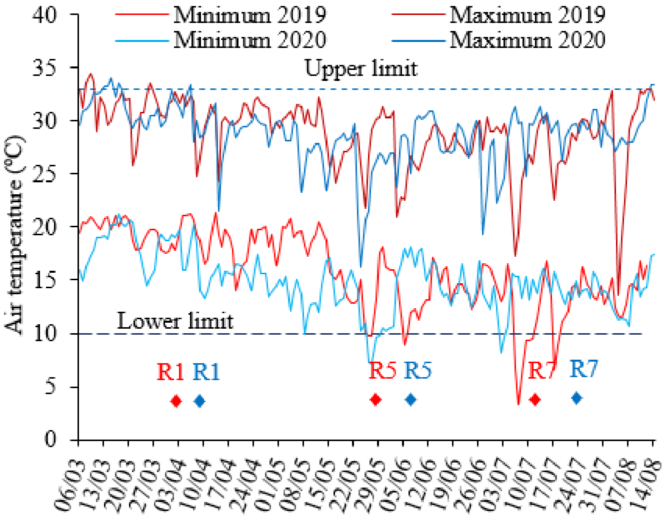
The ETo and ETm depths in 2019 (Figure 5A) were lower than those of 2020 (Figure 5B), which justifies the higher total depth (Precipitation + irrigation) received in 2020 (387 mm), compared to 2019 (332 mm), for the treatment under full irrigation (L1).

According to Baldwin & Harrison (1996), peanuts have a water demand between 500 and 700 mm for normal cropping cycles. França et al. (2021) found water demand for the second crop during autumn and winter in Jaboticabal (Brazil) of 470 mm for sowing in February and 360 mm for sowing in March, similar, therefore, to what was observed in the present study.



** Significant at p < 0.01

Figure 2. Distribution of precipitation as a function of distance from the sprinkler line



R1, R5 and R7 - Flowering, pod appearance and physiological maturation stages, respectively, in red for 2019 and blue for 2020

Figure 3. Maximum and minimum temperatures observed during the peanut cycles in the years 2019 and 2020, in Jaboticabal, São Paulo, Brazil

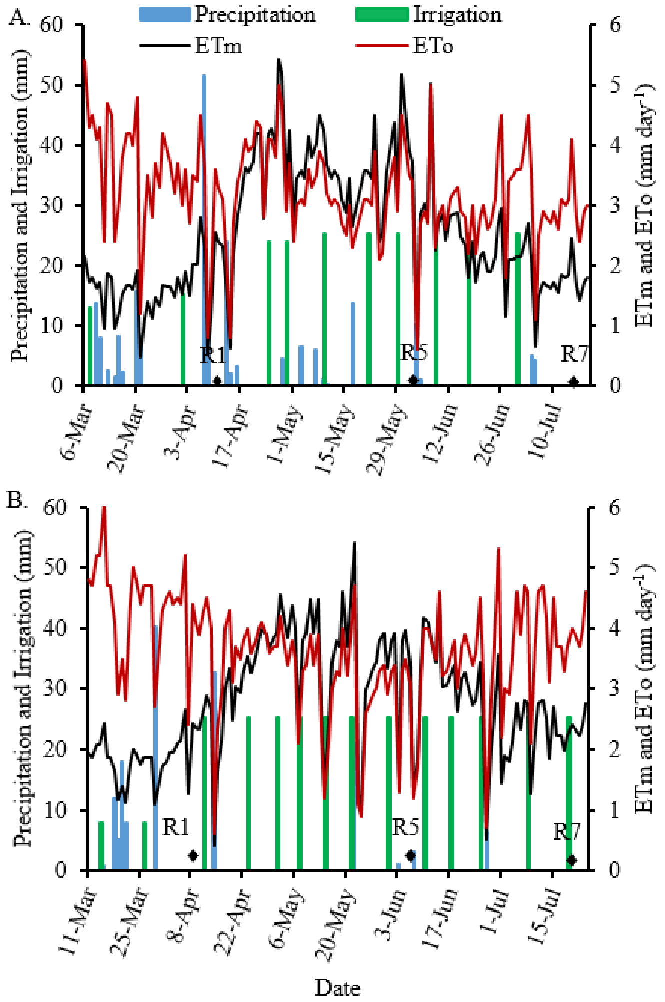
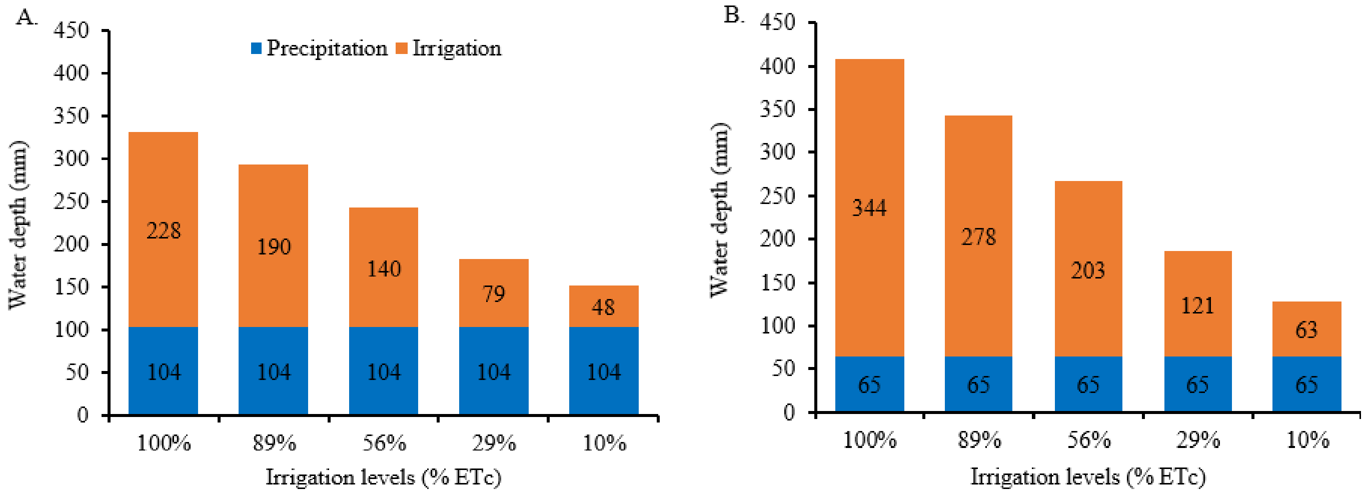


