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Potassium fertilization and sowing seasons on protein yield in soybean cultivars

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potassium
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ABSTRACT

The present study was conducted in order to determine the effects of potassium (K) fertilizer doses on the protein yield of different soybean cultivars, sown in two seasons, in the agricultural year 2013/14 (12/05/13 and 01/23/14), in Palmas-TO, Brazil. The experimental design, in each sowing season, was randomized blocks with 60 treatments and three replicates. The treatments were arranged in a 10 × 6 factorial scheme, represented by ten cultivars (BRS 325RR, M 9144RR, BRS 33871RR, TMG 1288RR, BRS 333RR, P 98Y70RR, TMG 1180RR, BRS 9090RR, M 8766RR and BRS 8990RR) and six doses of K fertilizer (0, 40, 80, 120, 160 and 200 kg ha⁻¹ K₂O). The late sowing decreased the protein yield. K fertilization increased the protein yield in soybean cultivars. The BRS 9090RR, BRS 33871RR and BRS 333RR cultivars, at high and low K doses, were the most promising for the protein yield, and their cultivation is strategic from the economic and environmental point of view.

Palavras-chave:

Glycine max
potássio
plantio
rendimento industrial

Adubação potássica e épocas de semeadura no rendimento de proteína em cultivares de soja

RESUMO

O presente estudo foi realizado visando determinar os efeitos de doses de adubação potássica no rendimento de proteína em diferentes cultivares de soja semeadas em duas épocas, no ano agrícola 2013/14 (05/12/13 e 23/01/14), em Palmas, TO. O delineamento experimental utilizado em cada época de semeadura foi de blocos casualizados com 60 tratamentos e três repetições. Os tratamentos foram dispostos em um esquema fatorial 10 × 6 representado por dez cultivares (BRS 325RR, M 9144RR, BRS 33871RR, TMG 1288RR, BRS 333RR, P 98Y70RR, TMG 1180RR, BRS 9090RR, M 8766RR e BRS 8990RR) e seis doses de adubação potássica (0, 40, 80, 120, 160 e 200 kg de K₂O ha⁻¹). A semeadura tardia promoveu redução no rendimento de proteína enquanto a adubação potássica elevou o rendimento de proteína nas cultivares de soja. As cultivares BRS 9090RR, BRS 33871RR e BRS 333RR em altas e baixas doses de potássio foram as mais promissoras visando ao rendimento de proteína sendo seus cultivos estratégicos do ponto de vista econômico e ambiental.



INTRODUCTION

Soybean is an agricultural commodity due to the versatility of application of its products for human and animal consumption and to its economic value in national and international markets. According to Silva Júnior & Demonte (2014), among the various protein sources of vegetal origin, soybean offered protein of high biological value, which motivated the development of innumerable foods derived from this species, thus demonstrating that it is a promising source of protein for human and animal consumption.

Pípolo (2002) claims that, at first, the protein contents of soybean grains are genetically regulated, but strongly influenced by the environment, especially during the period of grain filling. The protein content in the grains is four times more dependent on environmental conditions than on the variety (Benzain & Lane, 1986).

In this century, one of the main challenges for humanity is to provide enough food to a global population in rapid expansion, preserving the environmental and energy resources of our planet (Wendling, 2008). In this context, to avoid additional damages to the marginal environments and the increasing reduction of the yields, the increment in food production must come from the increase in the yield of the existing agricultural lands (Braga, 2013) and from the utilization of inputs that, when used in large amounts, result in contamination of the water table and acidification of the soils (EMBRAPA, 2011). Thus, the identification of cultivars with good performance in unfavorable environments, i.e., reducing the use of inputs, is strategic from the economic and environmental point of view, because it would substantially reduce the use of inputs.

