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Biometric Responses of Soybean to Different Potassium Fertilization Management Practices in Years with High and Low Precipitation

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ABSTRACT: Brazilian soybean producers commonly apply maintenance potassium (K) fertilization during cultivation to restore the K taken up by plants; however, this measure can modify the morphophysiological plant characteristics, since the functions of K are closely related with plant growth and development. This study assessed the morphological changes in soybean plants in response to K rates, sowing fertilization, and the application periods of K fertilization in a *Latossolo Vermelho eutroférrico* (Oxisol) under a no-tillage system, located in the municipality of Floresta, Paraná. A randomized block design was used in the experiment with four replications in a fully crossed factorial design (5 × 2 × 2). The experiment was carried out in two growing seasons (2015/2016 and 2016/2017), with a total of 80 experimental units. The rates corresponded to the first factor (0, 40, 80, 120, and 160 kg ha^{-1} of K). The application periods (pre-sowing and post-sowing) were the second factor, and sowing fertilization (0 and 30 kg ha^{-1} of K) the third. The following variables were measured: shoot dry weight, leaf dry weight, stem dry weight, leaf area, specific leaf area, leaf area ratio, and leaf area index, and these biometric parameters were correlated with soybean yield. The results showed that plants well-supplied with K exploited the environment better and this may be reversed for higher yields since there were correlations between grain yield and the biometric parameters. At lower water availability, the biometric changes were more evident.

Keywords: leaf area index, correlation, yield, drought.

INTRODUCTION

Soybean is one of the most important crops in several regions of the world, for being a substantial source of protein, vitamin, and oleaginous properties that meet human and animal food demands (Ávila et al., 2007). In Brazil, soybean fields represent almost half of the entire area used for grain production; therefore, soybean is the most important national crop. In 2016/2017, the Brazilian soybean production was estimated at 107 million tons; this ranks Brazil as the world's second largest soybean producer, with a similar output to that of the USA, the global leader in soybean production.

The increase in Brazilian soybean production capacity over the last several years occurred alongside with both scientific advances and the availability of new technologies in the agricultural production sector (Hirakuri and Lazzarotto, 2011). The current challenge for soybean production is to increase yield; scheduled and well-managed fertilization is essential to achieve this goal and can additionally help avoid unnecessary financial expenses. Of the nutrients involved in fertilization, K should be highlighted, since soybean has a K requirement of 20 g kg^{-1} grains produced (Wendling et al., 2008).

In the soil, K is found in the form of K^+; in this ionic phase, the element is mobile in the soil. Therefore, leaching can occur, mainly in sandy soils with a low cation exchange capacity (CEC) and low pH. It is in this ionic form that plants uptake the element. As the plants consume K^+ from the soil solution, the nutrient is replaced by exchangeable K that was adsorbed by the soil exchange complex. When exchangeable K contents become very low, the dissolution of the primary K minerals may occur (Mielniczuk, 2005). In this regard, the timing and forms of K applications can determine the adequate availability of the element for soybean.

The pre-application of K fertilizers accelerates the process of seeding, since a smaller number of stops of the sowing-fertilization equipment is needed to re-fill the recipients (Bernardi et al., 2009). In addition, performing fertilization prior to sowing improves the uniformity of the fertilizer distribution, whereas the tractor entrance to fertilize does not necessarily follow the sprayer track. In soil with a clay content of more than 200 g kg^{-1}, K can be applied to soybean from pre-sowing to stage V4 (four-node plants or three open trifoliates) (Pauletti and Motta, 2017).

Although K is found at rather low levels in most Brazilian tropical soils, the element is essential for soybean production, due to the large number of functions it has in the vegetable (Gierth and Mäser, 2007). Among these, the regulation of the cellular osmotic potential, synthesis of sugars and proteins, and the activation of membrane proton ATPases are particularly important; these functions are closely connected to all processes of plant growth and development. However, unlike nutrients such as nitrogen (N), calcium (Ca), phosphorus (P), and sulfur (S), K has no structural function in plant tissues, acting indirectly in the formation of the membrane walls and cells (Pettigrew, 2008).

During crop development, periods with low rainfall are frequent. In these periods, plants adjust osmotically, concentrating solutes, primarily K, in the tissues to retain water under conditions with low soil potential water (Vilela and Bull, 1999). Therefore, under drought, it is expected that plants benefit from a greater K availability in the soil to mitigate the effects of low water availability.

For soybean, interveinal chlorosis and necrosis of the edges and apexes of older leaves are symptoms of K deficiency (Sfredo and Borkert, 2004; Domingos et al., 2015). These symptoms reduce the photosynthetically active leaf area. Consequently, the growth of K-deficient plants is stunted, stems are weaker, the susceptibility to pests and diseases greater, and the ability to compete with weeds and yields is reduced (Yelverton and Coble, 1991; Fernández et al., 2008; Xu et al., 2011; Xiang et al., 2012).