Figure 4. Precipitation, irrigation, maximum crop evapotranspiration (ETm), and reference evapotranspiration (ETo), during the peanut cycles in the years 2019 and 2020, in Jaboticabal, São Paulo, Brazil



ETc: Crop evapotranspiration

Figure 5. Irrigation depth and precipitation (mm) within the irrigation levels applied during the peanut cycles in the years 2019 (A) and 2020 (B), in Jaboticabal, São Paulo, Brazil

Soil samples were collected in the 0-0.20 m layer for chemical analysis, according to the methodology proposed by van Raij (2001) 30 days before the experiment in 2019 and 2020, respectively (Table 1). As recommended by van Raij et al. (2001), the soil had ideal conditions for cultivation, with low acidity, organic matter content close to the ideal range, high K, high P_{resin}, base saturation, and high cation exchange capacity (CEC).

According to soil analysis, all fertilization was carried out at sowing, with 20 and 50 kg ha^{-1} of K_2O and P_2O_5 being applied, respectively (Ambrosano et al., 1997). The sources used were potassium chloride (60% of K_2O) and single superphosphate (18% of P_2O_5).

The physical attributes of the soil in the experimental area (Table 2) reveal a clayey texture (49.5% clay) of the Oxisol and its good water storage capacity.

Soil moisture in the experimental plots was measured at a depth of 0.20 m with the aid of the TDR probe (Hydrosense), which uses indirect methods to estimate the soil water content from measurements of the soil dielectric constant.

Soil moisture values measured in the 0-0.20 m layer (Figure 6A and B) in treatments under irrigation levels L1, L2, and L3 remained within the limits of available water, between field capacity and permanent wilting point, during the two crop cycles. In treatments under L4, moisture was higher than under L5 in both cropping cycles, but in both, the moisture contents remained below the permanent wilting point level.

During the experiments, phytosanitary controls were carried out according to the infestation of pathogens. Harvesting was performed manually at 159 days after sowing (DAS) in 2019 and at 160 DAS in 2020. The variables analyzed were:

- Growing degree-days (GDD): determined by the sum of the positive values of the difference between average daily temperature (Tm) and base temperature (Tb) assumed to be 12 °C:

$$GDD = \sum [Tm - Tb]$$

- Dates of occurrence of phenological stages: they were visually determined in the field weekly according to the method of Boote et al. (1982), where VE is emergence, R1 is the beginning of flowering, R5 is the beginning of seed formation, and R7 is the beginning of maturation.

Table 1. Chemical characteristics of the soil of the experimental area at a depth of 0-0.20 m in the years 2019 and 2020, in Jaboticabal, São Paulo, Brazil

