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SOIL WATER STATUS, MINERAL NUTRITION AND BIOLOGICAL RESPONSE OF SOYBEAN UNDER PROTECTED ENVIRONMENT CONDITIONS

Gabriel Corrêa Plodoviski
http://lattes.cnpq.br/7646871263908472

André Belmont Pereira
http://lattes.cnpq.br/7548805986719809

Eduardo Fávero Caires
http://lattes.cnpq.br/3850817367861711

Abstract: Soybean (Glycine max L.) has been gaining more and more importance in terms of crop production, once yield components are to be directly impinged upon soil water supply and phosphorus in the soil so that such a crop might be able to express its productive potential at a given specific-site and/or cropping region. The main aim of the current study was to assess both crop productivity and yield components for two distinct genotypes of soybean under the influence of different soil water regimes (120%, 100%, 80%, 60% and 40% ETm) and increasing doses of P_2O_5 (0 Kg ha^{-1}, 240 Kg ha^{-1}, 480 Kg ha^{-1} and 720 Kg ha^{-1}) throughout two crop growing seasons under protected environment conditions at the municipality of Ponta Grossa, Paraná State, Brazil. The statistical design was a randomized block design at a factorial scheme 4 x 2. A suitable soil water supply might trigger the best phosphorus uptake efficiency, since a soil water amount above crop water ideal climatic demand culminates in best agricultural responses at soybean commercial fields. Increasing water amounts are conducive to the highest yields in conjunction with nutritional status more favorable to crop physiology as a function of local atmospheric demand throughout the crop growing season.
Keywords: *Glycine max L*, greenhouse, soil water, soil fertility, yield components, atmospheric demand, evapotranspiration.

INTRODUCTION

Plants absorb water from the soil and release it constantly to the atmosphere in light of the fact that roughly 80% of agricultural productivity variability turns out to be a conspicuous consequence of the impact of both climate and weather conditions on physiological responsiveness of agricultural species grown at a given site and/or particular cropping regions.

Under cropping systems implanted in pots soil physical attributes evidence discrepancies in comparison to soils managed in commercial production fields. Different thresholds are usually expected for field capacity from soil placed in pots, even in the view of an identical material composition. This particular way of conducting field experiments well depict cultivation conventional systems, since soil is considered to be disaggregated, seized and placed in pots afterwards (BORTOLON et al., 2009).

Considering that soil fertility plays a pivotal role in the composition of crop integrated management practices, it is quite important to optimize use of fertilizers as to the amount to be applied and application timing. The productive potentiality of agricultural species is consistently conditioned by soil edaphic conditions; however, actual biological yield of crops is determined by soil edaphic conditions. Thus, scrutinizing the interactions among different regimes of soil water status as a function of atmospheric evaporative demand and dynamics of mineral nutrients in the soil is pivotal to assure agriculture sustainability at a given rural property.

However, biological yield of cultivated agricultural species under the influence of either appropriate or inappropriate soil water supply regimes in conjunction with nutrients availability is meant to be extremely dependent on local climatic conditions (FARIAS et al., 2009).

Throughout growth and development of soybean crop water requirements progressively increase. Thus, occurrence of water deficit episodes during the whole crop growing season will negatively impact biomass production, changing in turn plant hormonal balance between vegetative and reproductive phenological stages (MUNDSTOCK & THOMAS, 2005).

Phosphorus is absorbed by the crop mainly via diffusion, whose process is influenced by a number of factors, such as the overall amount of water present in the soil, distance traveled by the roots in the soil profile, content of phosphorus in the soil, and mean soil temperature at a particular depth. In general, the transport itself of phosphorus in tropical soils takes place at a low rate owing to a high content of colloids of the soil, which turns out to be a great problem related to phosphate fertilization in agriculture (AZEVEDO et al., 2004; PARFITT, 1989; KAMPF & CURY, 2003). It is well known that diffusive flux of phosphorus is governed by soil water status in the face of the highest levels of water supply, which are associated with a better efficiency in terms of nutritional reclamation. Nevertheless, soybean crop responsiveness to such an interaction (water and phosphorus) is not linear and an augment of doses of this particular nutrient promotes an increment in diffusive flux of phosphorus in the soil-plant system (COSTA, 2006).

MATERIAL AND METHODS

The experiment was installed and conducted at a greenhouse belonging to the State University of Ponta Grossa - UEPG. The municipality of Ponta Grossa, Paraná, Brazil, has a climate classified as Cfb according to Köppen and Geiger classification with a mean temperature on the coldest month below 18°C, with mild summers plus a mean temperature on the hottest month below 22°C, and deprived of a defined dry season.

The experiment was carried out in pots amounting to a total of 64 pots of 18 liters capacity, in which two plants were sown and kept for further evaluations.

The soil-type sampled was a Dystroferric red latosol (Oxisol), having been collected from the experimental station belonging to the UEPG, which was dried off in the sun and seized afterwards. The pots possessed a drainage system comprised of a geotextile blanket along with sand and crushed stone. Then, pots were filled up with soil so that soil fertilization could have been done in compliance with technical recommendations. In order to prepare the soil for sowing on the day before sowing all pots were irrigated up to the moment at which gravitational water percolated within the soil profile, indicating that field capacity was reached. Chemical analysis revealed the following results: 0.52 cmolc K dm^{-3}; 2.56 cmolc Ca dm^{-3}; 1.69 cmolc Mg dm^{-3}; 3.11 mg P dm^{-3}; 6.12 mg S dm^{-3}; and CEC (Cation Exchange Capacity) 7.43 cmolc dm^{-3}.