In the literature, several studies established recommendations for K fertilization of soybean in terms of fertilization rates, periods, and application forms, to determine how to maximize positive plant responses with these parameters. However, the results of these studies differ, do not always lead to higher final crop yields, depend strongly on environmental conditions, and are primarily focused on investigating soil chemical properties (Lana et al., 2002, 2003; Guareschi et al., 2008; Bernardi et al., 2009; Gonçalves Júnior et al., 2010; Martins et al., 2013).

In earlier research, soil chemical properties were typically assessed before and after the nutrient supply, aside from the assessment of the yield components and yield. The evaluation of associated biometric parameters, such as the leaf area index (LAI), leaf area ratio (LAR), leaf area (LA), specific leaf area (SLA), shoot dry weight (SDW), leaf dry weight (LDW), and stem dry weight (StDW) is less common. Correlating these variables with grain yield is not common either. Parameters such as LA are important indicators of ecological adaptation, competition with other species, and of management effects (Monteiro et al., 2005).

Understanding the biometric parameters of plants enables the identification of morphophysiological characteristics of adaptation and their production potential in specific environmental situations; in addition, biometric parameters indicate the plant phenotypic plasticity, which directly influences crop production. Thus, research addressing measurements of plant biometric indicators under different management systems is fundamental to understand the plant-environment relationship (Moraes et al., 2013).

The hypothesis of this study is based on the principle that plants with good soil K^+ availability can better exploit the environment, and changes in K^+ availability can underlie predictions of plant yield. In this context, the specific purpose of this study was to evaluate the changes in the morphological parameters of soybean after the application of increasing K rates before and after sowing; in addition, this study investigated the effects of applying K fertilization or not during soybean sowing in a no-tillage area.

MATERIALS AND METHODS

This study was carried out in the Technology Diffusion Unit (TDU) of a co-operative society called *Cooperativa Agroindustrial de Maringá* (Cocamar) in the municipality of Floresta, in the north central region of the state of Paraná (latitude 23° 35′ 42″ S, longitude 52° 04′ 02″ W). The soil of the experimental area was classified as *Latossolo Vermelho eutroférrico* (Oxisol), under no-tillage cultivation for more than 20 years. The climate was classified as Cfa (Alvares et al., 2013). The chemical and physical soil properties were: total organic C 23.2 g dm^{-3} (Walkley-Black); pH(H_2O) (soil:water ratio of 1:2.5) 5.55; 15.3 mg dm^{-3} P and 0.21 $cmol_c$ dm^{-3} K^+ (both extracted by Mehlich-1); 0.0 $cmol_c$ dm^{-3} Al^{3+}, 6.4 $cmol_c$ dm^{-3} Ca^{2+}, and 1.4 $cmol_c$ dm^{-3} Mg^{2+} (both extracted by KCl 1 mol L^{-1}); CEC_{pH7} 13.6 $cmol_c$ dm^{-3}; base saturation (V%) 58 %; sand 175 g kg^{-1}, silt 65 g kg^{-1}, and clay 760 g kg^{-1}.

The experiment was carried out for two consecutive years with soybean in the 2015/2016 and 2016/2017 growing seasons; before both soybean crops, straw from second season corn was left scattered across the area. The studied treatments tested combinations of the following factors: K rates (0, 40, 80, 120, and 160 kg ha^{-1} K), application periods (soybean pre-sowing and post-sowing), and sowing fertilization (0 and 30 kg ha^{-1} K), composing a fully crossed factorial design (5 × 2 × 2), outlined in randomized blocks with four replications, with a total of 80 experimental units. Potassium chloride (KCl) with exactly 58 % K_2O (Alcarde et al., 1998) was used as fertilizer. Soybean cultivar NA5909 was sown at a density of 31 seeds m^{-2}. The plots consisted of 10 rows, 8 m long, spaced 0.45 m apart. All cultural treatments from soybean planting to harvest were carried out according to the guidelines for technologies, products and services (TPS) of Embrapa (2011), and according to the region and the soil chemical and physical analyses, except for the K fertilization management. Seeds were inoculated with *Bradyrhizobium japonicum* at a concentration of 5.0×10^9 viable cells per mL g^{-1} and a seed rate of 2 mL kg^{-1}. Cobalt and molybdenum were added at levels of 2 and 12 g ha^{-1}, respectively. A total of 70 kg ha^{-1} P_2O_5 was applied in the form of monoammonium phosphate.

In the 2015/2016 and 2016/2017 growing seasons, respectively, the seedlings emerged on October 15th and October 4th and were harvested on February 4th and January 29th. The pre-sowing applications of K rates were carried out 15 days prior to the test implementation, on the same day as weed desiccation, and the post-sowing K rates were applied at the phenological stage V3. In both periods, the applications were manually performed on the soil surface.

