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Performance of soybean crop in response to palisadegrass pasture desiccation and nitrogen fertilization under integrated crop-livestock system

Flávia Werner[1]*, Alvadi Antonio Balbinot Junior[2], André Sampaio Ferreira[1], Julio Cezar Franchini[2], Henrique Debiasi[2] and Marcelo Augusto de Aguiar e Silva[1]

[1]Londrina State University, Rodovia Celso Garcia Cid, PR 445, Km 380, Caixa Postal 6001, 86051-980, Londrina, Paraná state, Brazil
[2]Embrapa Soybean, Rodovia Carlos João Strass, Distrito de Warta, CEP 86001-970, Londrina, Paraná state, Brazil

***Corresponding author: flawerner6@gmail.com**

Abstract

The desiccation (burn down) time of high-biomass pasture in no-tillage system and nitrogen (N) fertilization of pasture and soybean can influence the crop performance under crop-livestock system. The objective of this study was to evaluate the effect of desiccation times of palisadegrass pasture combined with three N fertilization levels of pasture and two N fertilization levels of soybean on crop yield, yield components and grain oil and protein concentration. Three N rates in the *U. brizantha* cv. BRS Piatã pasture were evaluated (0; 150 and 300 kg ha^{-1} of N as urea) in three different experiments. In each experiment, five pasture desiccation periods (60; 45; 30; 15 and 1 days before soybean sowing) and two levels of N fertilization of soybean (30 kg ha^{-1} of N distributed as urea at sowing + a control without urea) were evaluated. A randomized complete block design with five replications was used for each experiment. After statistical analysis of each experiment, a joint analysis of the three experiments was performed, allowing the comparison of the three rates of N in the pasture. The time interval between *Urochloa brizantha* pasture desiccation and soybean sowing did not influence soybean yield, yield components or the grain oil and protein concentrations, regardless of N fertilization of pasture and soybean. N fertilization of pasture induced a taller soybean plant height, insertion height of first pod, increased lodging, and reduced yield, but did not change the grain oil and protein concentration, regardless of the pasture desiccation time and N fertilization of soybean. Soybean grain yield was negatively affected by N fertilization of the crop, regardless of fertilization levels and desiccation times of the previous pasture.

Keywords: *Glycine max* L., *Urochloa brizantha* cv. BRS Piatã., No-tillage system, Yield components, Concentration of oil and protein in grains.

Abbreviations: ICLS_Integrated Crop-Livestock System; BNF_Biological Nitrogen Fixation; N_Nitrogen; K_Potassium; P_Phosphorus; Ca_ Calcium; Cl_Chlorine; S_ Sulfur; Mg_ Magnesium; C_Carbon; SCWB_Sequential Climatological Water Balance; AWC_Available Water Concentration; ETo_Reference Evapotranspiration; ETc_Culture Evapotranspiration; Kc); Kc_Crop; NIR_Near Infrared Reflection; ANOVA_Analysis of Variance; r_Correlation Coefficient; SCE_Standard Calibration Error.

Introduction

Species of the genus *Urochloa* (Syn. *Brachiaria*) have been widely used in Integrated Crop-Livestock System (ICLS) in tropical regions, particularly due to their high biomass production capacity, ensuring adequate mulching even in low-fertility soils (Franchini et al., 2014; Ferreira et al., 2015). One of the most important reasons for the success of ICLS is the desiccation management (burndown) of the previous crop with non-selective herbicides under no-tillage system (Ricce et al., 2011; Nepomuceno et al., 2012). An appropriate desiccation management is essential for an optimal establishment and development of the subsequent crops (Ricce et al., 2011).

If pasture is desiccated shortly before soybean sowing, operational difficulties may arise, due to the high amount of undecomposed biomass on the soil, which may influence the “plantability” and agronomic performance of the subsequent soybean (Franchini et al., 2015). In addition, desiccation close to sowing can increase the immobilization of nitrogen (N) required for straw decomposition at the beginning of the cycle of subsequent soybean (Balbinot Junior et al., 2016). On the other hand, desiccation more than 30 days before soybean sowing can reduce the amount of mulching at the beginning of the crop cycle, as well as allowing early weed emergence, which sometimes requires an additional desiccation close to soybean sowing (Monquero et al., 2010; Nascente and Crusciol, 2012).