The genotypes of soybean chosen for the current study were NS 5445 IPRO and Brasmax Zeus and sown manually from October to December of 2021.

Irrigation was also performed manually up until all pots had reached field capacity so that water treatments could be adopted for further investigation. To determine reference evapotranspiration (ETo), we made use of the Class A Pan approach in light of water evaporation measurements taken every other day and by multiplying them by a pan coefficient (Kp) corresponding to 0.75 (PEREIRA et al., 2002). Maximum evapotranspiration (ETm) for soybean crop was obtained by multiplying ETo by the following relative water consumption or crop coefficient values: 0.67 from day after sowing (DAS) 1 to 25; 1.59 from DAS 25 to 105; and 0.62 from maturation stage to harvest (MILA et al., 2016).

Water treatments imposed herein led to differences in terms of biological responses with regards to agricultural harvest in study. For the first agricultural harvest the soil water levels were 100%, 80%, 60% and 40% ETm. Since under the influence of 40% ETm treatment plants of soybean did not survive, treatment 40% ETm was replaced with 120% ETm. This particular water treatment might demonstrate that an amount of water above the ideal recommended for the crop could possibly be more beneficial to maximize soybean yields.

Soil fertilization treatments considered only and solely throughout the first agricultural harvest were as follows: 0, 240, 480, and 720 kg ha^{-1}.

The following response-variables were scrutinized in the current study: plant height, first pod insertion height, number of pods per plant, number of grains per pod, thousand kernel weight, and final yield.

The statistical design taken into consideration was a randomized block design at a factorial scheme 4 x 2. Experimental data were subjected to Shapiro Wilk test to assess verisimilitude of residues. Analysis of variance along with the F test was performed, as well as regression studies between imposed conditions in our experiment and crop response-variables under scrutiny by means of the R Software statistical package were borne in mind to firm up the outcomes reported.

RESULTS AND DISCUSSION

PLANT HEIGHT

The variation of plant height observed under the influence of treatments conducive to water deficit throughout the first crop growing season (Figure 1) is illustrated by a linear regression equation and, thus, demonstrates that inadequate soil water supply compromises crop growth and development in a such a manner as to significantly plummet plant height and, therefore, bring about negative impacts on the expression of crop productive potential at a given specific-site and/or cropping region.

For the second soybean agricultural harvest a significant interaction between water and phosphorus concerning the yield component plant height was detected. Water potentialized the effect of phosphate fertilizer applications at the doses of 240 kg ha^{-1}, 480 kg ha^{-1} and 720 kg ha^{-1} P_2O_5 in the face of the fact that the 240 kg ha^{-1} dose turned out to be the treatment that promoted the highest plant height (Figure 2). Treatments that did not receive any dose of P_2O_5 conditioned plant heights lower than those plants treated with phosphate fertilizer. As to water irrigation treatments, only the treatment corresponding to 120% ETm significantly impinged upon soybean plant height.

FIRST POD INSERTION HEIGHT

It was noticed for the first crop growing season that soil water amount applied and also phosphorus doses did not significantly impact first pod insertion height. Conversely, the second crop growing season presented distinct biological responses in a linear fashion under the influence of water treatment, since the highest levels of soil water status substantially reduced first pod insertion height (Figure 3).

With regards to interaction between phosphorus doses and water amounts applied to the soil no significant effect was detected for both crop growing seasons on first pod insertion height variable.

NUMBER OF PODS PER PLANT

Biological responsiveness of both soybean genotypes in study in the face of imposition of soil water treatments in conjunction with phosphorus doses applied in the soil was quite increasing and substantial. Figures 4 and 5 illustrate a significant rise in number of pods whenever water and phosphorus were found to be at more suitable levels for the soybean plants to show the best agricultural performance.