Mechanical sowing and fertilization were carried out simultaneously along the sowing lines with a seeding machine coupled to a tractor. The fertilizer (KCl) was placed at a distance of 0.05 m beside and 0.05 m below the seeds to avoid undesired saline effects during seed germination (Moterle et al., 2009).

The biometric responses were evaluated to assess soybean performance. Shoot dry matter (SDW) was determined in growth stage R2 (full flowering); for this purpose, 10 plants per experimental unit were randomly collected. The samples were identified in the field and taken to the laboratory, where they were packed in kraft paper bags and dried to constant weight in an oven with forced air circulation at 65 °C. Subsequently, the samples were weighed on a precision scale to two decimal places, to determine the dry weight per plant. Leaf dry matter (LDW) and StDW were obtained by determining the weight of plant leaves and stems separately. To measure LA, 10 plants per experimental unit were randomly collected in growth stage R2. These plants were identified and taken to the laboratory and the leaves detached for analysis with an LI 3100 LiCor® leaf area meter. The leaves were then dried and weighed, allowing the quantification of the specific leaf area (SLA), which is the LA/LDW ratio, and the leaf area ratio (LAR), which is the relation between the active photosynthetic area and shoot dry weight (LA/SDW). Since LAI is a variable that considers LA in relation to the soil area (SA) exploited by the plants, we have LAI = LA/SA. Therefore, to determine LAI, the plants of each experimental area were counted; from these values and the previously established LA for the 10 plants the LAI was computed for each unit.

The yield per 9 m^2 area was determined; the three external rows and 1.5 m at either end of the central rows were disregarded; only the four central rows of the experimental units were harvested.

All data of the variables were subjected to an analysis of basic statistic assumptions using the Shapiro-Wilk (error normality) and Bartlett (homogeneity of variances) tests ($p>0.01$). The two growing seasons and effects of the different K rates, application periods, and sowing fertilization, as well as the possible interactions among the factors were evaluated together by the F test in the analysis of variance. The quantitative data referred to as ‘rates’ were analyzed by means of regression, and beta coefficients subjected to the t-test, both in relation to the isolated factors and the possible rate interactions. All biometric variables were subjected to Pearson’s linear correlation analysis with soybean yield. For all statistical interpretations, a 5 % probability ($p<0.05$) was used (Zimmermann, 2014).

RESULTS AND DISCUSSION

SDW, LDW, and StDW

For all analyzed biometric variables, there were differences between the two seasons. In this regard, the rainfall was observed to affect the dependent variables. The rainfall data recorded during the two years of cultivation is shown in figure 1. In the first growing season, the rainfall was well distributed throughout the soybean development cycle. According to Catuchi et al. (2012), who investigated K^+ contents and soil water in environments without

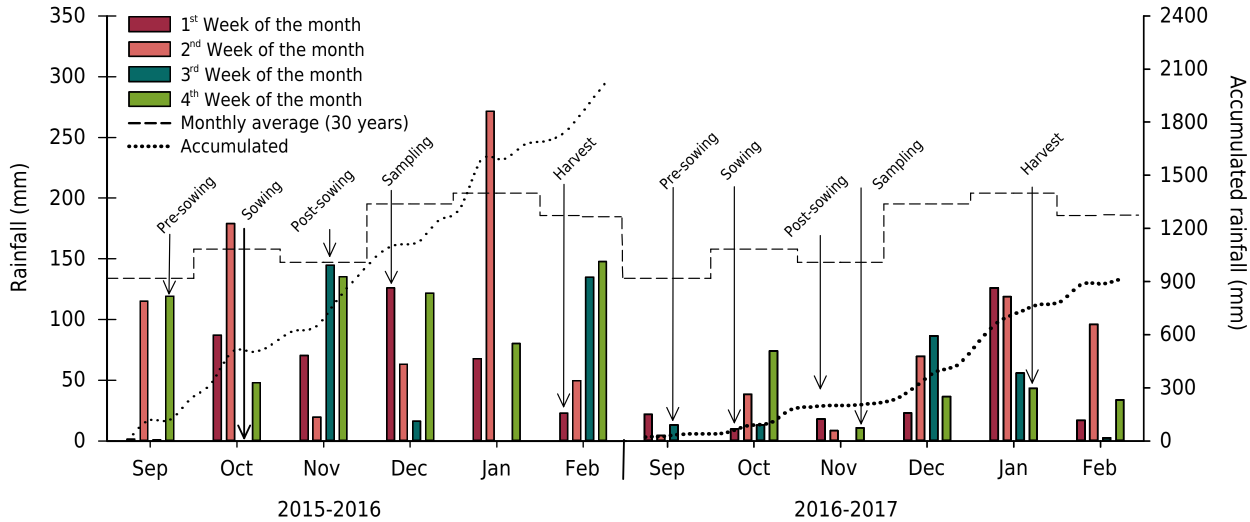

Figure 1. Weekly and accumulated rainfall during the experimental period for the crops in 2015/2016 and 2016/2017. Monthly average rainfall was considered the period between 1986 to 2016.

water restriction, soybean accumulated more biomass, which corroborates the data obtained in this study. In the case of water availability, reasonable increases in the available water cause a prolongation of the plant stomatal conductance, causing an increased input of CO_2 to the plant (Flexas et al., 2009) and, consequently, a higher carbon assimilation rate, resulting in a greater biomass accumulation (Zörb et al., 2014).

