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Effect of trees and cattle dung input on soybean yield and nutrition in Integrated Crop–Livestock Systems

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Abstract In integrated crop–livestock systems (ICLS), grazing cattle influence the distribution of nutrients in the soil. When trees are present, they may affect the cattle dung distribution, as well as the nutrient cycling and crop yield. The objective of this experiment is to evaluate the influence of the presence of cattle dung and trees on soybean nutrition and yield in ICLS during 2018–2019. Two areas were used in this study, that is, with trees (CLT, 1.1 ha) and without trees (CL, 1.2 ha). Both areas have been considered as ICLS (soy–beef cattle), since 2009. The experimental design was in a split–split–plot, the main plots followed the CL and CLT systems, the subplots were the cattle dung input (presence and absence), and the sub-subplots were three positions between two tree rows (i.e., sampling points). In the CL system the plant height (+18.1%), the number of pods per plant (+51.2%), grains per pod (+7.2%), shoot biomass (+60%) and grain yield (+52.9%) were increased compared to the CLT system. The highest values for plant height, shoot biomass, grain yield, grain weight, pods per plant, grains per pod, and phosphorus (P) concentrations in soybean, were observed in the central position among the tree rows, when comparing the positions nearest to the trees. However, in the position adjacent to the rows, an increased content of P in the soil was found and an increased content of sulfur (S) in the plant. The presence of cattle dung increased the availability of soil P (+30%) and potassium (K, + 52.3%), as also the content of P (+ 4.3%), K (+ 5.2%), and S (+ 5.1%) in plant, and the grain yield (+ 22%). The great effect on soybean yield was due the trees presence (3.6 Mg ha^{-1} in the CL system vs. 1.7 Mg ha^{-1} in the CLT). The light restriction, the competition for nutrients with trees and drought periods were factors to be considered, to explain the difference in productivity between the CL and CLT systems.

Keywords Agroforestry · Carbon · Nutrient cycling · Plant nutrition · Shade

Introduction

The Integrated Crop–Livestock Systems (ICLS) are categorized by exploring synergies between their components and by emerging properties (Moraes et al. 2014; Carvalho et al. 2018). They constitute

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interactions planned at different space—time scales, which include the exploitation of agricultural crops and animal production in the same area that can be an alternative to reconcile conflicts of interest to society (Carvalho et al. 2018).

The bovine in ICLS represents the entry of new flows (intensification of nutrient cycling) and interactions within the system, also increasing the economic resilience and soil quality (Moraes et al. 2014; Carvalho et al. 2018). The presence of grazing animals is beneficial for the culture implanted in succession, as it influences the cycling and distribution of nutrients in the soil, via defoliation of plants, and their return to the soil, through excreta, such as dung and urine (Dubeux et al. 2007).

Nutrients like nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) can undergo different transformations in the different compartments of the ecosystem. These transformations can leave the element available for absorption and use by plants and microorganisms, as well as give more exposure to processes that result in the loss of these nutrients (Dubeux et al. 2007). For example, a study with long-term soybean–cattle showed that in areas with dung, the levels of available P and K in the soil, as well as the number of pods per plant were considerably higher, increasing the grain yield of soybean in relation to the areas without cattle dung (da Silva et al. 2014).

The nutrients are not evenly distributed between the faeces and urine. The P, for example, practically returns only through feces; urine is the main pathway for the return of K; even as N and S are excreted in both forms (Williams and Haynes 1990). The amount of macronutrients released from cattle dung and potentially available for crops, current and subsequent, depends mainly on the number of animals during the grazing period (Carpinelli et al. 2020b), age of the animals, and the amount of nutrients present (quality). Furthermore, due to the high concentration of dung in the rest areas and near water tanks, there is an increase in the levels of P and K in the soil in these areas (Sanderson et al. 2010) and a heterogeneous distribution of cattle dung (Carpinelli et al. 2020b).

When including trees (CLT) in pasture locations, in addition to enhancing environmental benefits, trees provide greater resilience to the system, as well as shelter and an improvement in pasture quality (Jose and Dollinger 2019). In general, C_3 species, as soybean, are more tolerant to the shade than C_4 species (Lista et al. 2019). According to Magalhães et al. (2019), the soybean crop only shows a reduction in productivity due to the lower incidence of sunlight after the fourth year of implementation of the CLT system, while maize has shown a drop in productivity after the third agricultural year. Similarly, in CLT systems, grazing animals spend proportionally more time under the shade of trees, contributing to greater uniformity in the spatial distribution of excreta when the trees are well-distributed in the entire plot (Carpinelli et al. 2020b).