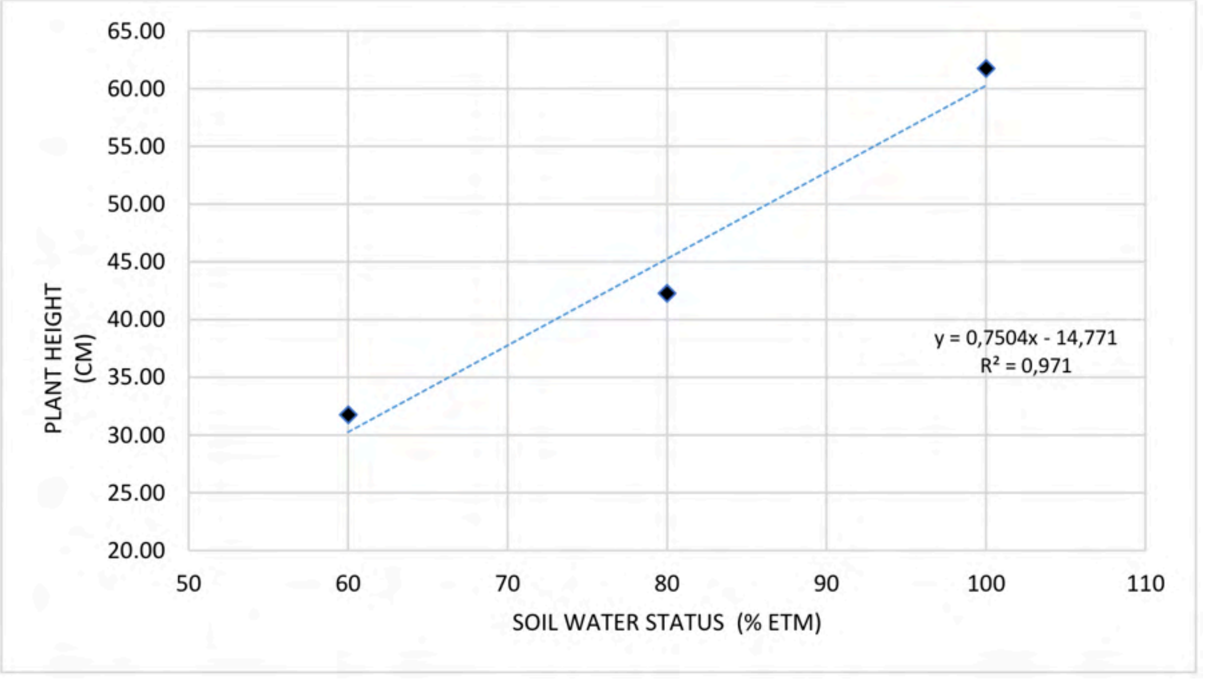

Figure 1 – Relationship between water irrigation amount applied and plant height throughout the first soybean agricultural harvest grown in Ponta Grossa, Paraná, Brazil.

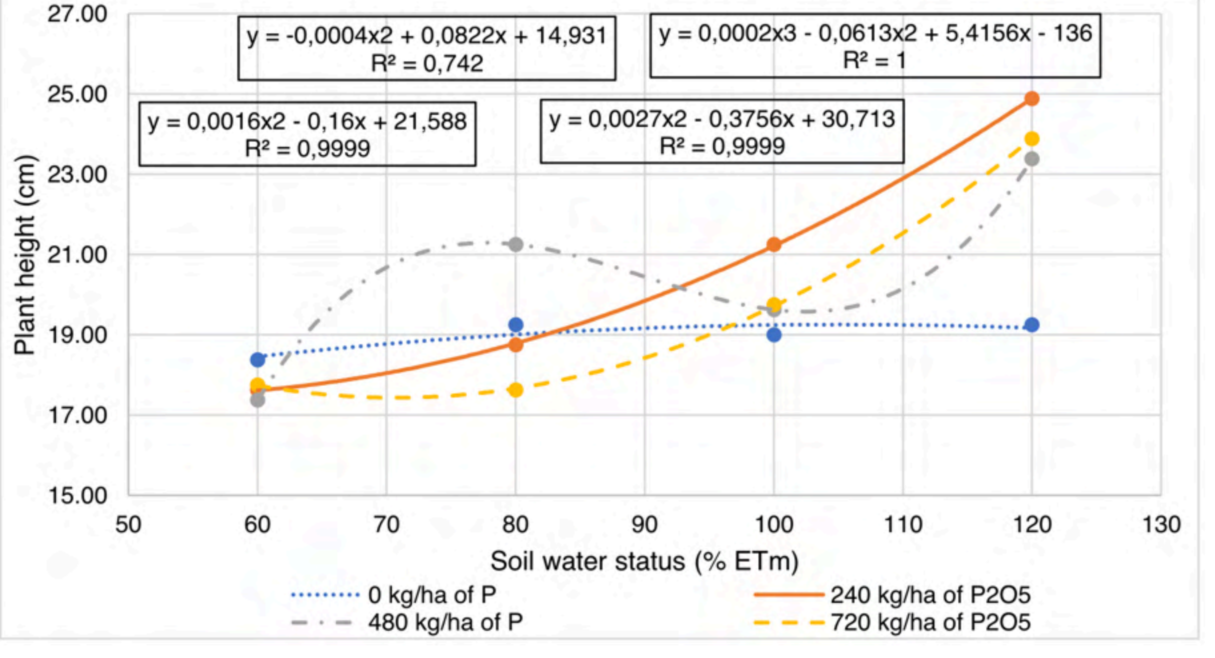

Figure 2 – Interaction of irrigation water levels (ETm) and phosphorus dose (P_2O_5) on plant height with regards to the second soybean agricultural harvest in Ponta Grossa, Paraná, Brazil.