In the second year, one week after sowing, a period without rainfall of approximately 25 days occurred (Figure 1), affecting the plant development due to lower amounts of SDW accumulation (Figure 2).

In the first growing season, there were no statistically significant differences in the variables SDW, LDW, and StDW for the isolated factors and interactions between the factors, with means of 46.6, 25.7, and 20.9 g, respectively (Figures 2a, 2b, and 2c). Since the initial soil K^+ content was intermediate (0.21 $cmol_c$ dm^{-3}), the K^+ availability in the control treatment was adequate and contributed to a lack of response in the first growing season; however, after the corn - soybean crop sequence, this availability may have decreased due to K^+ extraction at harvest. In the second soybean crop, there was no interaction among the factors; on the other hand, when the factors were analyzed separately, quadratic regression models were adjusted, with maximum values of 31.8 g for SDW, 17.7 g for LDW, and 14. 5 g for StDW, at rates of 94.5, 98.6, and 91.9 kg ha^{-1} K, respectively (Figures 2a, 2b, and 2c).

According to Mak et al. (2014), this occurred because the absorbed K accumulated in the leaf mesophyll and decreased the water potential, which caused a greater tolerance in the cultivated soybean plants. These authors also showed a positive correlation between the K flow and leaf water content, stomatal opening and SDW, which indicates that K fertilization may attenuate the effects of water deficit, in agreement with the data of this study.

In addition to the described K effects, appropriate levels of this nutrient in the plant tissues because of adequate K fertilization enable better plant development and growth (Guareschi, 2011; Catuchi et al., 2012). When the soil availability of K^+ is increased, plants can exploit a larger soil volume due to the better development of their root system, improving the support of plants during drought (Sangakkara et al., 2001; Wang et al., 2013; Zörb et al., 2014).

Despite these beneficial effects, a decrease in plant growth was observed after a determined amount of K was applied to the soil (Figures 2a, 2b, and 2c). This may occur because K^+ has a higher affinity for membrane carriers than other cations. Thus, with the increase in K^+ in the soil, competition increased at the binding sites of membrane