One of the main chemical elements required by the soybean crop is potassium (K), which is found at low concentrations in the Brazilian tropical soils, but with direct effect on grain, protein and oil yields. According to Pettigrew (2009) and Rengel & Damon (2008), under conditions of low K availability in the soil, soybean cultivars adapted and efficient regarding this nutrient exhibit better production performance.

Thus, the present study was conducted to evaluate the behavior of soybean in different sowing seasons and doses of K fertilization, for the protein yield.

MATERIAL AND METHODS

In the agricultural year 2013/14, two experiments of competition between soybean cultivars were carried out in the Agrotechnological Center of the Federal University of Tocantins, Campus of Palmas (220 m of altitude, 10° 45' S and 47° 14' W). Sowings were performed on December 05, 2013, and January 23, 2014, in dystroferic Red Yellow Latosol, with sandy loam texture, on a flat relief, well drained and without history of cultivation with annual crops. In the experimental area, 20 soil samples were collected at the depth of 0.20 cm, homogenized and a subsample of 1 kg was sent to the laboratory for chemical and physical analyses. The obtained results were: pH: 4.1, K: 14.0 mg dm⁻³, P(Mehlich): 1.5 mg dm⁻³, Ca: 0.7 cmol_c dm⁻³, Mg: 0.5 cmol_c dm⁻³, OM: 12.0 g dm⁻³, CEC: 4.6 cmol_c dm⁻³ and SB: 26.7%. The analyses were

performed according to the Embrapa method of soil analysis (Silva, 2009).

The data of rainfall and mean temperature, recorded along the experimental period, obtained from the laboratory of Meteorology and Climatology of the Federal University of Tocantins - UFT, University Campus of Palmas, are presented in Figure 1.

The experimental design in each sowing season was randomized blocks with 60 treatments and three replicates. The treatments were arranged in a 10 x 6 factorial scheme, represented by ten soybean cultivars (BRS 325RR, M 9144RR, BRS 33871RR, TMG 1288RR, BRS 333RR, P 98Y70RR, TMG 1180RR, BRS 9090RR, M 8766RR and BRS 8990RR) and six doses of K fertilization (0, 40, 80, 120, 160 and 200 kg of K₂O ha⁻¹), half applied in the sowing furrow and half applied 35 days after emergence, using potassium chloride as source of K₂O. Based on the soil chemical analysis, the recommended dose would be 120 kg ha⁻¹ of K₂O (Lopes, 1994).

The experimental plot was composed of four 5.0-m-long rows spaced by 0.45 m. For harvest, 0.45 m was disregarded on each end of the central rows. The evaluation area of the plot was represented by the two central rows, constituting 3.6 m².

After previous soil chemical and physical analyses, liming was initially applied using 2 t of Filler dolomitic limestone per hectare. Soil tillage occurred 30 days after correction and consisted in the operations of plowing, harrowing and furrowing. Fertilization at sowing was manually applied using 750 kg ha⁻¹ of single superphosphate, which correspond to approximately 150 kg of P₂O₅ ha⁻¹.

At sowing, the seeds were treated with fungicides, followed by inoculation with strains of *Bradyrhizobium japonicum*. Sowing was performed to obtain a density of 10 to 14 plants m⁻², according to the cultivar, and thinning was made 15 days after sowing. Pests, diseases and weeds were controlled as necessary.

The plants of each experimental plot were harvested one week after showing 95% of mature pods, i.e., in the R₈ stage of the scale of Fehr et al. (1978).