The straw of *Urochloa* species, which has a high C/N ratio, can temporarily immobilize N from the soil solution (Calonego et al., 2012; Woli et al., 2013). This aspect, associated with the easiness of sowing soybean, has increased the intervals between pasture desiccation and soybean sowing to more than 30 days. However, N fertilization of pasture can reduce the C/N ratio of the biomass, allowing desiccation closer to soybean sowing. In addition, based on the high C/N ratio of the remaining biomass of *U. brizantha* pasture, it has been hypothesized that mineral N should be supplied at soybean sowing to increase N availability at the beginning of the crop cycle, until biological N fixation (BNF) is fully established (Franchini et al., 2015).

However, the response of soybean to N fertilization during crop establishment in an ICLS with palisadegrass pasture may depend on the time of pasture desiccation, as this practice can alter the availability of soil inorganic N (Castoldi et al., 2014). Similarly, N fertilization of pasture can influence the crop responses to N fertilization during crop establishment, by altering the soil N concentration (Garcia et al., 2014). In this sense, understanding these possible interactions is essential to improve the management of integrated *Brachiaria* - soybean systems under no-tillage system.

The objective of this study was to evaluate the effect of desiccation times of palisadegrass pasture combined with three N fertilization levels of pasture and two N fertilization levels of soybean on crop yield, yield components and grain oil and protein concentration.

Results and Discussion

There was no interaction between N fertilization of *U. brizantha* cv. BRS Piatã, pasture desiccation, and N fertilization of successional soybean, on any of the variables. It should be mentioned that air temperature and water availability during the experiments were suitable for soybean (Figure 1).

Effect of N fertilization of pasture on soybean crop

There was no effect of N fertilization of *Brachiaria* pasture on the initial soybean plant density (Table 1). However, there was effect of N fertilization of pasture on soybean height, insertion height of first pod, and lodging (Table 1). The N application to pasture has intensified soybean plant growth, raising the insertion height of first pod and, consequently, increasing lodging.

There was no effect of N fertilization of pasture on soybean stem diameter, number of pods, grains m^{-2}, and thousand-grain weight. However, application of 300 kg ha^{-1} of N to the pasture reduced soybean yield compared with no N fertilization, albeit at low magnitude (3.8%). N application to pasture intensified the vegetative growth of soybean, impairing the allocation of photoassimilates to the reproductive organs and increasing lodging susceptibility. There were no differences in first pod insertion height, plant density, grain yield, and yield components of soybean after maize intercropped with *Urochloa brizantha* cv. Xaraés, *Urochloa ruziziensis*, cv. Tanzania, and *Panicum maximum* cv. Mombasa N fertilization rates from 0 to 200 kg ha^{-1} (Garcia et al., 2014). Thus, N fertilization of the previous forage had little influence on soybean yield and yield components, probably because the symbiosis with the N-fixing bacteria supplied soybean with the necessary amount of N. The oil and protein concentrations were not influenced by the pasture N fertilization.

Effect of desiccation time of pasture on soybean crop

Desiccation time significantly affected the initial density and plant height of soybean, in which the early desiccation raised the values of both variables (Table 2). Any desiccation time closer to soybean sowing hampered the sowing process, with greater difficulties of cutting the forage residues and placing the seeds in the sowing furrows, as reported by Ricce et al. (2011), and Franchini et al. (2014). In addition, desiccation closer to sowing formed a stronger physical barrier of residues against the emergence of soybean seedlings (Monquero et al., 2010). Early desiccation improved conditions for a fast development of soybean, resulting in taller plants. Despite higher plant density in the treatments with early desiccation, no significant differences in soybean lodging rates were observed for any of the factors in any experiment, although increased lodging is rather common at higher plant densities (Balbinot Junior et al., 2015).

There was no effect of desiccation times on first pod insertion height, stem diameter, number of pods, grains m^{-2}, thousand-grain weight, and grain yield of soybean. According to Nepomuceno et al. (2012), the first pod insertion height of soybean did not differ significantly in response to four *U. ruziziensis* desiccation times of (0, 10, 20, and 30 days before soybean sowing). Despite increase in plant density after early desiccation, the grain yield as well as oil and protein concentrations were not affected, when compared with desiccation closer to soybean sowing (Table 2). This indicates that desiccation time generally affected soybean development and oil and protein concentrations, but not grain yield.