The present study is based on the hypothesis that the nutrients that are returned to the soil via cattle dung would affect their availability in the area and positively impacts the grain yield of the crop implanted in rotation to pasture. Moreover, the more homogeneous distribution of cattle dung in wooded areas can contribute to minimizing the negative effects of shading on soybean production. The objective of the present study is to evaluate the influence of the presence of cattle dung and trees, in ICLS, on the contribution of the chemical attributes to the soil, soybean nutrition, and production.

Materials and methods

Local characteristics, experimental design and treatments

The present study was conducted at the Rural Development Institute of Paraná—IAPAR—Emater (25 07′22′'S, 50 03′01′'W) in Ponta Grossa, Paraná, Southern Brazil. The climate type was Cfb, humid subtropical, according to Köppen's classification. The mean annual temperature was 18.3 °C, ranging from 14.2 °C in July to 24.5 °C in February, with a mean annual rainfall of 1170 mm (Table 1). The soils were classified as Typic Distrudept and Rhodic Hapludox. The average soil chemical and granulometric attributes (0–20 cm layer) at the end of crop stage (May 2018) were: pH–$CaCl_2$ = 4.9, P (Mehlich–1) = 23.4 mg dm^{-3}; 2, 28 and 11 $mmol_c$ dm^{-3} of exchangeable K, calcium (Ca) and magnesium (Mg); respectively; base saturation of 48.4%; carbon (Walkley–Black) was 14.9 g dm^{-3}; 270, 30, and 710 g kg^{-1} of clay, silt, and sand, respectively.

In October 2006, three tree species (eucalypt, *Eucalyptus dunnii*; pink pepper, *Schinus molle*; and

Table 1 Mean monthly temperature (°C) and total rainfall (mm) during the experimental period (2018–2019) and historical minimum–maximum (HM, 21–year mean)

Months	Temperature (°C)		Total rainfall (mm)	
	2018–2019	HM	2018–2019	HM
May (2018)	16.4	9.4–17.3	37.0	6.4–213.8
June	14.2	11.9–17.3	109.6	4.8–327.6
July	15.2	11.5–15.8	11.0	2.0–273.4
August	13.9	13.13–17.3	43.4	2.2–315.2
September	17.0	14.8–19.8	43.6	27.2–301.6
October	17.8	16.5–20.9	238.6	35.6–267.6
November	19.7	17.9–22.6	26.8	20.2–247.4
December	22.0	20.3–22.4	162.4	29.4–261.2
January (2019)	22.8	20.3–22.8	72.4	68.0–337.4
February	20.7	20.20–22.6	138.8	11.2–351.2
March	20.6	19.7–22.7	181.6	21.0–319.6
April	19.7	17.7–21.2	104.8	3.8–260.2

Source SIMEPAR (station 25,135,001, situated about ~ 8 km southwest of the present study), Ponta Grossa–PR

silver oak, *Grevillea robusta*) were planted in the CLT. The species were interspersed in the same rows, running crosswise in relation to the slope, 3 × 14 m spacing (238 trees ha^{-1}). The direction of the layout was predominantly facing Southwest–Northeast. After some thinning (see Pontes et al. 2020), during the present study, the new tree arrangement was 9 × 28 m (~ 40 trees ha^{-1}), with only eucalypt.

Since the 2010 winter, the production system integrated cattle grazing (Purunã beef heifers) cool-season pastures (ryegrass, *Lolium multiflorum* plus black oat, *Avena strigosa*), with a variable number of animals, periodically adjusted to maintain the desired sward height of 20 cm, i.e. the "put-and-take" method (Mott and Lucas 1952). Maize (*Zea mays*) or soybean (*Glycine max*) crops were cultivated alternately in the summer, in the same area, using no-till.