Based on the evaluation area of the plot, the yield grain was determined (weight in kg ha⁻¹, after moisture was corrected to 12%). Then, three samples containing 100 grains of each plot were separated and sent to the laboratory of the Embrapa Soybean, in Londrina-PR, Brazil, to determine the protein

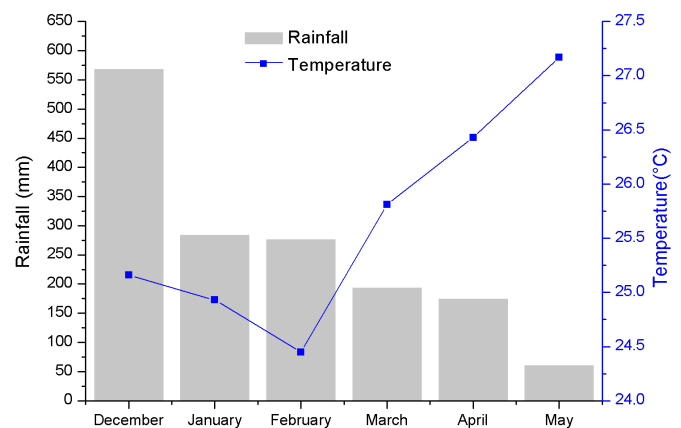


Figure 1. Rainfall and mean temperature along the experiments in the period from Dec/13 to May/14

content (%), which was obtained through the Near-Infrared Reflectance (NIR) technique, according to Heil (2012).

Then, the protein yield (kg ha^{-1}) was determined by multiplying the protein content (%) by the grain yield (kg ha^{-1}).

Protein yield data were subjected to individual analysis of variance and, subsequently, to joint analysis, in which the lowest residual mean square did not differ by more than seven times the highest mean square (Cruz & Regazzi, 2004), and the highest means of the cultivars and sowing seasons were compared by Scott-Knott test at 0.05 significance level. For the K_2O doses, in each cultivar, regression analysis was applied and the significance of the angular coefficients of the equations were determined by the Student's t-test, at 0.05 significance level.

In order to obtain an experimental error of higher accuracy, the degrees of freedom of the triple interaction (periods x cultivars x doses) were added to the experimental error. With this addition, the calculated values of the sources of variation result in higher F values, increasing the probability of detecting significant differences (Gomes, 2009).

In addition, the Maximum Technical Efficiency (MTE) was determined and the point of maximum K_2O dose was obtained from the first derivative of the regression equation, equaling it to zero.

The analyses were made using the statistical program SISVAR 5.0 (Ferreira, 2011) and the graphs were built using the software Origin Pro 8.0.

RESULTS AND DISCUSSION

The joint analysis of variance for protein yield (kg ha^{-1}) showed significant effect for periods, cultivars and fertilization (Table 1).

The significance of the interactions Periods x Cultivar, Periods x Doses and Cultivar x Doses indicates that the isolated effects of the factors do not explain all the observed variation; thus, follow-up analyses were carried out. The significance of

Table 1. Summary of the joint analysis of variance for protein yield (kg ha^{-1}) in ten soybean cultivars subjected to six K_2O doses, in two sowing seasons, in Palmas-TO, Brazil, crop year of 2013/14

SV	DF	MS
Blocks/periods	4	44991,3 ^{ns}
Periods	1	111371485,7*
Cultivar	9	299646,9*
Doses	5	1741390,8*
Periods x cultivar	9	248407,6*
Periods x doses	5	902811,0*
Cultivar x doses	45	24381,7*
Error	281	12567,8
CV (%)		11,19
Overall mean		1001,5

^{ns}Not significant; *Significant at 0.05 significance level by F test

Table 2. Mean of protein yield (kg ha^{-1}) in ten soybean cultivars as a function of the sowing seasons, in Palmas-TO, Brazil, crop year of 2013/14

Cultivar	BRS 325RR	M 9144RR	BRS 33871RR	TMG 1288RR	BRS 333RR	P 98Y70RR	TMG 1180RR	BRS 9090RR	M 8766RR	BRS 8990RR	Mean
Period 1*	1.644 bA	1.479 cA	1.639 bA	1.444 cA	1.765 aA	1.397 dA	1.514 cA	1.721 aA	1.651 bA	1.323 dA	1.557 a
Period 2**	273 dB	533 aB	519 aB	573 aB	478 bB	385 cB	481 bB	460 bB	423 bB	326 dB	445 b
Mean	959 C	1.006 B	1.079 A	1.009 B	1.121 A	891 D	997 B	1.090 A	1.037 B	825 E	