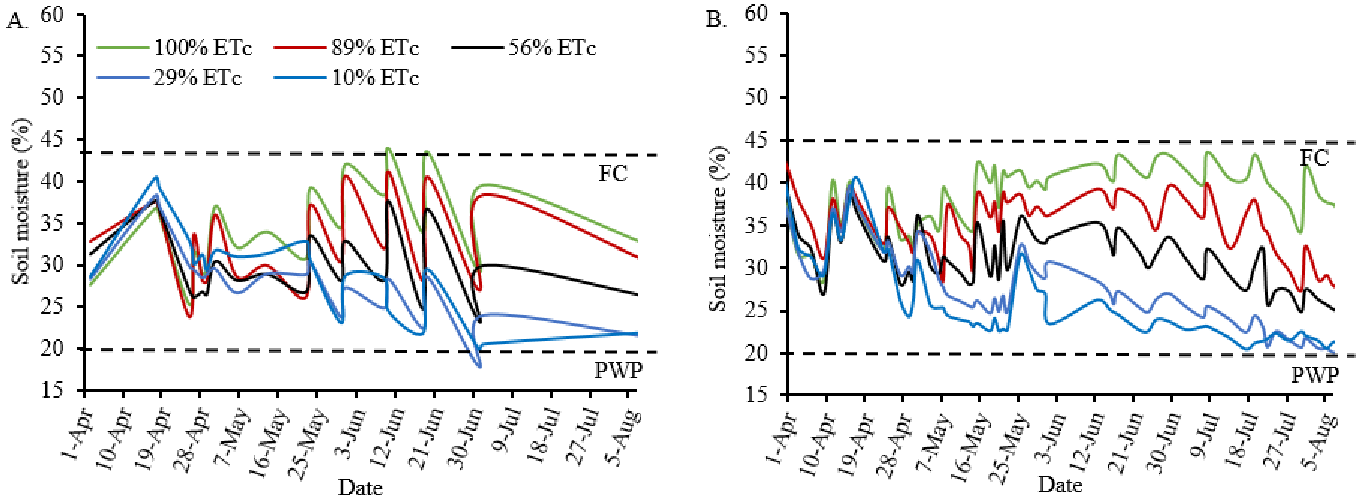
Year	pH	OM	P_{resin}	S	H + Al	Al	K	Ca	Mg	SB	CEC	V%
	$CaCl_2$	(g dm^{-3})	(mg dm^{-3})		(mmol$_c$ dm^{-3})							
2019	5.9	21	35	8	23	0	3.9	36	12	52.4	75.4	70
2020	6.1	23	72	3	15	0	3.5	48	12	63.9	79.1	81

OM - Organic matter; S - Sulfur; H + Al - Potential acidity; SB - Sum of bases; CEC - Cation exchange capacity; V - Base saturation. Extractants used: pH - in $CaCl_2$ by potentiometry; H + Al - In SMP buffer by potentiometry; OM - By spectrophotometry; P - In resin by spectrophotometry; S - By turbidimetry; K, Ca and Mg - By atomic absorption spectrometry; Al - In KCl by titration

Table 2. Parameters of the water retention curve by the model of van Genuchten (1980) and texture of the soil of the experimental area (0-0.40 m depth), in Jaboticabal, São Paulo, Brazil

Retention curve*	Moisture (m^3 m^{-3})			Parameters of Van Genuchten				Fit
	θs	θfc	θpwp	α	θr	m	n	R^2
	0.478	0.399	0.280	0.042188	0.226	0.19299	1.239156	0.998
Texture (g kg^{-1})	Sand			Silt		Clay		
	292			213		495		

* - Volumetric moisture at saturation (θs), field capacity (θfc) and permanent wilting point (θpwp); parameters θr, α (cm^{-1}), m and n, and the fitting coefficient (R^2) between values measured and estimated by the model



FC - Field capacity; PWP - Permanent wilting point

Figure 6. Soil moisture in the 0-0.20 m layer, as a function of irrigation levels, during the peanut cycles in the years 2019 (A) and 2020 (B), in Jaboticabal, São Paulo, Brazil

- Soil cover fraction (SC): determined with the help of the Canopeo® mobile application (Patrignani & Ochsner, 2015), at 35, 49, 63, 77, 91, 105, 119, 133, and 147 DAS. Photographs of the area delimited by a 0.9 x 1.0 m wooden template placed in the experimental plot were used to estimate the fraction of the area covered with green vegetation.

- Aerial part biomass and pod mass: collected throughout the cycle, taking three plants per plot, starting at 35 DAS, and then collected every 14 days. The material was taken to the Soil and Water Laboratory at Unesp, and separated into shoots (stem + leaves) and pods (grains + husks). Each part was washed, then placed in paper bags and taken to an oven for drying with forced air circulation, keeping it at 65 °C until constant weight is reached. Afterward, the material was weighed on a precision scale to obtain the weights of the aerial part (stem + leaves) and pods (grains + husks).

- Production components: determined at the end of the cycle, by taking ten plants from the observation area and analyzing them for the mass of pods per plant (MP), mass of seeds per plant (MS), number of seeds per plant (NS), and unit mass of seeds (UMS).

- Final yield of biomass and pods: Two rows in the observation area were considered, disregarding one row on each side, from which all plants and pods were removed.

- Water productivity was calculated by the relationship:

$$WP = 0.1\frac{Y_i}{D_i}$$

where:

WP - water productivity (kg m^{-3});
Yi - pod yield (kg ha^{-1}); and,
Di - total water depth received during the cycle (irrigation + rain, mm).

The obtained data were subjected to analysis of variance using the F test. When there was a significant effect, the data were subjected to regression analysis using the statistical software SISVAR® 5.6 (Ferreira, 2019).

Results and Discussion

In the two years of experimentation, irrigation levels did not affect the cycle length, but the peanut crop cycle was longer in 2020 (133 days - Figure 7A) than in 2019 (121 days - Figure 7B). Since the peanut crop is considered to be photoperiod-neutral (Ferrari Neto et al., 2012) and the sowing dates were close in both experiments, the longer cycle in 2020 is due to the low temperature during the R1-R7 period, from April 10 to June 30 of that year (Figure 3).