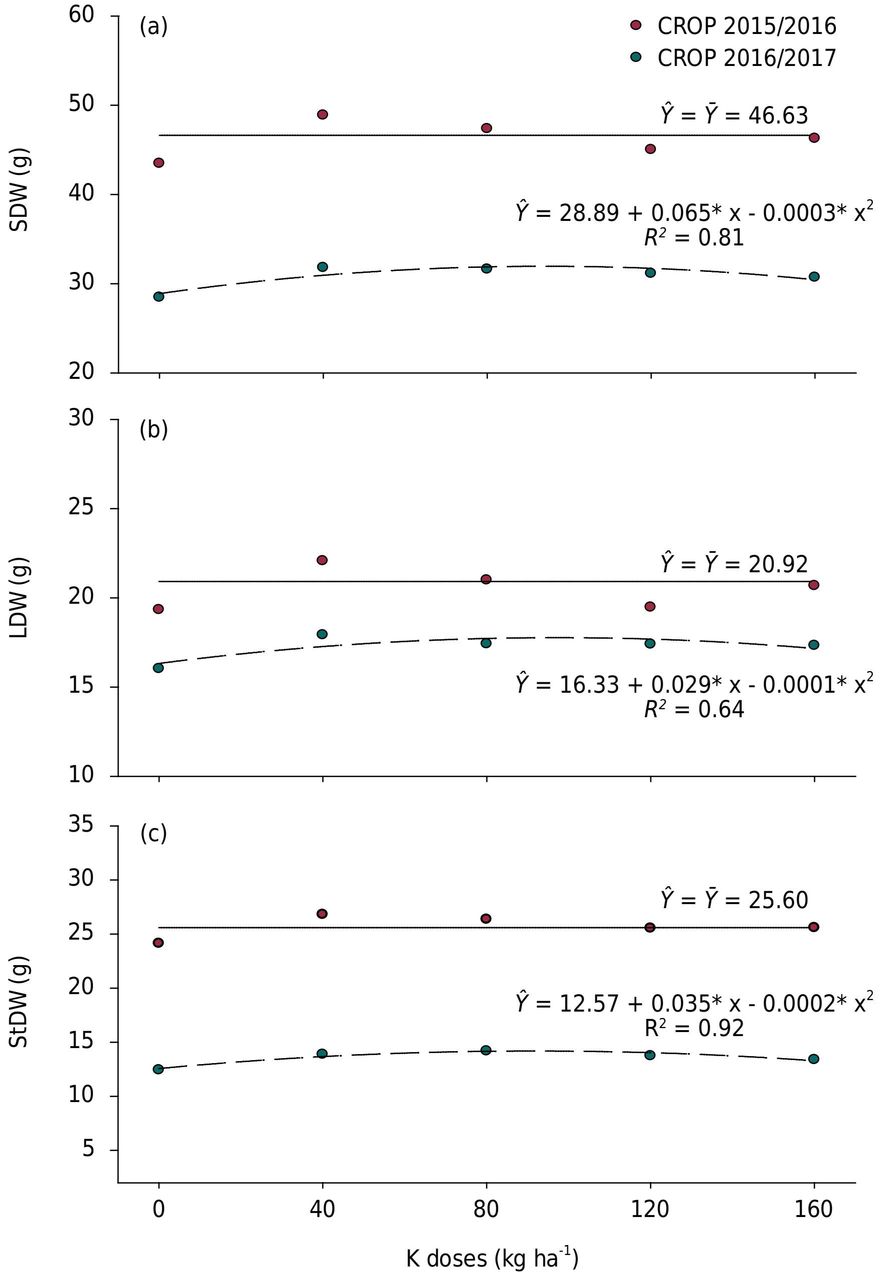

Figure 2. Shoot dry weight (SDW) (a), leaf dry weight (LDW) (b), and stem dry weight (StDW) (c) of soybean for the crops in 2015/2016 and 2016/2017 after the application of different K rates. * = significant at 5 %.

carriers, which may have decreased the uptake of Ca^{2+}, an element that is related to cell wall formation and membrane stability (Marschner, 2011). Some authors also report that chlorine toxicity may occur when high rates of KCl fertilizer are used (Mascarenhas, 1982; Parker, 1983); however, it is unlikely that this effect occurred during this study because there were no symptoms of chlorine toxicity in the plants, and this problem is more common in poorly drained soils.

LAR, LA, SLA, and LAI

In the first soybean crop, the interactions among the factors were not assessed. When analyzed separately, LAR, LA, and LAI had means of 122.1 $cm^2\ g^{-1}$, 5,623 cm^2, and 1.41 $m^2\ m^{-2}$, respectively (Figures 3a, 3b, and 3d). However, significant differences were found during the sowing - fertilization experiment; the application of 30 kg ha^{-1} K in the furrow promoted the highest mean SLA values.