*Period 1 - Sowing on 12/05/2013; **Period 2 - Sowing on 01/23/2014

Means followed by the same letter, lowercase in the rows and uppercase in the columns, belong to a same group, according to the grouping criterion of Scott-Knott at 0.05 significance level

the interaction Period x Cultivar indicates that the cultivars showed different behavior according to the climate conditions to which they were subjected. Such interaction was expected, since there was large variation in both rainfall and temperature, during the periods of the experiments (Figure 1). This result is in agreement with those obtained by Albrecht et al. (2008), Lélis et al. (2010), Barbosa et al. (2011) and Lopes et al. (2014), in soybean cultivated in different sowing seasons.

The significant interaction Cultivar x Doses reveals a different response of the cultivars when grown in soils with different doses of K_2O . This interaction for protein yield was also found by Minuzzi et al. (2009), Toledo et al. (2010), Petter et al. (2014) and Sales et al. (2016).

The means of the cultivars as a function of the periods are shown in Table 2. For all cultivars, the first sowing season (Dec/5) led to higher protein yield in comparison to the second one (Jan/23), which were 1,557 and 445 kg ha^{-1} on average, respectively.

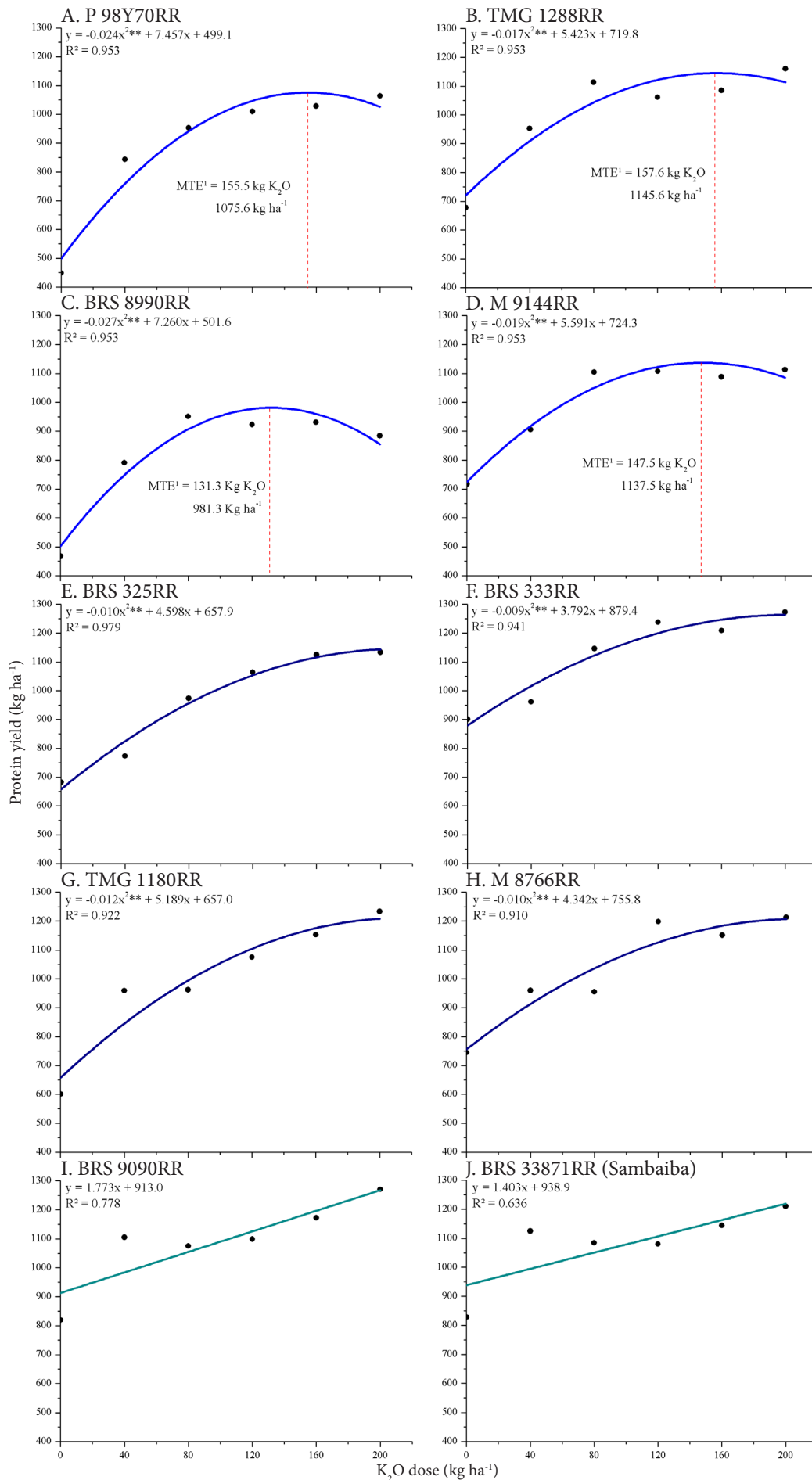
The lower protein yield of all cultivars in the second sowing season (Jan/23) resulted from the water restrictions imposed by the decrease in rainfalls that coincided with the reproductive stage of grain filling (Figure 1). It should be highlighted that the values of protein yield must reflect the values of grain yield, since they were obtained from the product between protein content and grain yield. According to Pípolo (2002), when it is not possible to explain the difference in the protein contents of soybean between the sowing seasons through the thermal oscillation, it can be explained by the distribution of rainfalls during the grain filling stage.