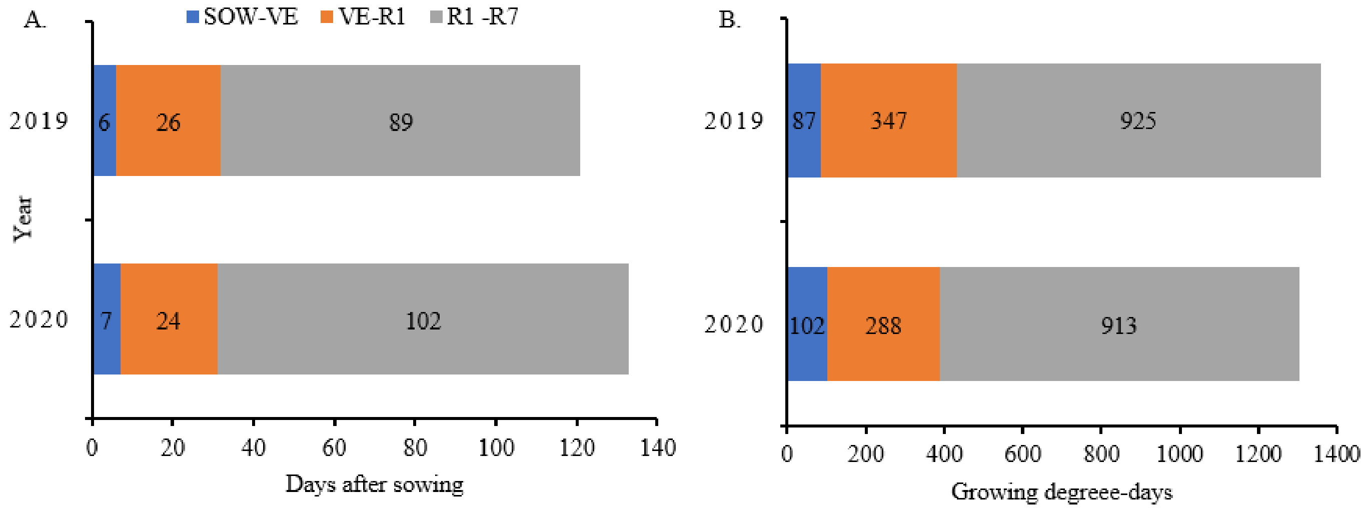
Low temperatures in 2020 resulted in a decrease in the phenological development rate of the crop and, consequently, an extension of the R1-R7 period, from 89 days in 2019 to 102 days in 2020. According to Godoy et al. (2017), the cultivar IAC 503 is considered to have a long cycle, from 130 to 140 days, corroborating the results of the present study.

The effect of temperature on the phenological development rate of the cultivar IAC 503 is evidenced by the sum of degree-days from sowing to physiological maturity, totaling values in the two cultivation cycles of 1359 and 1223 degree-days in 2019 and 2020, respectively (Figure 7A and B).

The thermal sums computed for the phenological periods during the cycle were similar, including for the R1-R7 period, which had greater variation, indicating that the growing degree-days (GDD) is suitable for prediction of peanut phenology.

These results were similar to those observed by França et al. (2021), who found cycles of 117 and 142 days and GDD of 1288 and 1282 for the cultivar IAC 505, sown in February and March 2018 at the same location as the present experiment.

For the tested irrigation levels and years of cultivation, the fraction of soil cover by the canopy (SC) reached about 35% at 40 DAS (R1), followed by an increase to maximum values of 65 to 87% at 91 DAS. However, there was a subsequent reduction in SC due to the natural senescence of the crop (Figure 8). The effects of irrigation levels were more evident from R1 to R5 in 2019, with lower SC observed in the more water-stressed treatments (L3, L4, and L5). In 2020, the differences in SC among treatments only became apparent after R5, with a final SC of 20 to 30% (Figure 8A), compared to 40 to 60%



SOW-VE - Sowing to emergence; VE-R1 - Emergence to beginning of flowering; R1-R7 - beginning of seed formation to beginning of maturation

Figure 7. Duration of peanut phenological periods in days after sowing (DAS - A) and sum of degree-days (GDD - B), in the year 2019 and (B) in 2020, in Jaboticabal, São Paulo, Brazil

in 2019 (Figure 8B). This difference can be attributed to the lower plant growth due to the lower temperature in the R1-R5 period. Song et al. (2020) observed that peanuts reduce their metabolic activities, delaying growth, when subjected to low temperatures, as observed in the present study.