Franchini et al. (2014) observed that soybean yield was not affected by desiccation times (8 - 35 days before soybean sowing) of *Urochloa ruziziensis* pasture. Corroborating with our findings, desiccation times of *U. ruziziensis* pasture (35, 28, 20, and 8 days before soybean sowing), and N fertilization rates of soybean had no effect on number of pods per plant, number of grains per pod, thousand-grain weight, and grain yield of soybean (Balbinot Junior et al., 2016).

Effect of N fertilization of soybean on its performance

There was no effect of N fertilization of soybean on initial plant density, plant height, height of first pod insertion, stem diameter, and lodging (Table 3). This demonstrates that N fertilization was not advantageous and therefore superfluous for plant growth in all studied scenarios. According to Franchini et al. (2015), application of 30 kg ha^{-1} of N to soybean increased plant and first pod insertion heights but no effect on yield. N fertilization of soybean decreased soybean yield around 3.0% (Table 3). These results support that inoculation with N-fixing bacteria, in addition to soil-available N, provides adequate N nutrition for plants, without requiring applications of mineral N (Franchini et al., 2015; Hungria and Mendes, 2015; Werner et al., 2016; Moretti et al., 2018). It is possible that nitrogen fertilization impairs the nodulation as observed by Saturno et al. (2017) and Zilli et al. (2021). These authors highlight the negative effects on BNF if mineral N is used at early stages of plant development, and the lack of effects on grain yields when used at late stage. Under good inoculation techniques, inoculation with successful *Bradyrhizobium* sp. strains will secure the bacterial survival and biologically provides N required even for high grain yield potentials.

The mineral N application to soybean did not increase grain protein and oil concentrations (Table 3). In 57 soybean cultivars, Wilson et al. (2014) observed no effects of 560 kg ha^{-1} of N on grain oil and protein concentrations.

Table 1. Initial plant density (thousand plants ha^{-1}), plant height (cm), height of first pod insertion (cm), stem diameter (cm), lodging rate, number of pods, grains m^{-2}, thousand-grain weight (g), grain yield (kg ha^{-1}), and oil and protein concentrations (%) as a function of N fertilization of palisadegrass pasture (*Urochloa brizantha* cv. BRS Piatã) (average of intervals between pasture desiccation and soybean sowing and soybean N fertilization). Londrina, PR, 2017/18 growing season.

Variables	N fertilization of pasture			CV (%)
	0 kg ha^{-1}	150 kg ha^{-1}	300 kg ha^{-1}	
Initial plant density (thousand plants ha^{-1})	464 a	460 a	460 a	6.9
Plant height (cm)	104 c	107 b	111 a	5.8
Insertion height of first pod (cm)	17.9 b	19.4 a	17.9 b	14.8
Stem diameter (cm)	5.9 a	6.0 a	6.0 a	7.1
Lodging rate	1.54 b	1.55 ab	1.68 a	18.5
Number of pods m^{-2}	1282 a	1248 a	1204 a	14.8
Number of grains m^{-2}	3103 a	2964 a	2896 a	16.1
1000-grain weight (g)	163.3 a	163.0 a	166.2 a	7.6
Grain yield (kg ha^{-1})	4912 a	4795 ab	4723 b	5.9
Oil (%)	23.43 a	23.33 a	23.11 a	3.2
Protein (%)	33.61 a	33.67 a	33.73 a	2.9

[1] Means followed by a same lowercase letter in the row are statistically equal by the Tukey's test.