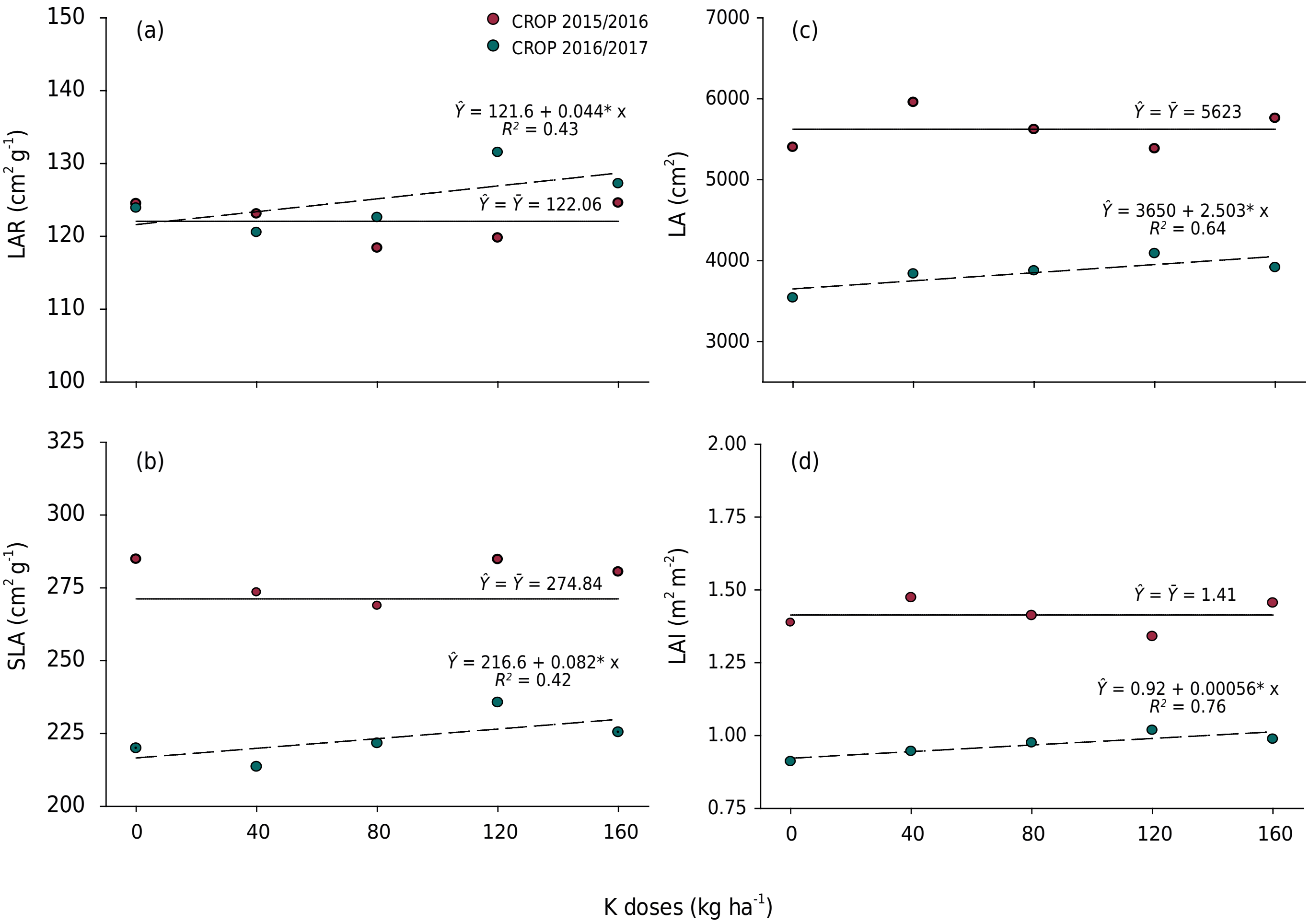

Figure 3. Leaf area ratio (LAR) (a), leaf area (LA) (b), specific leaf area (SLA) (c), and leaf area index (LAI) of soybean for the crops in 2015/2016 and 2016/2017 after the application of different K rates. * = significant at 5 %.

Among the mechanisms involved in plant nutrient uptake, diffusion is the main contact process between soil K^+ and plant roots, although mass flux may have a relevant level of participation (Oliveira et al., 2004). Diffusion is defined as the movement of ions from the soil to the roots due to differences in the concentrations (Barber, 1995). Thus, the K provided by fertilizing the sowing furrow may have a positive influence on SLA values, since K increases the turgor pressure by reducing the internal water potential of the cells, allowing a greater amount of elongation of the cell walls and indirectly increasing their photosynthetic rate and photoassimilate production.

Concerning the data for the second crop, there was no interaction among the factors assessed, although when analyzing the factors K rate and sowing-fertilization separately, differences were observed between LA, SLA, LAR, and LAI (Figures 3a, 3b, 3c, and 3d).

Therefore, a linear regression model for LA was adjusted, by which each kg of K applied increased the LA by 2.5 cm^2. Extrapolating this result to a density of 260,000 soybean plants ha^{-1}, which was the final mean plant density in both growing seasons, the data were equivalent to an additional 6.5 m^2 ha^{-1}. Leaf dropping of soybean plants is a natural event, since, with the advancement of the cultivation cycle, the leaf area is reduced due to the lower capacity of plants to produce new leaves, in addition to increases in leaf senescence and dropping of older leaves (Benincasa, 2003). On the other hand, K fertilization may delay this phenomenon and maintain the leaves photosynthetically active longer, which enables increases in the soybean yield components.

Regarding the SLA, the linear regression model was adjusted so that each kilogram of applied K increased the SLA by 0.082 $cm^2 g^{-1}$. The LAR also increased linearly with K rate applications. Each kg of K added increased the LAR by 0.044 $cm^2 g^{-1}$. For most cultivated plants, the LAR increases until the vegetative phase and decreases during maturation and senescence (Valmorbida et al., 2007). The results of this study indicate that K application might delay the natural decrease in LAR; thus, the leaf area used for interception of light energy and CO_2 assimilation remains active for a longer period than other parts of the plant that do not directly contribute to the photosynthetic process. This is confirmed by data of Fernández et al. (2009).

For the LAI, a positive linear regression model was adjusted so that each kilogram of applied K increased the LAI by 0.0006 $m^2 m^{-2}$. When analyzing the vegetative development of soybean at different K levels in the soil, Fernández et al. (2009) showed that unbalanced levels of K^+ in the soil may decrease the LAI by 23 % compared to that of soils with adequate K^+ levels.

The differences between treatments were more evident in the second year due to the lower water availability. When investigating K fertilization and water contents for two bean cultivars, Sangakkara et al. (2001) showed that K applied in a nutritive solution promoted greater growth and development of the plants under drought than unstressed conditions for the two cultivars analyzed in the study. More specifically, for soybean, Catuchi et al. (2012) investigated plant responses to increasing K rates under low soil water conditions.