These data reinforce the information of agricultural zoning that indicates the sowing season comprehended between Sep/22 and Dec/21 as of lowest climatic risk for the soybean crop in the Tocantins state (CONAB, 2016).

In the first sowing season (Dec/05), the cultivars were distributed in four groups. The first group, with higher production potential, was formed by the cultivars BRS 333RR and BRS 9090RR, with protein yields of 1,765 and 1,721 kg ha^{-1} , respectively. On the other hand, the group with the lowest means was formed by the cultivars P 98Y70RR (1,397 kg ha^{-1}) and M 8990RR (1,323 kg ha^{-1}).

In the second sowing season (Jan/23), also divided into four groups, the cultivars with highest yields were TMG 1288RR with 573 kg ha^{-1} , M 9144RR with 533 kg ha^{-1} and BRS 33871RR with 519 kg ha^{-1} . The lowest means were obtained by BRS 325RR (273 kg ha^{-1}) and BRS 8990RR (326 kg ha^{-1}).

The protein yield as a function of the sowing seasons and K_2O doses is presented in Table 3. The first sowing season (Dec/05) led to higher protein yield in comparison to the second period (Jan/23) for all K doses, since in this period the cultivars showed higher protein yield (Table 2), promoted by the better distribution of rainfall (Figure 1).



¹MTE: Maximum technical efficiency ** Significant at 0.05 by t-test

Figure 2. Mean protein yield of the soybean cultivars in the sowing seasons, as a function of the K₂O doses

Table 3. Mean protein yield (kg ha⁻¹) in two sowing seasons as a function of the K₂O doses (kg ha⁻¹) in Palmas-TO, Brazil, crop year of 2013/14

Dose (K ₂ O)	0	40	80	120	160	200	Mean
Period 1*	1,017 eA	1,453 dA	1,610 cA	1,703 bA	1,750 bA	1,813 aA	1,557 a
Period 2**	360 cB	422 bB	454 aB	469 aB	468 aB	498 aB	445 b
Mean	689	938	1.032	1.085	1.109	1.155	