The experimental data collected in this study only refers to the twelfth pasture–crop rotation year (i.e. between May 2018, when the pasture was sown, until Mars 2019, when the soybean was harvested). The black oat (cv. IPR61) plus ryegrass (cv. São Gabriel) mixture was sown in rows with 45 and 15 kg ha^{-1} of seeds, respectively, at the end of May 2018. In addition, 400 kg ha^{-1} of commercial N–P_2O_5–K_2O fertilizer 04–30–10 was applied. On 18 June, 2018, 90 kg ha^{-1} of N was applied in the form of urea.

The statistical arrangement was a split-split-plot design with two ICLS (with and without trees, CLT and CL, respectively) and two cattle dung concentrations (presence versus absence of cattle dung), with six replications (Fig. 1). In the CLT, there were three positions between the two tree rows, namely: P3, the central position between two tree rows; P1, positions adjacent to the rows; and P2, the intermediate positions (Fig. 2), totaling 12 plots for CL and 36 plots for CLT.

The experimental area (2.3 ha) was divided into two paddocks (see Fig. 1): one paddock (1.2 ha) was used since 2006 in the CLT system and another paddock (1.1 ha) in the CL. This experiment has been part of a long-term study protocol (e.g. see Pontes et al. 2018).

The grazing period in the current study occurred between July and October 2018, where in, the cattle dung input was geo–referenced every 20 days, using a geodesic GPS. A digital map was then created based on the spatial distribution of cattle dung accumulated during the grazing period using the ArcView GIS 3.2 software.

Prior to the soybean establishment, the plots were demarcated according to the dung spatial contribution digital map in each system, as represented in Fig. 1. Each plot consisted of 6 soybean rows, 3.0 m in length, spaced 0.4 m apart, totaling 7.2 m^2. The size of plots was defined based on the cattle dung congregation that is, with visual presence or absence of dung in the plots according to the treatment.

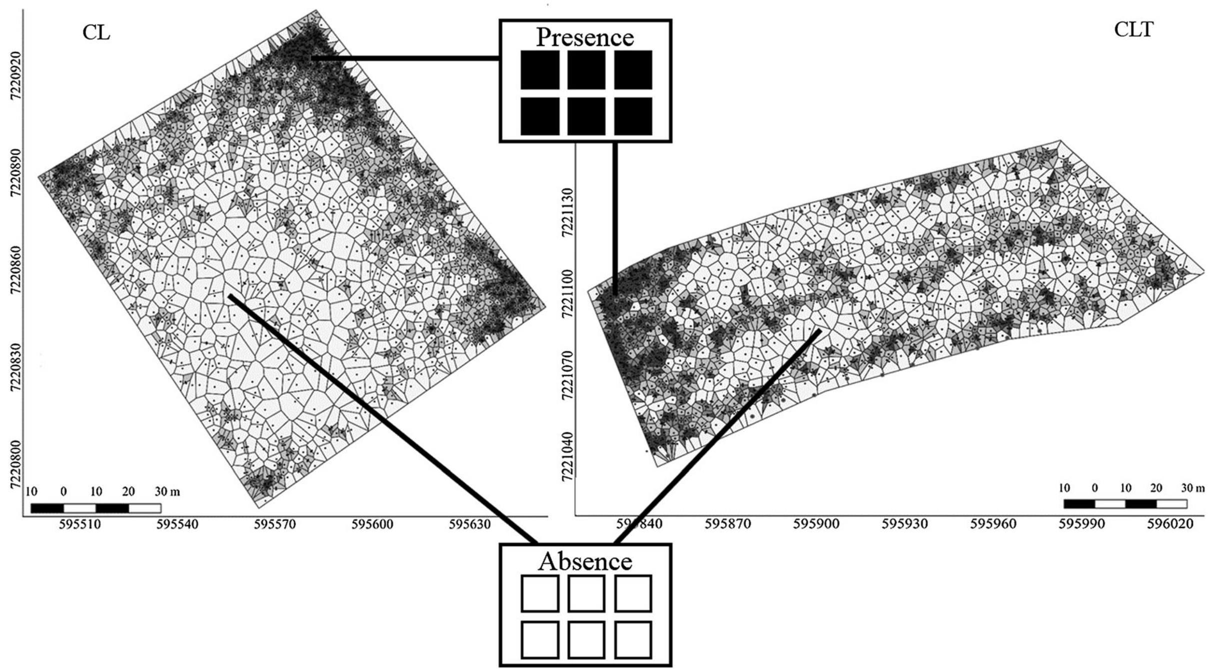

Fig. 1 Digital map indicating the absence and presence of cattle dung in the different areas (CL, crop–livestock and CLT, crop–livestock–tree systems). Dark gray represents areas with presence of cattle dung, whereas, the white areas indicate absence of cattle dung. Axes X and Y with Universal Transverse Mercator (UTM) (in meters)