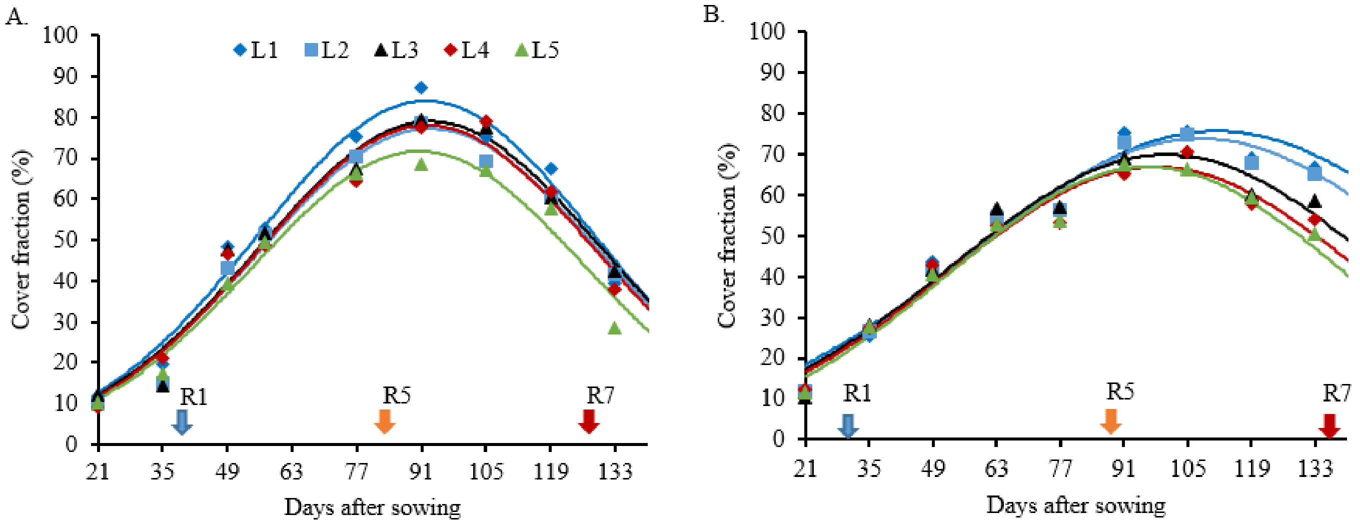
Similar response of canopy growth was observed by França et al. (2021), with a higher SC at 100 days after sowing. Similar to the present study, these authors observed no full crop cover for the same row spacing as used in this research (0.9 m). The SC index is directly proportional to the radiation interception by the plant canopy, which, in turn, affects photosynthesis and plant growth. Overall, the irrigation level without water deficit (L1) promoted the highest faction of soil cover by the canopy, with values greater than 80% in the first year and 70% in the second year.

Since the maximum SC in both experiments was approximately 65 to 87%, it can be inferred that, for peanut cultivation in the second crop at the study site, the spacing between rows should be reduced, so that the SC is close to 100%, thus obtaining better use of solar radiation and yield. However, when the spacing is reduced, the leaf area index (LAI) increases and, consequently, the water consumption also increases, so additional studies are recommended.

Higher biomass accumulation was observed in 2020 (Figure 9A) compared to 2019 (Figure 9B). The increase was slow until 49 DAS, then there was a sharp increase until reaching a plateau close to 105 DAS, followed by a decrease, in both years of cultivation, due to senescence, similar to the trend observed for SC in Figure 8.

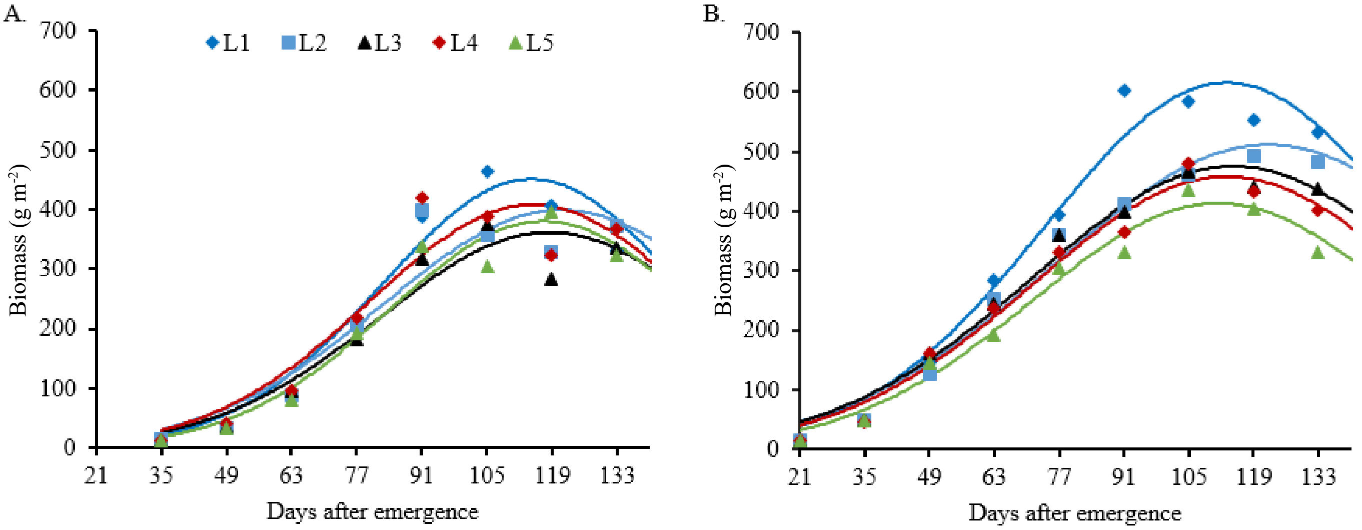
In the two years of experimentation, the production of biomass throughout the cycle was reduced because of the reduction of the applied water depths (Figure 9), similarly to SC variation (Figure 8). Biomass production is directly related to the cover fraction, with a maximum occurring at the same time in both years (105 DAS), followed by a decrease due to natural senescence at the end of the cycle.