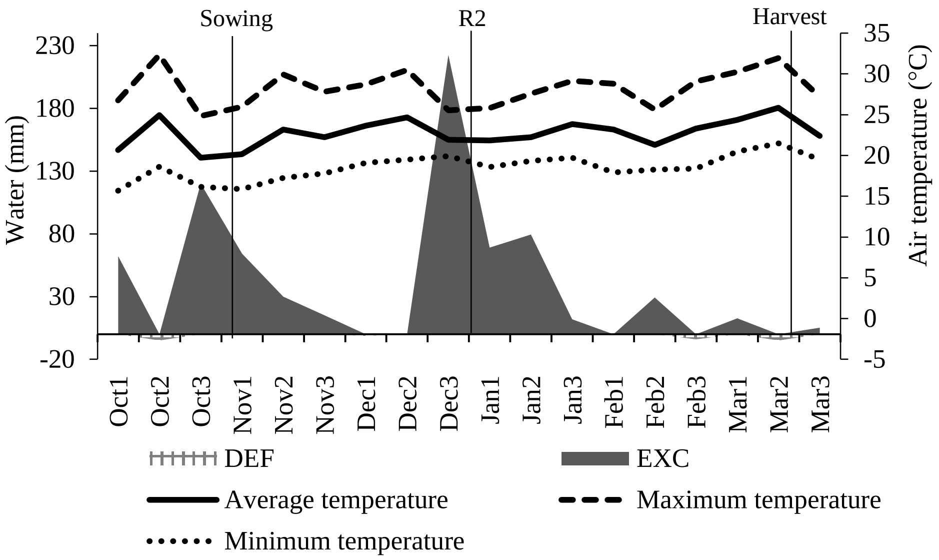

Figure 1. Sequential climatological water balance at an AWC of 75 mm and means of maximum, medium, and minimum temperatures (°C) during the experimental period in the growing season of 2017/18. Londrina, PR.

Table 2. Initial plant density (thousand plants ha^{-1}), plant height (cm), first pod insertion height (cm), stem diameter (cm), lodging, number of pods, grains m^{-2}, thousand-grain weight (g), grain yield (kg ha^{-1}), and oil and protein concentrations (%) measured in the different intervals between pasture (*Urochloa brizantha* cv. BRS Piatã) desiccation (average of N fertilization of *Brachiaria* pasture and soybean). Londrina, PR, 2017/18 growing season.

Variables	Intervals between pasture desiccation and soybean sowing (days)					Adjusted equations	R^2	CV (%)
	1	15	30	45	60			
Initial stand density (thousand plants ha^{-1})	430	456	468	477	476	$\hat{Y}$ = 4E08** + 753334x**	83.5	6.9
Plant height (cm)	103	108	106	109	111	$\hat{Y}$ = 104.03** + 0.1108x**	73.1	5.8
Insertion ht of 1^{st} pod (cm)	19	18.6	18.1	18.3	18.3	$\hat{Y} = 18.46^{ns}$		14.8
Stem diameter (cm)	5.9	5.9	6.0	6.1	6.0	$\hat{Y} = 5.98^{ns}$		7.1
Lodging	1.54	1.7	1.51	1.63	1.56	$\hat{Y} = 1.59^{ns}$		18.5
Number of pods m^{-2}	1207	1219	1290	1287	1220	$\hat{Y} = 1244^{ns}$		14.8
Number of grains m^{-2}	2876	2909	3021	3142	2988	$\hat{Y} = 2987^{ns}$		16.1
Thousand-grain weight (g)	161.6	167.9	166.8	160.9	163.6	$\hat{Y} = 164.2^{ns}$		7.6
Yield (kg ha^{-1})	4811	4842	4829	4795	4777	$\hat{Y} = 4811^{ns}$		5.9
Oil (%)	23.20	23.21	23.35	23.38	23.30	$\hat{Y} = 23.28^{ns}$		3.2
Protein (%)	33.73	33.91	33.61	33.36	33.74	$\hat{Y} = 33.67^{ns}$		2.9

ns, non-significant, ** and *, significant at $p < 0.01$, $p < 0.05$, respectively, by the F test.

Table 3. Initial plant density (thousand plants ha^{-1}), plant height (cm), height of first pod insertion (cm), stem diameter (cm), lodging, number of pods, grains m^{-2}, thousand-grain weight (g), grain yield (kg ha^{-1}), and oil and protein concentrations (%) as function of the N fertilization of soybean (average of N fertilization of palisadegrass pasture, and the intervals between pasture desiccation and soybean sowing). Londrina, PR, 2017/18 growing season.

Variables	N fertilization of soybean		CV (%)
	0 kg ha^{-1}	30 kg ha^{-1}	
Initial stand density (thousand plants ha^{-1})	459 a	463 a	6.9
Plant height (cm)	106 a	108 a	5.8
Insertion height of first pod (cm)	18.2 a	18.7 a	14.8
Stem diameter (cm)	5.9 a	6.0 a	7.1
Lodging	1.61 a	1.57 a	18.5
Number of pods m^{-2}	1236 a	1254 a	14.8
Number of grains m^{-2}	2970 a	3004 a	16.1
thousand-grain weight (g)	165.1 a	163.3 a	7.6
Grain yield (kg ha^{-1})	4891 a	4730 b	5.9
Oil (%)	23.27 a	23.31 a	3.2
Protein (%)	33.64 a	33.70 a	2.9

[1]Means followed by a same lowercase letter in a row are statistically equal by the F test.

application of 45 kg ha^{-1} of N at V2 growth stage. Oil and protein concentrations were continuously around 23% and 33-34%, respectively, demonstrating that under favorable environmental conditions for plant development, the protein and oil levels are not affected by mineral N inputs, as confirmed by Sultan et al. (2015). It is worth mentioning that in all treatments, the protein grain concentration was less than 35%. In the last decades, the protein concentration in soybean grains has been declining, thus reducing the quality of soy-based products (Mahmoud et al. 2006).