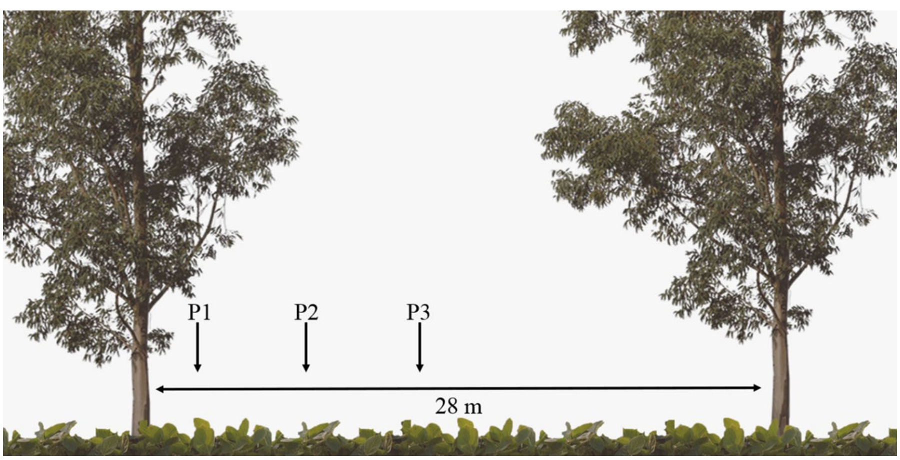

Fig. 2 Positions between the tree rows in the crop–livestock system, namely: P3, the central position between two tree rows; P1, position adjacent to the rows; and P2, the intermediate position. At the start of the experimental period (December 2018), the mean percentage of light reduction under the tree canopy was 51% for P1, 38% for P2, and 22% for P3

Soybean management and measures

The area was desiccated with glyphosate (2.3 L ha^{-1}) on November 6, 2018. On November 7, 2018, the soybean (Apollo – RR) seeds were inoculated with *Bradyrhizobium* and sown at a density of 10 seeds m^{-1} spaced 0.40 m between rows, and 230 kg ha^{-1} of the commercial $N–P_2O_5–K_2O$ (02–20–18) fertilizer was applied.

Soil samples from plots with and without cattle dung plus the respective positions between the tree lines were collected on January 14, 2019. From these samples the available P and exchangeable K was estimated, according to Pavan et al. (1992).

At the phenological stages V3 (Fehr and Caviness 1977), 35 days after sowing, the initial stand (i.e. number of plants found in 2 m linear) was evaluated in each plot. To determine the shoot biomass (stage V8 and R2), 10 plants were collected, cut above the surface of the soil, and dried at 50 °C, until constant weight. After drying, the soybean samples were weighed, ground, and analyzed for the levels of N, P, K, and S, according to Malavolta et al. (1997).

At the R8 stage (full maturity, i.e. on Mars 21, 2018), the following evaluations were recorded: the height of 20 plants, measured randomly, and the final stand (i.e. number of plants found in 2 m linear); and, in 10 plants per sub-subplots: pods per plant; grains per pod; insertion of the first pod and the weight of 1000 grains (estimated by the count of three samples of 100 grains). The weight values of 1000 grains and productivity were adjusted to the moisture content of 130 g kg^{-1}.

Statistical analyses

Analysis of variance was performed for all parameters using the split-split-plot model in program RStudio (R Core Team 2019). The main plots were the systems (CL and CLT), subplots were cattle dung input (presence and absence), and sub-subplots were positions between the tree rows (P1, P2, and P3, nested in the systems). All the factors, except the blocks, were considered as fixed terms. The error term for systems was "block(system)" and for the subplot error was "dung*block(system)". Interactions were checked for each variable and removed from the model if they had a p-value > 0.05.