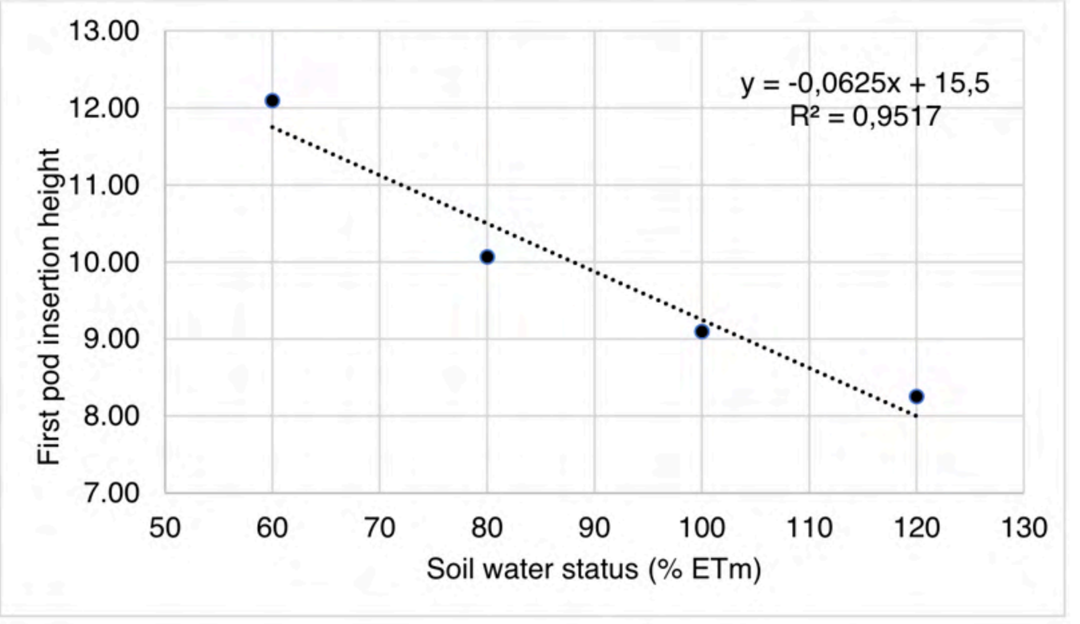

Figure 3 – First pod insertion height for the Brasmax Zeus IPRO genotype grown throughout the second soybean crop growing season as a function of water amount applied in Ponta Grossa, Paraná, Brazil.

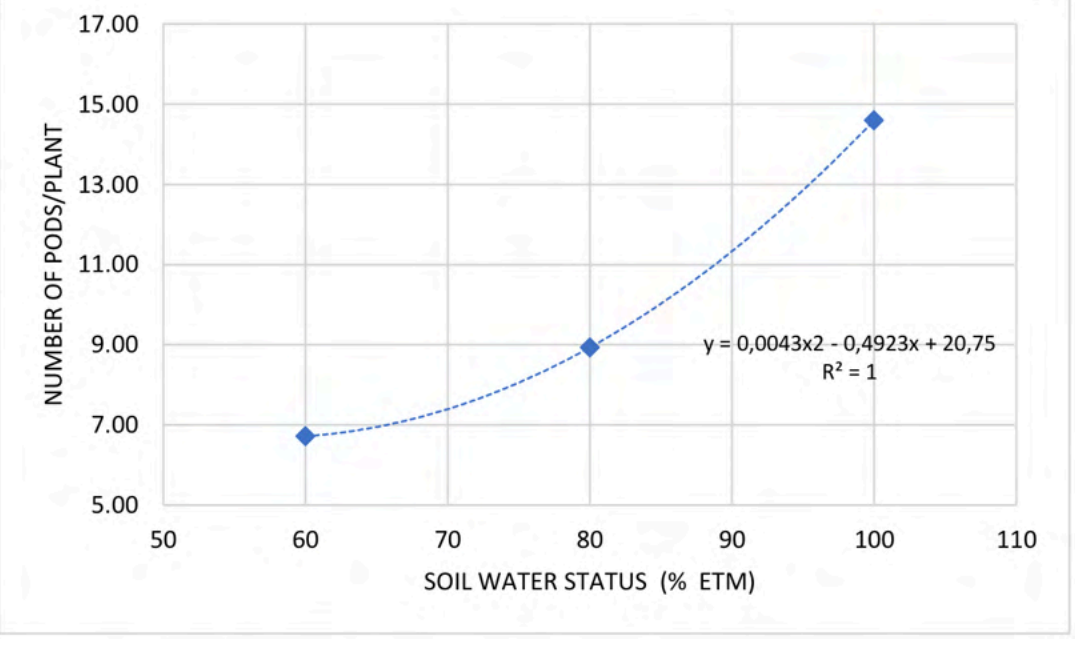

Figure 4 – Relationship between soil water amount applied to the soil (% of ETm) and number of pods for the NS 5258 RR genotype grown throughout the first soybean crop growing season in Ponta Grossa, Paraná, Brazil.