Another noteworthy factor was the absence of significant interactions between the factors (N fertilization of palisadegrass pasture, N fertilization of soybean, and pasture desiccation times), indicating that the application of mineral N to soybean was not agronomically advantageous in any of the studied situations, even under conditions favorable to N immobilization by soil microorganisms like high plant biomass and desiccation shortly after soybean sowing (Franchini et al., 2015).

Shorter periods between pasture desiccation and soybean sowing can enable significant gains in animal production, and avoid further weed desiccation operations (Franchini et al., 2015). In this sense, producers do not need to desiccate the brachiaria pasture more than 30 days before soybean sowing, increasing the use of forage. The results of this study indicated that mineral N fertilization of soybean was not necessary, since grain yield was high under all conditions (about 4,700 kg ha^{-1}). This can provide savings on N fertilizers and nitrous oxide emission reductions (Lesschen et al., 2011; Nogueira et al., 2016). Thus, it is recommended to inoculate soybean seeds with N-fixing bacteria as prescribed, dispensing mineral fertilization of the oil crop, even in ICLS producing high amounts of residues.

Materials and methods

Experimental site and soil

The study was carried out between March 2016 and March 2018, in Londrina, PR (23°11′ S, 51°11′W; 620 m a.s.l.) on a soil classified as Latossolo Vermelho distroférrico (Santos et al. 2018), with a very clayey texture. The area had been cropped under no-tillage rotation for 15 years, with soybean in the summer and wheat (*Triticum* sp.) or black oats (*Avena strigosa*) in the winter. The soil (0-20 cm layer) had the following properties: 27.9 g dm^{-3} organic C; pH ($CaCl_2$) 4.8; 15.5 mg dm^{-3} P (Mehlich-1); 0.53 cmolc dm^{-3} exchangeable K; 3.2 cmolc dm^{-3} exchangeable Ca; 1.4 cmolc dm^{-3} exchangeable Mg; 15.3 mg dm^{-3} S, and 49% base saturation.

Treatments, experimental design and study development

In March 2016, palisadegrass (*Urochloa brizantha* cv. BRS Piatã) was sowed in rows spaced 20 cm apart, intercropped with second season maize (*Zea mays*), using 5 kg ha^{-1} of pure and viable seeds. The experimental area was divided into three paddocks of approximately 1.2 ha each. The pasture of paddock 1 did not receive N fertilization, while 150 and 300 kg ha^{-1} of N per year were applied in paddocks 2 and 3, broadcast as urea (45% N; half in September and half in November 2016).

From October 2016 to July 2017, the three paddocks were continuously grazed by male cattle (live weight 350 - 550 kg), maintaining a pasture height of 30 cm. Thereafter, the area was left ungrazed until August 2017, when one experiment per paddock was set up in a complete randomized block design, with five replications, in a 5 × 2 factorial scheme. The treatments consisted of five desiccation times (60; 45; 30; 15 and 1 days before soybean sowing) and two N fertilization levels of soybean (without and with 30 kg ha^{-1} of N broadcast at sowing as urea). The methodology and experimental design of the three experiments were the same. Only the N rate of palisadegrass pasture varied.

The pasture was desiccated with glyphosate at 1,500 g a.i. ha^{-1}, sprayed with flat-fan nozzles on a tractor-pulled herbicide sprayer with a volume of spray of 200 L ha^{-1}. At all desiccation times, the atmospheric and soil moisture conditions were adequate for maximized herbicide efficiency.