Results

Plant height, shoot biomass, pods per plant, grains per pod, soybean yield and K content in soil were higher in the CL systems than CLT (Table 2). In contrast, the insertion of the first pod was higher in the CLT system (Table 2). The N, P, K, and S content in the soybean plant did not differ among the different ICLS (Table 2), as also the initial and final stand, grain weight, and P content in the soil.

Table2 Plant parameters and nutrient contents in plant and soil in relation to two Integrated Crop–Livestock Systems (with and without trees, CLT and CL, respectively)

Parameter	CL	CLT
Initial stand at V3 (n · m^{-2})	18.9a	18.8a
Final stand at R8 (n · m^{-2})	17.2a	17.4a
Plant height at R8 (cm)	58.7a	48.1b
Shoot biomass V8 (Mg ha^{-1})	46.3a	19.1b
Shoot biomass R2 (Mg ha^{-1})	111.5a	44.8b
Plant N at V8 (g kg^{-1})	32.9a	33.2a
Plant N at R2 (g kg^{-1})	28.8a	30.9a
Plant P at V8 (g kg^{-1})	2.0a	2.0a
Plant P at R2 (g kg^{-1})	1.9a	1.9a
Plant K at V8 (g kg^{-1})	36.2a	35.0a
Plant K at R2 (g kg^{-1})	24.2a	23.9a
Plant S at V8 (g kg^{-1})	1.7a	1.8a
Plant S at R2 (g kg^{-1})	1.6a	1.7a
Grain yield (Mg ha^{-1})	3.6a	1.7b
1000—grain weight (g)	143.7a	147.4a
Pods per plant (n ·)	88.9a	43.3b
Grains per pod (n ·)	2.4a	2.2b
Insertion of the first pod (cm)	8.6b	9.6a
Soil P (mg dm^{-3})	35.7a	39.1a
Soil K ($mmol_c$ dm^{-3})	5.7a	2.6b

Means followed by distinct letters on the line differ according to Tukey's test ($P < 0.05$)

Greater values for soybean yield, grain weight, pods per plant and grains per pod, as well as, soil P and K contents were seen in areas with cattle dung input (Table 3). In contrast, soybean P, K, and S contents were affected by cattle dung input at V8, but not at R2 (Table 3). However, the initial and final stand, plant height, shoot biomass, soybean N content and insertion of the first pod were not changed regarding the presence of cattle dung (Table 3).

For the different positions between trees, in general, the shoot biomass, soybean yield, grain weight and pods per plant were higher at P3 (Table 4). The soybean plants height and the number of grains per pod were higher at P2 and P3 (Table 4). The soybean P content was greater at P3; the opposite was observed for S, whereas, the greatest content was observed at P1 (Table 4). However, the initial and final stand, the insertion of the first pod, plant N and K content, did not differ among the different positions (Table 4).

Table3 Plant parameters and nutrient contents in plant and soil in relation to the presence or absence of cattle dung in integrated crop–livestock systems

Parameter	Cattle dung	
	Presence	Absence
Initial stand at V3(n · m^{-2})	18.8a	18.9a
Final stand at R8 (n · m^{-2})	17.5a	17.3a
Plant height at R8 (cm)	51.4a	50.1a
Shoot biomass V8 (Mg ha^{-1})	26.3a	25.6a
Shoot biomass R2 (Mg ha^{-1})	62.3a	60.6a
Plant N at V8 (g kg^{-1})	33.5a	32.7a
Plant N at R2 (g kg^{-1})	31.2a	29.6a
Plant P at V8 (g kg^{-1})	2.1a	2.0b
Plant P at R2 (g kg^{-1})	1.9a	1.9a
Plant K at V8 (g kg^{-1})	36.2a	34.3b
Plant K at R2 (g kg^{-1})	25.5a	22.4a
Plant S at V8 (g kg^{-1})	1.8a	1.7b
Plant S at R2 (g kg^{-1})	1.6a	1.7a
Grain yield (Mg ha^{-1})	2.5a	1.9b
1000—grain weight (g)	149.7a	143.3b
Pods per plant (n ·)	60.2a	49.3b
Grains per pod (n ·)	2.3a	2.2b
Insertion of the first pod (cm)	9.4a	9.3a
Soil P (mg dm^{-3})	45.0a	31.5b
Soil K (mmol$_c$ dm^{-3})	4.6a	2.2b

Means followed by distinct letters on the line differ according to Tukey's test ($P < 0.05$)