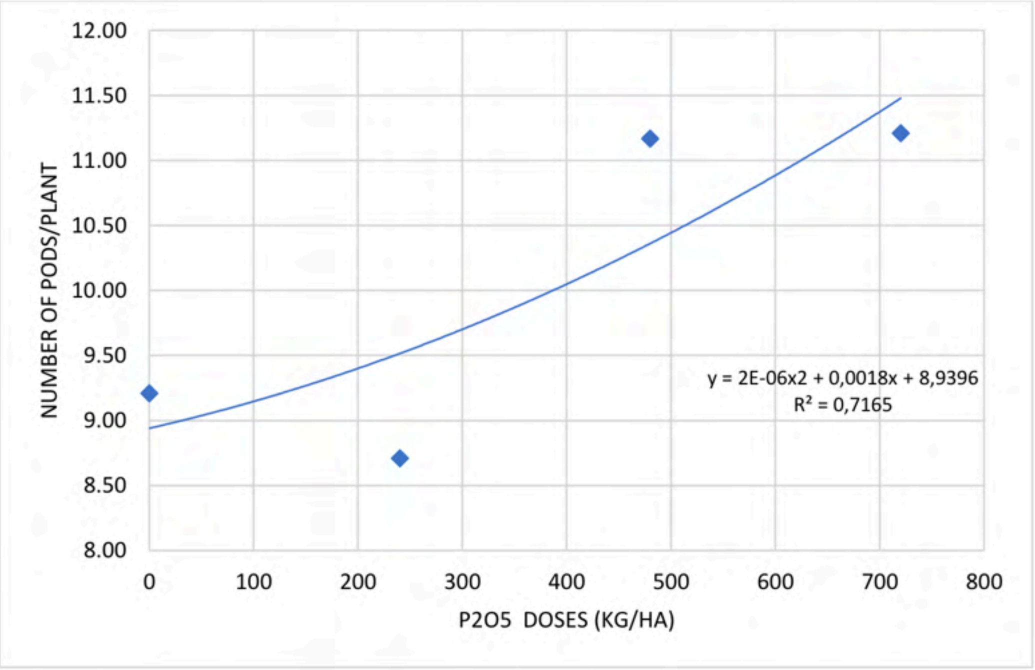

Figure 5 – Relationship between phosphorus doses (P_2O_5) and number of pods for the NS 5258 RR genotype grown throughout the first soybean crop growing season in Ponta Grossa, Paraná, Brazil.

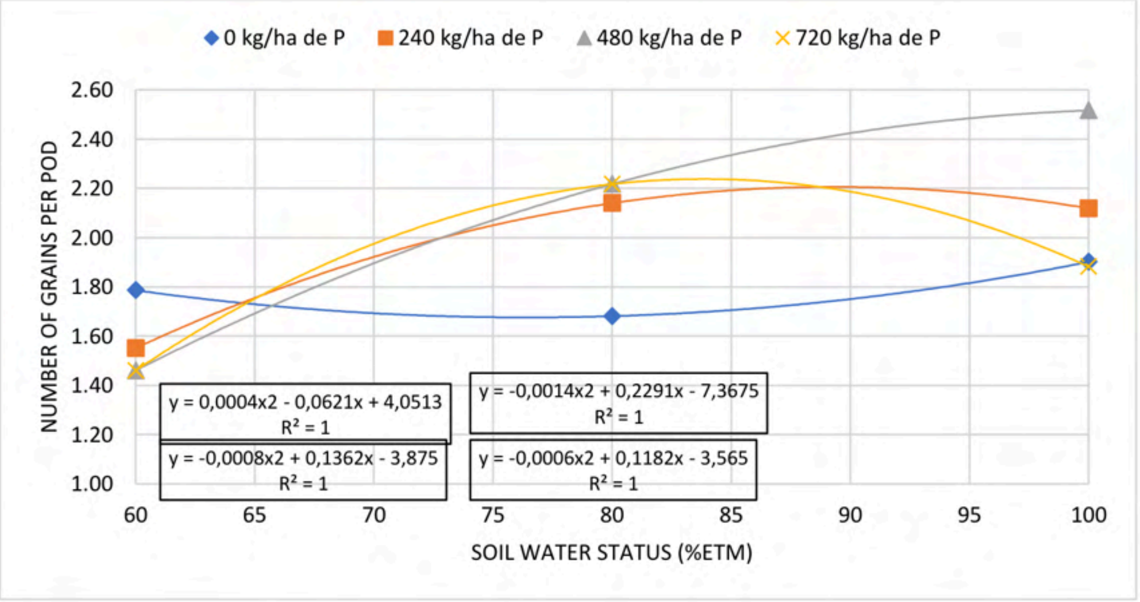

Figure 6 – Interaction between phosphorus doses (P_2O_5) and soil water status (% of ETm) on the number of grains per pod for the NS 5258 RR genotype grown throughout the first soybean crop growing season in Ponta Grossa, Paraná, Brazil.

NUMBER OF GRAINS PER POD

Number of grains per pod demonstrated interaction between phosphorus (P_2O_5) doses and soil water status (% of ETm) throughout the first soybean crop growing season. However, differently from observation for the number of pods per plant, at which the highest phosphorus dose (720 kg ha^{-1} of P_2O_5) culminated in best agricultural responses, it is pertinent to highlight that for such a yield component the P_2O_5 dose equivalent to 480 kg ha^{-1} along with favorable soil water supply conditions (100% ETm) referred to treatments promoting the best crop physiological response, resulting in an average of 2.52 grains per pod (Figure 6). Conversely, such a yield component did not suffer any influence of phosphorus doses and soil water status factors.

THOUSAND KERNEL WEIGHT

A significant effect of irrigation water applied to the soil on thousand kernel weight has been detected by means of a regression approach either for the first or second soybean crop growing season. With regards to phosphorus, only throughout the second growing season an impact of phosphate fertilizer doses on a response-variable in study was verified as illustrated by the graphs shown in Figures 7 and 8.

Figure 7 illustrates the interaction between soil water status and thousand kernel weight (TKW) and highlights the negative impact of water deficit on soybean yield. Thus, water amounts leading to a soil water status below 100% ETm were conducive to a performance below that expected for the 100% ETm treatment, under which TKW was of 155 g. Water deficit treatments limited potential productivity and, in particular, the 40% ETm treatment did not allow the plants to complete the crop cycle, causing them to die 50 days after emergency. The same linear behavior was observed for TKW concerning the second agricultural harvest (Figure 8) in light of the fact that the 120% ETm treatment was the one responsible for the highest TKW (169 g) among all the four water treatments under scrutiny.

FINAL YIELD

Among all water and phosphorus treatments adopted throughout the first crop growing season, we observed that soybean plants did not survive facing 40% ETm treatment.