*Period 1 - Sowing on 12/05/2013; **Period 2 - Sowing on 01/23/2014

Means followed by the same letter, lowercase in the rows and uppercase in the columns, belong to a same group, according to the grouping criterion of Scott-Knott at 0.05 significance level

In both sowing seasons, there was an increment in protein yield as a function of the K doses. In the first period, the highest protein yield was obtained at the K₂O dose of 200 kg ha⁻¹, followed by the yields obtained at the doses of 160 and 120 kg ha⁻¹. The lowest yields occurred at the doses of 0 and 40 kg ha⁻¹. On the other hand, in the second period there were no significant differences at doses from 80 kg ha⁻¹ on. As occurred in the first period, the lowest yields were obtained at the doses of 0 and 40 kg ha⁻¹.

The highest protein yields, in both periods, occurred at K doses above the value recommended by the soil analysis (120 kg ha⁻¹). These results are consistent with those obtained by Pedroso Neto & Rezende (2005), Gonçalves Júnior et al. (2010) and Petter et al. (2014), who observed higher yields when K₂O was applied above the dose recommended by the soil analysis, regardless of the mode of application.

For the cultivars P 98Y70RR (Figure 2A), TMG 1288RR (Figure 2B), BRS 8990RR (Figure 2C) and M 9144RR (Figure 2D), the K₂O doses significantly influenced the protein yield (kg ha⁻¹), following a quadratic model of response. These cultivars showed increase in protein yield until achieving the maximum technical efficiency (MTE), which was 1,075.6 kg ha⁻¹ (P 98Y70RR), 1,145.6 kg ha⁻¹ (TMG 1288RR), 981.3 kg ha⁻¹ (BRS 8990RR) and 1,137.5 kg ha⁻¹ (M 9144RR).

From the dose that resulted in the MTE of each cultivar, there was a reduction in protein yield (kg ha⁻¹), possibly as a direct consequence of the antagonistic effect of K₂O, which reduced the absorption of other cations, i.e., it had strong competitive effect on the nutrients (Ca, Mg, N and P), negatively influencing the development of the plants (Malavolta, 1980).

Pettigrew (2009) and Veiga et al. (2010) claim that K plays vital roles and is essential in the synthesis and transport of protein to the organs.

Pedroso Neto & Rezende (2005), in Lavras (clayey Red Yellow Podzol) and in Uberaba (sandy loam Dark Red Latosol), also observed significant and quadratic effect of the K doses on the protein yield, confirming the essential nature of K in the synthesis and transport of protein to the organs.

For the cultivars BRS 325RR (Figure 2E), BRS 333RR (Figure 2F), TMG 1180RR (Figure 2G) and M 8766RR (Figure 2H), the model that best fitted was also the quadratic one, and for these cultivars the utilized doses did not allow the identification of the maximum technical efficiency.

For the cultivars BRS 9090RR (Figure 2I) and BRS 33871RR (Figure 2J), the linear model was the most adequate to explain the relationship between the K₂O doses and protein yield, indicating that the K doses used in the present study were not sufficient for these cultivars to achieve the maximum protein yield, i.e., to fully develop their potential.

In general, it can be inferred that the cultivars BRS 333RR, BRS 33871RR and BRS 9090RR exhibited higher protein yields at the different K doses.

Due to the different behavior of the cultivars in response to K fertilization and sowing seasons, some of them did not achieve the maximum protein yield, but further research must be conducted with K₂O doses above that recommended by the soil analysis, in soils under Cerrado vegetation and at low latitude.

CONCLUSIONS

1. The late sowing caused reduction in protein yield.
2. Potassium fertilization increased the protein yield of the soybean cultivars.
3. The cultivars BRS 9090RR, BRS 33871RR and BRS 333RR, at high and low potassium doses, were the most promising ones regarding the protein yield and their cultivation is strategic from the economic and environmental point of view.

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