Table4 Plant parameters and nutrient contents in plant and soil in relation to the three positions between the two tree rows (see Fig. 2 for positions codes) in integrated crop–livestock systems

Parameter	P1	P2	P3
Initial stand at V3(n · m^{-2})	18.8a	18.8a	18.9a
Final stand at R8 (n · m^{-2})	17.2a	17.5a	17.5a
Plant height at R8 (cm)	42.7b	49.4a	52.2a
Shoot biomass V8 (Mg ha^{-1})	14.9b	17.8b	24.6a
Shoot biomass R2 (Mg ha^{-1})	28.2c	41.7b	64.3a
Plant N at V8 (g kg^{-1})	33.0a	33.3a	33.1a
Plant N at R2 (g kg^{-1})	31.6a	30.8a	30.4a
Plant P at V8 (g kg^{-1})	2.0b	1.9b	2.3a
Plant P at R2 (g kg^{-1})	1.9b	1.9b	2.1a
Plant K at V8 (g kg^{-1})	33.6a	35.7a	35.5a
Plant K at R2 (g kg^{-1})	24.2a	23.9a	23.5a
Plant S at V8 (g kg^{-1})	1.9a	1.7b	1.7b
Plant S at R2 (g kg^{-1})	1.8a	1.6b	1.6b
Grain yield (Mg ha^{-1})	1.1b	1.5b	2.5a
1000—grain weight (g)	144.4b	141.4b	156.3a
Pods per plant (n ·)	28.8b	40.9b	60.3a
Grains per pod (n ·)	2.1b	2.2ab	2.2a
Insertion of the first pod (cm)	9.7a	9.8a	9.2a
Soil P (mg dm^{-3})	55.5a	27.1b	34.6b
Soil K (mmol$_c$ dm^{-3})	2.4a	2.2a	3.4 a

Means followed by distinct letters on the line differ according to Tukey's test ($P < 0.05$)

Regarding the positions of the trees, the soil K content did not change, but the soil P content displayed greater value at P1 (Table 4).

The biggest difference in P in plants, at V8 stage (Fig. 3), between ICLS occurred in areas without cattle dung.

Interactions between cattle dung and positions were observed only for grain weight and soil K content (Fig. 4). The grain weight varied between 145.5 (P1) and 153.6 g (P3) in the treatment with cattle dung and between 131.0 (P2) and 159.1 g (P3) in the absence of cattle dung (Fig. 4a). The K content in the soil varied between 2.4 (P2) and 4.6 mmol$_c$dm^{-3} (P3) in the treatment with cattle dung. In the absence of cattle dung, the K concentration in the soil remained at ~ 2.0mmol$_c$dm^{-3} regardless of tree positions (Fig. 4b).

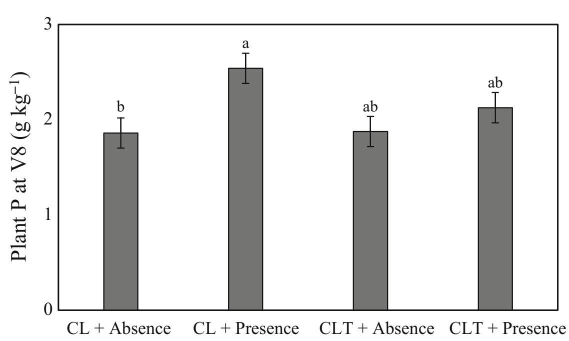

Fig. 3 Plant P from soybean residue, as affected by treatments (CL, crop–livestock *vs.* CLT, crop–livestock–trees systems; presence *vs.* absence of cattle dung). Means followed by the same lower case do not differ from each other by the Tukey's test ($P < 0.05$). Bars represent standard error