Compared to the treatment without fertilization, fertilizing the sowing furrow with 30 kg ha^{-1} K increased the means of the following variables: SLA (227.4 and 219.0 $cm^2 g^{-1}$ for the fertilized and non-fertilized treatments, respectively), LAR (127.7 and 122.6 $cm^2 g^{-1}$ for the fertilized and non-fertilized treatments, respectively), and LAI (1.00 and 0.93 $m^2 m^{-2}$ for the fertilized and non-fertilized treatments, respectively). Potassium application in the sowing furrow improved soybean growth and development, since all parameters related to leaf growth were improved, even under well-watered conditions, since the mean SLA value in the 2016/2017 growing season was also higher with sowing fertilization (278.5 $cm^2 g^{-1}$) than without sowing fertilization (217.2 $cm^2 g^{-1}$) (Table 1).

Results related to variations in the application period are presented in table 2. There were no differences in the biometric variables analyzed, which is corroborated by the study of Bernardi et al. (2009), Petter et al. (2012), and Zambiazzi (2014), who found no differences either between the studied soybean characteristics. The lack of significance of this factor can be attributed to the K use efficiency of the plants; the initial K levels in the soil, which were at a critical level; or even the low amount of precipitation between the applications. Under these conditions, the recommended application form should optimize the operability and fertilizer distribution reducing the cost of this practice.

Table 1. Means of biometric parameters for the sowing fertilization factor

Treatment	SDW	LDW	StDW	LAR	LA	SLA	LAI
		g		$cm^2 g^{-1}$	cm^2	$cm^2 g^{-1}$	$m^2 m^{-2}$
			2015/2016				
SF[(1)]	46.8 A	20.7 A	26.0 A	123.3 A	5,739.7 A	278.5 A	1.6 A
WSF[(2)]	45.7 A	20.3 A	25.4 A	120.9 A	5,506.8 A	271.2 B	1.5 A
			2016/2017				
SF	31.3 A	17.6 A	13.7 A	127.7 A	3,990.9 A	227.4 A	1.0 A
WSF	30.3 A	16.9 A	13.4 A	122.6 B	3,710.3 B	219.1 B	0.9 B

[(1)] Sowing fertilization. [(2)] Without sowing fertilization. SDW = shoot dry weight; LDW = leaf dry weight; StDW = stem dry weight; LAR = leaf area ratio; LA = leaf area; SLA = specific leaf area; LAI = leaf area index. Means followed by the same capital letter in a column do not differ from each other at 5 % probability by the F test.

Correlations

When analyzing the correlations between yield and biometric parameters (Tables 3 and 4), no significance was found for the following pairs in the first crop: YLD × StDW (r = 0.09), YLD × SLA (r = -0.08), YLD × SDW (r = 0.05), YLD × LA (r = -0.03), YLD × LAI (r = 0.01), and YLD × LDW (r = -0.05). For the second crop, with lower rainfall volume, the following correlations between the biometric variables and yield were significant: YLD × StDW (r = 0.37*), YLD × SLA (r = 0.37*), YLD × SDW (r = 0.41*), YLD × LA (r = 0.54*), YLD × LAI (r = 0.43*), and YLD × LDW (r = 0.42*).

All these pairs were directly and positively correlated, which indicates that the increases in StDW, SLA, SDW, LA, LAI, and LDW resulted in an increase in soybean grain yield. It should also be highlighted that LA was the biometric component with the highest contribution to yield (Table 1).

Leaves are plant organs with a high degree of polymorphism, i.e., they can adapt to different conditions. Based on their differentiation degree and species, leaves respond to changes in the environment to keep their photosynthetic and water levels close to optimal (Pereira, 2000). This explains the differences in the treatments assessed in this study, as well as the correlations among the leaf biometric parameters and the other responses.

Stem growth and development directly affect the whole plant structure and may also influence the temporal pattern of the physiological activity of leaves (Tanaka et al., 2008), as clearly shown in this study by the high correlations between StDW and SDW and leaf-related parameters (Table 4).

Table 2. Means of biometric parameters for the factor application period

Treatment	SDW	LDW	StDW	LAR	LA	SLA	LAI
	g			$cm^2\ g^{-1}$	cm^2	$cm^2\ g^{-1}$	$m^2\ m^{-2}$
2015/2016							
Pre-sowing	44.3 A	19.7 A	24.5 A	119.7 A	5,409.9 A	267.9 A	1.5 A
Post-sowing	45.4 A	20.2 A	25.2 A	119.0 A	5,510.6 A	267.2 A	1.5 A
2016/2017							
Pre-sowing	29.8 A	16.8 A	13.1 A	123.5 A	3,776.6 A	219.8 A	1.0 A
Post-sowing	30.2 A	16.9 A	13.3 A	120.7 A	3,736.8 A	215.8 A	0.9 A

SDW = shoot dry weight; LDW = leaf dry weight; StDW = stem dry weight; LAR = leaf area ratio; LA = leaf area; SLA = specific leaf area; LAI = leaf area index. Means followed by the same capital letter in a column do not differ from each other at 5 % probability by the F test.