The production of pods throughout the cycle was higher in 2019 (Figure 10A). The lower production of pods in 2020



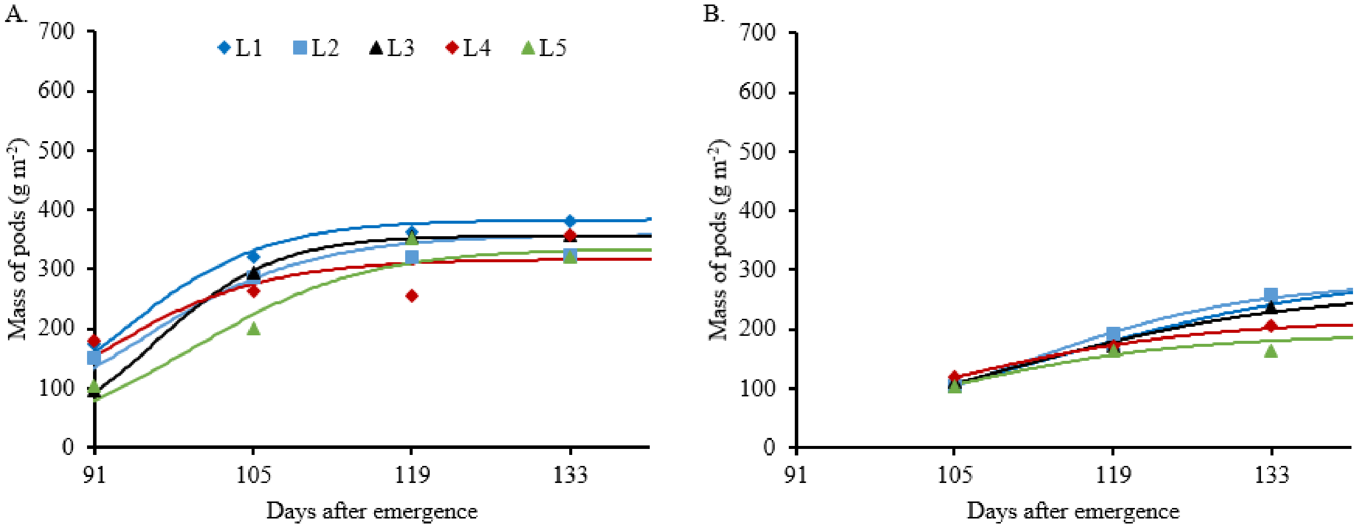
L1, L2, L3, L4 and L5 - Replenishment of 100, 89, 56, 29 and 10% of crop evapotranspiration, respectively

Figure 8. Cover fraction during crop cycles in 2019 (A) and 2020 (B) under different irrigation levels, in Jaboticabal, São Paulo, Brazil



L1, L2, L3, L4, and L5 - Replacements of 100, 89, 56, 29, and 10% of crop evapotranspiration, respectively

Figure 9. Aerial part biomass (stem + leaves) throughout the crop cycles in the years 2019 (A) and 2020 (B) at different irrigation levels, in Jaboticabal, São Paulo, Brazil



L1, L2, L3, L4 and L5 - Replacements of 100, 89, 56, 39 and 10% of crop evapotranspiration, respectively

Figure 10. Mass of pods throughout the crop cycles in 2019 (A) and 2020 (B) as a function of irrigation levels, in Jaboticabal, São Paulo, Brazil

(Figure 10B), despite the higher biomass in this year, can be explained by the suboptimal temperatures (Figure 3), during the period between flowering and beginning of grain formation (R1-R5), which may have led to pod abortion, as shown in Figure 10.