The soybean cultivar BRS 1010 IPRO, with an indeterminate growth type and relative maturity of 6.1 was sown. The soybean seeds were pre-treated with carboxine (30 mL a.i. 50 kg^{-1} of seeds) and tiram (30 mL a.i. 50 kg^{-1} of seeds) and inoculated with *Bradyrhizobium elkanii* at 5 × 10^{9} CFU mL^{-1} (100 mL 50 kg^{-1} of seeds). They were sown on March 11, 2017 with a seeder-fertilizer equipped with a furrow-cutting mechanism for fertilizer placement and offset double discs for the seeds. At sowing, 350 kg ha^{-1} of the formula 0-20-20 N-P-K fertilizer was applied. In the 5 × 8 m plots (total area of

40 m^2), the seeder was adjusted to an inter-row spacing of 0.45 m.
Diseases, insect pests, and weeds were controlled according to the technical recommendations for soybean. Meteorological data were obtained at the agrometeorological station of Embrapa Soybean, 700 m away from the experimental site. The sequential climatological water balance (SCWB) of Thornthwaite and Mather (1955) was calculated during the experiments (Figure 1). For the same period, the reference evapotranspiration (ETo) was calculated with the Penman-Monteith equation and transformed into soybean evapotranspiration (ETc = ETo × Kc), as recommended by FAO based on the crop coefficient (Kc). The SCWB was calculated for 75 mm of available water content (AWC) in the soil.

Variables collected

The initial soybean plant density (thousand plants ha^{-1}), lodging, plant height (cm), height of first pod insertion (cm), stem diameter (cm), number of pods m^{-2}, number of grains per pod, thousand-grain weight (g), grain yield (kg ha^{-1}) and oil and protein concentrations (%) were evaluated. The initial plant density was determined by counting all plants at stage V2 in a total area of 3 m^2 per plot. For evaluating plant height, insertion height of first pod, stem diameter, and yield components, 20 plants in a row were collected from each experimental plot at stage R7. Plant height was measured from the soil surface to the apex of the main stem, with a millimeter ruler. First pod insertion height was measured as the distance between the plant collar to the first pod insertion with a millimeter ruler. Stem diameter was determined between the first and second node of the plant stem with a digital caliper.
The number of pods and grains m^{-2} was determined by counting all pods and grains in the 20 sampled plants. After counting total number of pods and grains, the number of pods and grains m^{-2} was calculated from the final plant density. For thousand-grain weight, two subsamples with 100 grains per replication were weighed and results expressed in g (Brasil 2009). The intensity of plant lodging in the useful area was assessed at harvest on a 1-5 score scale, as follows: 1 - no lodged plants; 2 - lodging of 25% of the plants; 3 - lodging of 50% of the plants; 4 - lodging of 75% of the plants; 5 - lodging of 100% of the plants.
The harvest was made with a plot harvester (Classic, Wintersteiger®, Austria), in 15 m^2 of each plot, moisture standardized to 13%, and yield expressed in kg ha^{-1}. Protein and oil concentrations were determined in whole grains by Near Infrared Reflection (NIR), according to Heil (2010) using an Antaris II, Thermo® spectrometer, equipped with an integration sphere at a resolution of 4 cm^{-1}, with a mean of 32 scans and background for each reading. Mathematical models developed by Embrapa Soybean in 2011/12 were used for the prediction of protein (180 standards, correlation coefficient (r) = 0.97, standard calibration error (SCE) = 0.64, and oil (170 standards, r = 0.98 and RMSEC = 0.45).

Statistical analysis

The data were analyzed for normality and homoscedasticity by the Shapiro-Wilk and Hartley tests, respectively, to check for assumptions of analysis of variance (ANOVA) for each experiment. As residual variances between the three experiments were homogeneous, a combined statistical analysis was performed such as Franchini et al. (2014). In response to N fertilization, the means of the variables were compared by the F test for soybean and by the Tukey's test for pasture. The effects of desiccation times were analyzed using second-degree polynomial regression. All analyses were run at 5% of probability using the software Sistema para Análise de Variância - SISVAR (Ferreira 2011).

Conclusions

The interval between palisadegrass pasture (*Urochloa brizantha* cv. BRS Piatã) desiccation and soybean sowing (from 1 to 60 days) does not influence soybean yield, yield components, and grain oil and protein concentrations, regardless of N application to the pasture or to soybean crop.
Mineral N fertilization of palisadegrass pasture does not influence soybean yield components, and grain oil and protein concentrations. However, the N application to pasture increases soybean plant height, the first pod insertion height, lodging, and reduces yield.
Mineral N fertilization (30 kg ha^{-1} of N) at soybean sowing does not influence the grain oil and protein concentrations, regardless of the desiccation time and N fertilization of pasture, but negatively affects grain yield.

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