For the first crop growing season there was no conspicuous interaction between soil water status and phosphorus doses applied to the soil on biological responsiveness of soybean; however, it is possible to notice that different amounts of water applied directly impinged upon soybean final productivity.

Throughout the second crop growing season the records show that interaction between increasing doses of phosphorus and amounts of irrigation water applied to the soil had a significant effect on rises in soybean final productivity under protected environment at the site in study (Table 1).

Figure 9 reveals that whenever phosphorus is not applied to the soil growing amounts of soil water contribute to significant increments in final crop yield, and when a dose of 240 kg P_2O_5 ha^{-1} is applied yield increases linearly insofar as soil water content escalates. In the view of application of 480 kg P_2O_5 ha^{-1} to the soil crop yield increases whenever soil water status remains within the range of 60% and 80% ETm. Moreover, actual yield stabilizes between 80 and 100% ETM and considerably rises whenever water requirements excel crop maximum evapotranspiration under the influence of such a phosphate fertilizer level. By applying 720 kg P_2O_5 ha^{-1} to the soil a substantial increment in yield is obtained

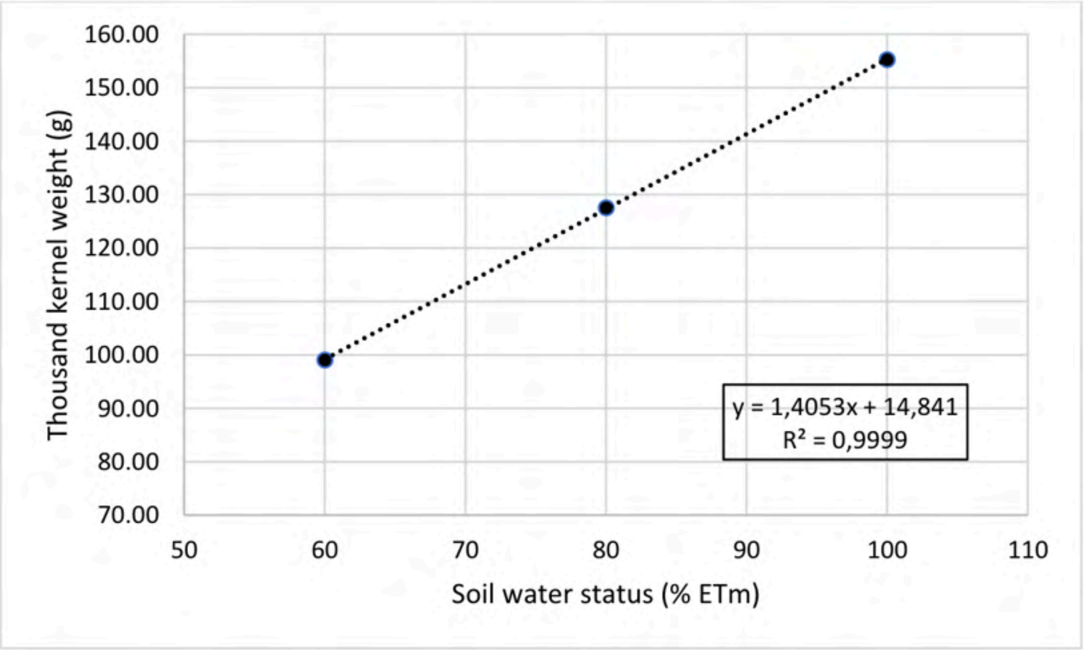

Figure 7 – Influence of soil water status (% of ETm) on thousand kernel weight for the NS 5258 RR genotype grown throughout the first soybean crop growing season in Ponta Grossa, Paraná, Brazil.