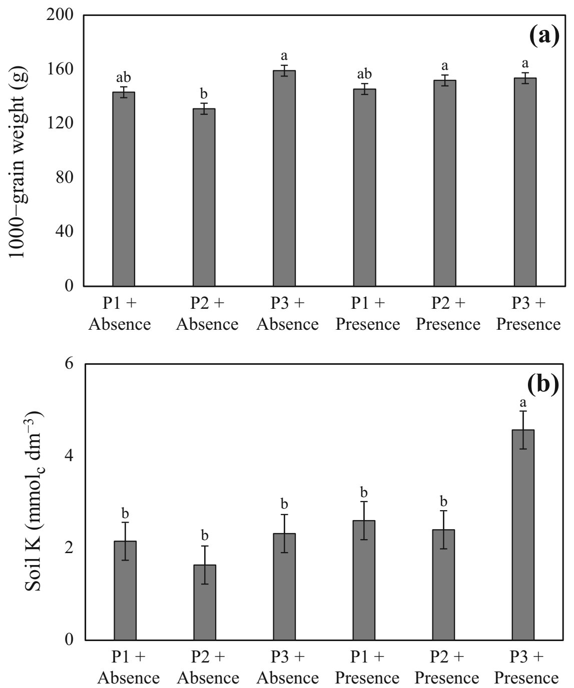

Fig. 4 Grain weight (a) and soil K content (b) from soybean residue, as affected by treatments (presence *vs.* absence of cattle dung; three positions between the two tree rows (see Fig. 2 for positions codes). Means followed by the same lower case do not differ from each other by the Tukey's test ($P < 0.05$). Bars represent standard error

Discussion

Phosphorus and K soil availability

The P content in the soil did not differ among the different ICLS. Management practices that increase soil microbiota, that is, ICLS, can increase the availability of P and its uptake by plants increasing the recycling efficiency of this nutrient (Sharma et al. 2013). However, differences were observed for the different positions, with the amount of P in the soil greater at P1. First of all, since grain yield was lower in P1 and P2 compared to P3 (Table 4), thus a lower P exportation by soybean grains is expected in these positions. Further, our hypothesis is also that animals in search of shade can directly interfere in the distribution of P returned by ruminants in CLT systems, making the concentration of P in the soil higher in areas closer to the shadows of the trees. It must be considered that long-term grazing cattle modify the soil environment, as cattle influence the decomposition of litter and accelerate the release of nutrients (Semmartin et al. 2008). Another hypothesis is that the different amounts of tree residue that each position provides, will probably result in different amounts of nutrients being released over time. The shorter the distance from the trees (P1), the greater the proportion of branches and bark of the tree residue. Potassium in the soil was higher in the CL, as this nutrient returned very quickly to the system through animal excrement and plant residues (Dubeux et al. 2007). Since the quantity of shoot plant residue and animal excrement were greater in CL system than CLT, due tree effect, a greater return of K by cycling is expected in CL (Carpinelli et al. 2020a, b).

The P and K in the soil had higher concentrations in the area with the presence of dung input. The soil P nutrient content increased by 30% (45.0 mg dm^{-3}) in areas with dung, in relation to the absence of it. In relation to the beginning of the current study, P content in the soil in plots with dung input had an increase of 92.1% and the plots without this input, the increase was only 34.7%. The soil K content at the 12th year was 4.6 and 2.2mmol$_c$ dm^{-3} in areas with and without dung, respectively. In relation to the beginning of the current study the K content in the plots with dung input had an increase of 130%. On the other hand, in the plots without dung the K increased by just 10%. Thus, cattle dung input contributes for a better soil fertility during the soybean cycle, since the mineral fertilizer input was the same for the presence and absence of dung input. These data agree with those reported by da Silva et al. (2014), where cattle dung increased the P content in the soil by 37.5%, even as the soil K content, was increased by 52.3% (4.6 mmol$_c$ dm^{-3}).

Soybean nutrition

The N, P, K, and S content in the plant was not affected by the different system. The N is associated with the capacity of soybeans to make a symbiotic N fixation in the atmosphere, making the soy less dependent on the supply of N fertilizers and on N from animal excreta. The deposition of cattle dung and its spatial distribution resulted in variations in the attributes of plants, but not in the efficiency and capacity of the rhizobia in adequately nourishing the soy with N. Any practices that negatively influence biological soil fixation are unsustainable, and in ICLS, verified variations have not changed the N nutrition of soybeans.

However, regarding the different positions, the P content was higher in P3 (central line), and the opposite was observed for the S content, which was higher in P1 (closer to the trees). A study in the same area showed that the greatest P release from shoot biomass occurred in the central position between two tree rows (P3, 5.4 kg ha^{-1}) and the lowest release close to the trees (P1, 2.0 kg ha^{-1}, Carpinelli et al. 2020a). The greatest nutrient cycling occurred, therefore, in the middle of the crop strip.