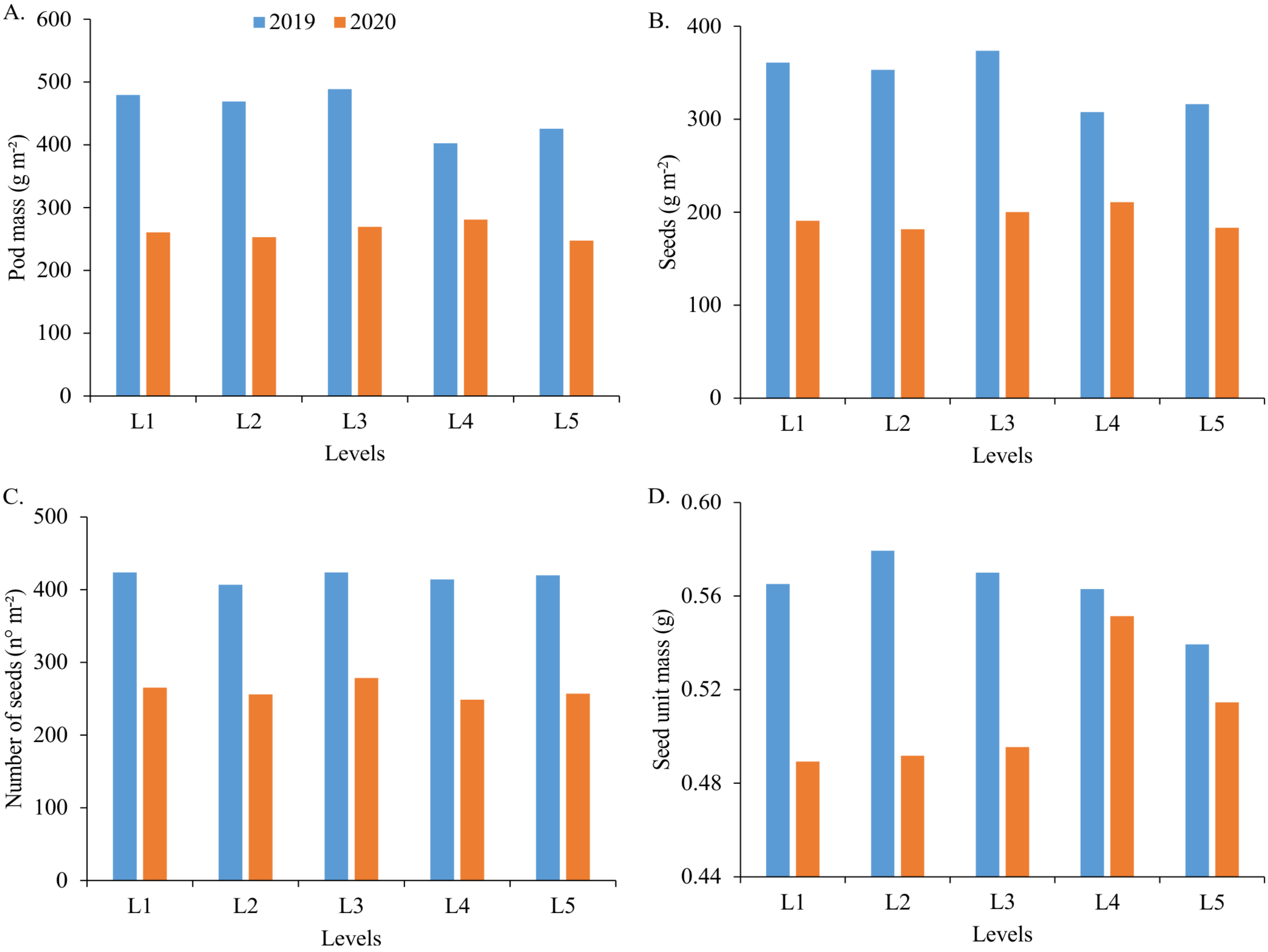
The lower number of pods per plant might have reduced the demand for nutrients for seed formation, causing higher availability of assimilates to maintain biomass growth at high rates, resulting in high biomass production in 2020. In addition, in the second year there was a delay in crop stages, so that the biomass could accumulate higher values at the end of the cycle.

The effects of low temperature during the R1-R5 period (Figure 4B), with minimum temperatures below 10 °C, are evidenced by the analysis of the production components determined at the end of the cycle (pod and seed mass - Figure 11A and B, number and unit mass of seeds - Figure 11C and D), which were higher in 2019 compared to the cultivation in 2020. There was no difference in these yield components between treatments at irrigation levels. Therefore, the reduction in pod and seed mass in 2020 is related to lower seed development and lower seed unit mass.

According to Song et al. (2020) explain that low temperatures affect peanut metabolic processes, reducing its development and growth. Low night temperatures are considered the main climatic factor responsible for the insufficiency in the formation of pods.

The average yield for the five irrigation levels was higher in 2019 (3,440 kg ha^{-1}), compared to the 2020 cycle (2,370 kg ha^{-1}). As mentioned previously (Figures 3, 10, and 11), this effect is attributed to the low temperature in the R1-R5 period, which reduced the development of pods and seeds in the second year of the experiment.

The maintenance of high yield in treatments with replenishment of 89, 56, and 29% of ETc can be partially explained by the moderate tolerance to water stress in peanuts, despite the water deficit having been imposed in the reproductive period. Another possibility that the effect of water stress on crop yield has been mitigated lies in the fact