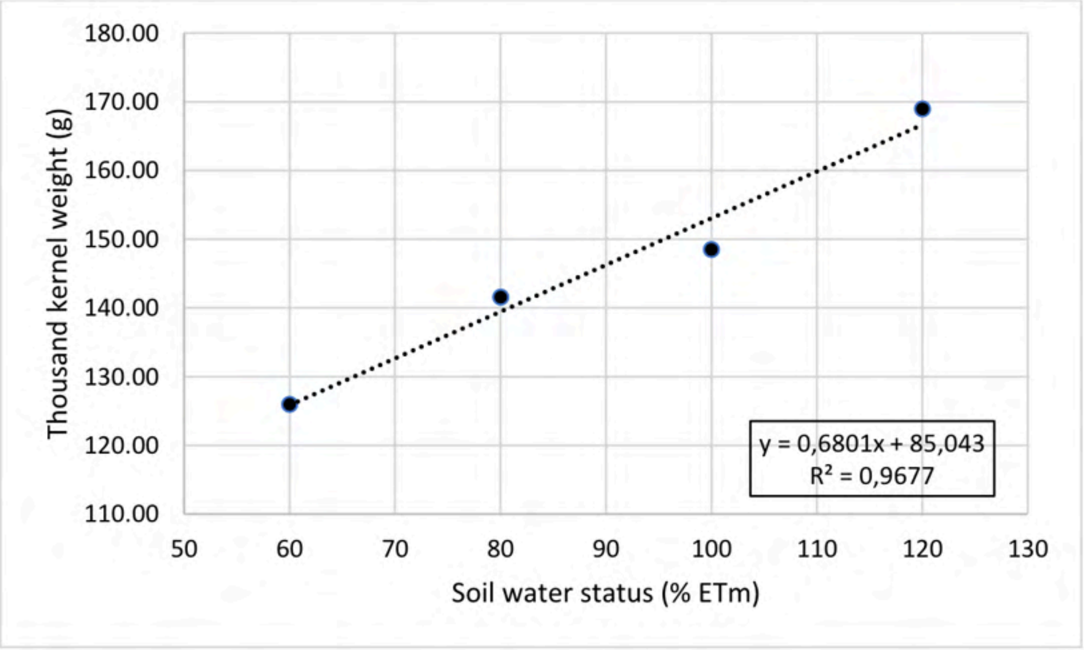

Figure 8 – Influence of soil water status (% of ETm) on thousand kernel weight for the Brasmax Zeus IPRO genotype grown throughout the second soybean crop growing season in Ponta Grossa, Paraná, Brazil.

Dose of P (kg ha-1) / % ETm	0	240	480	720
60	236.8 ± 5,88	416.4 ± 4.88	420.7 ± 6,16	440.9 ± 8.02
80	489.7 ± 4,78	738.6 ± 3,86	769.1 ± 5,88	503.4 ± 5.83
100	542.7 ± 4,56	1015.3 ± 8,36	821.0 ± 5,19	1039.6 ± 7.53
120	764.1 ± 5,83	1423.6 ± 6,98	1511.9 ± 5,01	1491.7 ± 7.41

Table 1 – Averages of soybean actual yield, in kg ha^{-1}, obtained from the second agricultural harvest of 2020 as a function of soil water status and application of phosphorus in the soil at the municipality of Ponta Grossa, Paraná, Brazil.

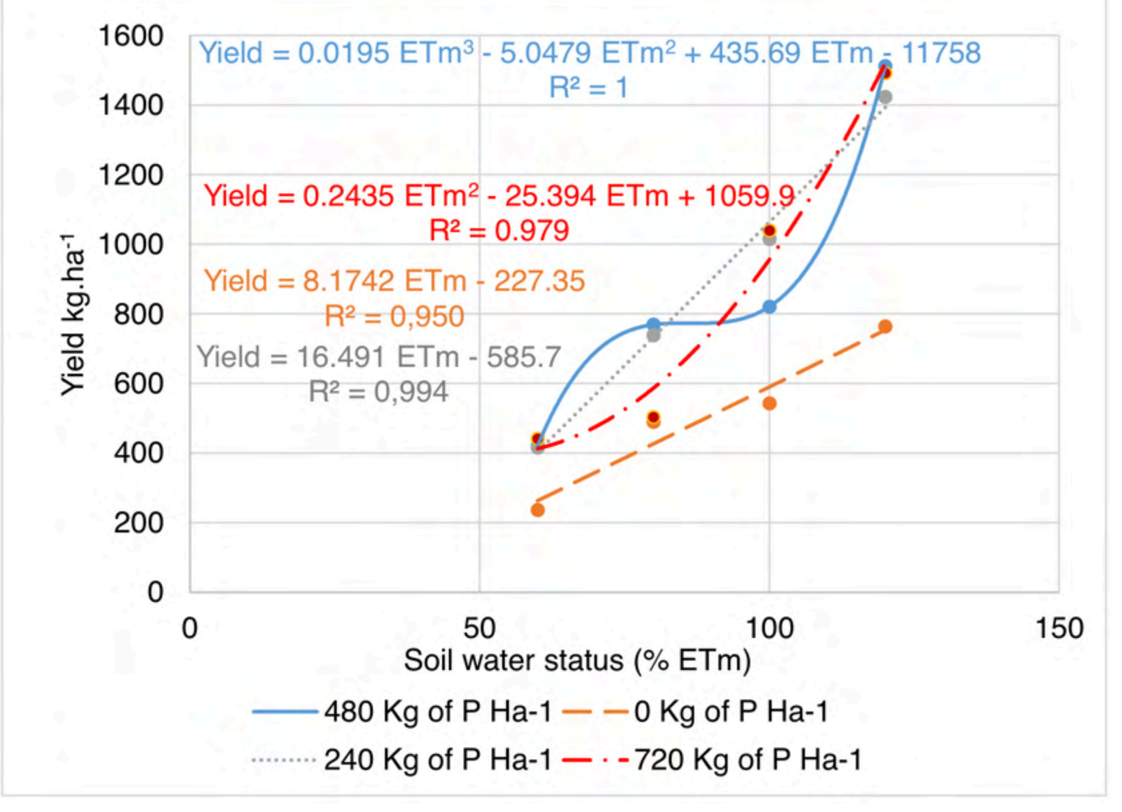

Figure 9 – Data of soybean actual yield, in kg ha^{-1}, as a function of soil water status (fractions of ETm) within the factor phosphorus doses applied in the soil at Ponta Grossa, Paraná, Brazil.