Table 3. Simple linear correlation matrix between soybean yield and the biometric parameters in the first crop (2015/2016)

Parameters(1)	Correlation coefficient						
	StDW	LDW	SDW	LAR	LA	SLA	LAI
YLD	0.09	-0.005	0.05	-0.19	-0.03	-0.08	0.01
StDW		0.89*	0.98*	-0.38*	0.87*	-0.18	0.85*
LDW			0.97*	-0.15	0.94*	-0.29*	0.91*
SDW				-0.29	0.92*	-0.23	0.90*
LAR					0.09	0.69*	0.07
LA						0.05	0.97*
SLA							0.06

(1) YLD = soybean yield; StDW = stem dry weight; LDW = leaf dry weight; SDW = shoot dry weight; LAR = leaf area ratio; LA = leaf area; SLA = specific leaf area; LAI = leaf area index. * = significant at 5 % probability.

During the growing season with good water availability, the random variables analyzed were statistically superior to those of the crop with a lower rainfall volume; however, the variables and crop yield were only correlated in the second growing season. This shows the importance of these growth variables for the development of plants under stress.

The mean yield data used for the correlations with the biometric variables are presented in table 5. There were yield differences between the 2015/2016 and 2015/2016 growing seasons, which can also be explained by the differences in water availability between the two years (Catuchi et al., 2012).

Table 4. Simple linear correlation matrix between soybean yield and the biometric parameters in the second crop (2016/2017)

Parameters[(1)]	Correlation coefficient						
	StDW	LDW	SDW	LAR	LA	SLA	LAI
YLD	0.37*	0.42*	0.41*	0.32*	0.54*	0.37*	0.43*
StDW		0.80*	0.95*	-0.05	0.75*	0.26	0.70*
LDW			0.94*	0.01	0.79*	0.10	0.72*
SDW				-0.02	0.81*	0.20	0.75*
LAR					0.56*	0.91*	0.55*
LA						0.69*	0.94*
SLA							0.67*

[(1)] YLD = soybean yield; StDW = stem dry weight; LDW = leaf dry weight; SDW = shoot dry weight; LAR = leaf area ratio; LA = leaf area; SLA = specific leaf area; LAI = leaf area index. * = significant at 5 % probability.

Table 5. Soybean yield in two consecutive growing seasons (2015/2016 and 2016/2017)

Pre-sowing	Sowing	Post-sowing	2015/2016	2016/2017	Mean	Variation in relation to the control
K application			Crop			
kg ha^{-1}						%
0	0	0	3,573 A[(1)]	2,656 B	3,115	-
40	0	0	3,569 A	2,870 B	3,220	3.26
80	0	0	3,480 A	2,804 B	3,175	0.88
120	0	0	3,606 A	3,132 B	3,369	7.55
160	0	0	3,646 A	3,218 B	3,432	9.25
0	30	0	3,564 A	2,747 B	3,156	1.30
40	30	0	3,693 A	2,917 B	3,305	5.76
80	30	0	3,531 A	3,386 B	3,459	9.95
120	30	0	3,628 A	2,969 B	3,299	5.58
160	30	0	3,676 A	2,974 B	3,325	6.33
0	0	40	3,553 A	2,851 B	3,202	2.73
0	0	80	3,504 A	2,648 b	3,076	-1.25
0	0	120	3,504 A	2,969 B	3,237	3.77
0	0	160	3,629 A	3,218 B	3,424	9.03
0	30	0	3,373 A	2,967 B	3,170	1.75
0	30	40	3,482 A	2,855 B	3,169	1.70
0	30	80	3,644 A	3,002 B	3,323	6.27
0	30	120	3,874 A	3,049 B	3,462	10.02
0	30	160	3,537 A	2,949 B	3,243	3.96

[(1)] Means followed by the same capital letter in a column do not differ from each other at 5 % probability by the F test.

CONCLUSIONS

Plants in soil with greater K^+ availability exploited their environment better, and changes observed in soil K^+ availability can be used to predict yield, since the measured biometric parameters and crop yield were positively and significantly correlated.

Potassium fertilization during soybean cultivation should be carried out by applying part of the K in the sowing furrow and part in the pre-sowing or post-sowing stage, since the application period did not influence the biometric parameters of the studied soybean crops.

The differences in biometric variables in relation to K rates were more evident in the year with the lowest precipitation. Furthermore, K applications and sowing fertilization promoted improvements in the parameters relevant for soybean development.

In summary, this study shows that K^+ availability in the soil influences the biometric characteristics of soybean plants, especially in dry years.

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