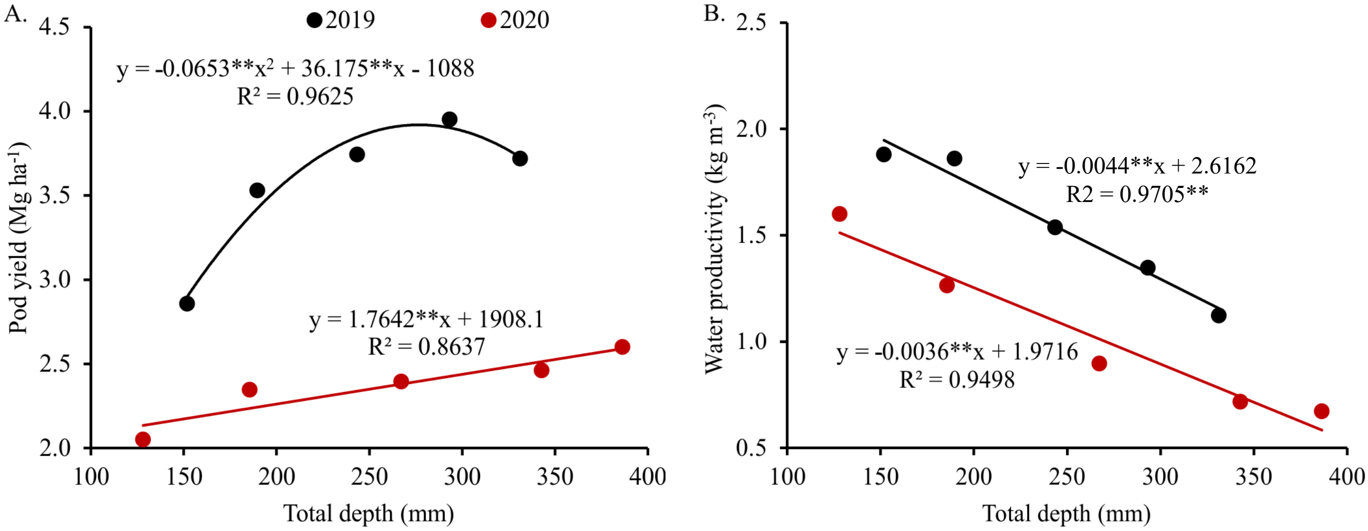


L1, L2, L3, L4, and L5 - Replacement of 100, 89, 56, 29, and 10% of crop evapotranspiration, respectively

Figure 11. Pod mass (A), seeds (B), number of seeds (C), and seed unit mass (D) evaluated at the end of the crop cycles in the years 2019 and 2020 as a function of irrigation levels, in Jaboticabal, São Paulo, Brazil

that soil moisture in the 0-0.20 m layer remained within the limits of available water in all treatments, except L4 and L5 (Figure 6), as discussed earlier. The maintenance of moisture content at a favorable level in these treatments may be due to the low consumption by peanuts during the autumn and winter period (Figure 4) and to the use of moisture stored in the soil, in addition to the deficit level received in each treatment (Figure 6).

The maximum yields obtained in this study, from 3,530 to 3,952 kg ha^{-1}, obtained in 2019, were twice the magnitude of the



**Significant at $p < 0.01$

Figure 12. Pod yield (A) and water productivity (B) as a function of total water depth (precipitation + irrigation) received during peanut cultivation in the years 2019 and 2020, in Jaboticabal, São Paulo, Brazil

world average for the peanut crop in 2021/2022 (USDA, 2022). Additionally, they were equivalent to the average considered ideal for the crop (Godoy et al., 2017) and higher than the national average of 3,500 kg ha^{-1} of the last five years in the rainy season and 1,800 kg ha^{-1} in the dry season (CONAB, 2021). In 2020, yield was lower than the national average of the first season in all the studied treatments due to the low temperature at the beginning of the reproductive phase.

The pod yield response curves as a function of the water received by the crop (precipitation + irrigation) were described by a quadratic regression equation (Figure 12A). The maximum yields of 3,922 kg ha^{-1}, obtained in 2019, occurred under water depth of 277 mm. The maximum yield was 35% higher compared to irrigation management with the lowest level (L5 - 2,902 kg ha^{-1}). For 2020, since the beneficial effect of irrigation in addressing the water deficit was reduced by the occurrence of suboptimal temperatures at the beginning of the reproductive phase, the maximum yield plateau was not reached (Figure 12A). In the second year, peanut yield increased by 17.6 kg ha^{-1} for every 10 mm of water added.

As the applied depths were similar in the two years and the pod yield was lower in 2020, the water productivity was higher in 2019 (1 to 2 kg m^{-3}) than in 2020 (0.7 to 1.6 kg m^{-3}), according to Figure 12B. The linear fit of these functions with similar slope values (-0.0036 and -0.0044 kg mm^{-1}) indicates that the yield of pods per unit depth was maintained in both years and that the effect of temperature on yield reduction was 33%, calculated by the relationship between the intercept values of the fitted equations for 2019 and 2020, respectively.

Conclusions

1. Adequate irrigation supply increases fraction of soil cover, biomass, and mass of pods during the crop cycle;
2. Under optimal thermal conditions, application of full irrigation (270 mm) increases peanut yield (3,920 kg ha^{-1}) by 35%, compared to the lowest irrigation level (2,910 kg ha^{-1}, 48 mm);
3. Sub-optimal thermal conditions cause a 33% reduction in crop yields, compared to the crop grown in normal years;
4. Although irrigation can enable the intensive cultivation of peanuts in off-season in the state of São Paulo, low temperatures pose a risk to peanut yield.

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