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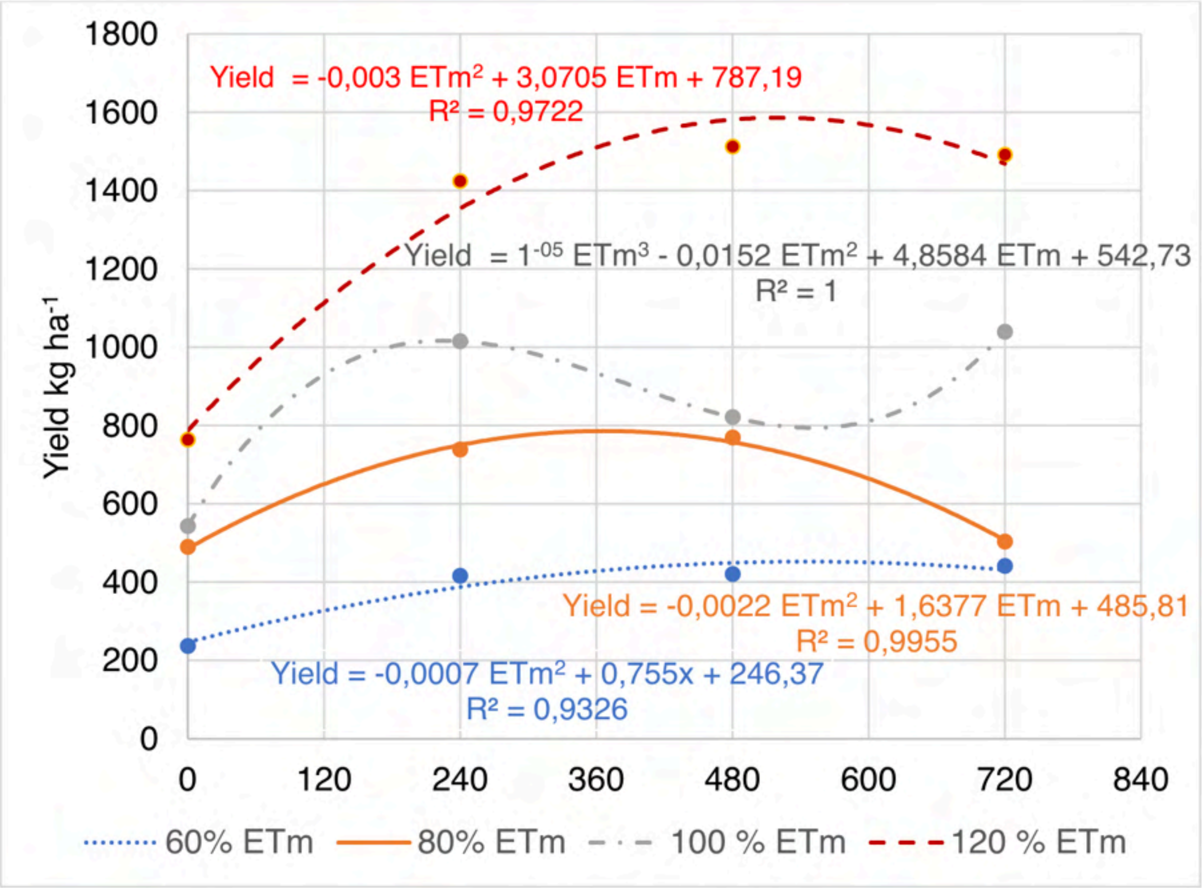

Figure 10 – Data of soybean actual yield, in kg ha^{-1}, as a function of interaction between phosphorus doses and soil water status (fractions of ETm) at Ponta Grossa, Paraná, Brazil.

insofar as available water to soybean plants prevails.

The maximum yield was reached whenever soybean crop was subjected to the soil water amount corresponding to the 120% ETm treatment. This was achieved by means of an application of 511.75 kg P_2O_5 ha^{-1} to the soil, which culminated in a final actual yield of 1572 kg ha^{-1}.

Soybean actual yields in light of the influence of different doses of phosphorus and when subjected to soil water status corresponding to 60% ETm did not bring about significant discrepancies among treatments as to crop yield. In contrast, insofar as soil water supply rises up to 80% ETm an increase in yield is noticed with a yield maximum inflection point reached at a dose of 372.2 kg P_2O_5 ha^{-1}, whereas phosphorus doses higher than such a threshold resulted in substantial yield gaps.

In light of the effect of phosphorus doses on soybean yield components under the 100% ETm treatment a cubic regression equation was obtained to describe the relationship between such response-variables and predicted factors in study (Figure 10). Although there is no agronomic meaning for a third-degree regression equation to explain crop biological responsiveness, we came up with the conclusion that final actual yield has been considerably conditioned by increments in phosphorus doses in conjunction with soil water amounts applied. The higher soil water status the most efficient the uptake of phosphorus by the plants will be in such a way as to increase soybean crop actual yield.

CONCLUSIONS

High plant heights were ascribed to the highest phosphorus doses along with adequate soil water conditions.

First pod insertion height decreased linearly insofar as the highest soil water amounts were applied to the soil throughout the first crop growing season. However, no significant biological responses were detected during the second growing season under the influence of phosphate fertilizer application.

The number of pods per plant linearly increased as a function of phosphorus doses and soil water status, reaching the highest mean number of pods at a dose of 720 kg P_2O_5 ha^{-1}.

The number of grains per pod throughout the first crop growing season was the highest under adequate soil water conditions.

All yield components were remarkably affected by soil water status and crop yield significantly increased in light of water amounts above 20% soybean maximum evapotranspiration.

Addition of P_2O_5 to the soil substantially contributes to increments in soybean as long as water supply is adequate to the uptake of phosphorus by the plants.

Suitable water supply improves phosphorus use efficiency and, therefore, maximizes actual yield at soybean production fields.

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