The P, K and S contents in the plant increased by 4.3%, 5.2% and 5.1%, respectively under dung presence in relation to absence (Table 3). These results are similar to the previous report by da Silva et al. (2014), which reported the positive effect of cattle dung on soybean nutrition. However, the N content in the plant was not affected by the presence of dung, because most of the N returned via urine, and little returned via cattle dung (Haynes and Williams 1993). This heterogeneous distribution of nutrients in the two via excreta returns (faeces and urine), and the occurrence of these returns in different areas, increases the heterogeneity of the nutrient returns in pasture soils, which can affect the absorption of these nutrients by the plant.

Effect of trees on soybean yield

During the experimental period, the mean percentage of light reduction under the tree canopy (CLT) compared to CL ranged from 37% in the beginning of this study, that is, in December 2018, to 39.1% in March 2019. Despite C_3 photosynthetic mechanism to be more tolerant to shading, since becomes light-saturated at approximately 50% of full sunlight (Pang et al. 2019), trees presence still affected the intercropping. The light restriction is only one resource that varies in CLT systems, with water, nutrients and probably soil biophysical properties also influencing plant productivity and development (Reynolds et al. 2007; Jose and Dollinger 2019).

The trees negatively affected the plant height, shoot biomass, pods per plant, grains per pod, and consequently grain yield. Also, these variables showed higher averages in the central position, than in the position close to the trees. Although other positions were not evaluated, they would probably have a curve with parabolic effect, with the apex of the parabola (i.e., greatest yield) occurring in the middle of the crop strip, with yield reduced nearest the tree row.

Further, a strong drought right after sowing probable contributed to increase the negative trees effect on soybean productivity. In addition, in the previous winter of 2018, the lack of rain in the months of May, July and August (37.0 mm, 11.0 mm, 43.4 mm, respectively) impaired the maintenance of the desired sward height (i.e., 20 cm, reducing biomass deposition, particularly in the CLT system, Pontes et al. 2020). Consequently, there was a reduction in the supply of nutrients via cycling, as the amount of biomass and cattle dung are the main factors affecting nutrient cycling (Carpinelli et al. 2020a, b).

Areas with trees led to smaller soybean plants, but with larger first pod heights. Therefore, plants in CLT systems are probably less susceptible to grain depreciation caused by harvest. The average grain yield in CL (3.6 Mg ha^{-1}) is above the average for Brazil in the 2018–2019 harvest (Conab 2019), which was 3.2 Mg ha^{-1}, and in the Paraná State was 2.9 Mg ha^{-1}. It is important to highlight that the yield soybean in the CLT was extrapolated to hectares to facilitate a comparison with the results recorded under CL, when the soybean productivity per se was analyzed. The soybean occupied 85.7% of the area, with the remaining 14.3% being taken up by the trees, i.e., would be wood-producing. Thus, the real soybean yield achieved in 85.7% of the area of this association of soybean plus trees would be 1.5 Mg ha^{-1} of grains. Consequently, soybean yield with mature trees is compromised, even after a drastic thinning of the trees and a low tree density ($\sim$ 40 trees ha^{-1}) in the 12^{th} experimental year. However, intercropping production in the CLT systems may be equal, or even higher, to that for open areas during some periods of tree developing (Porfirio-Da-Silva et al. 2015), contributing to accelerate the cash flow when using ICLS as a strategy to recovery degraded areas.

Effect of cattle dung on soybean yield

The dung input increases the number of pods per soybean plant by 18.2% and the soybean yield by 22% in relation to the absence of dung, regardless the ICLS. These data corroborate with those observed by da Silva et al. (2014), that the presence of dung increase the number of pods per plant by 20% and soybean production by 23% when compared to the absence of cattle dung. The smaller number of pods per plant is considered as one of the main components of soybean crop yield, indicating its correlation with productivity (Carpentieri-Pípolo et al. 2005).

However, we found that these positives effects of presence of dung did not compensate or minimize with the tree effect, despite a better distribution of dung patches in CLT systems (Carpinelli et al. 2020b). First of all, due the high losses in soybean yield with mature trees. Further, because dung patches, on general, cover only little surface of grassland (Haynes & Williams 1993; Carpinelli et al. 2020b; da Silva et al. 2020). Thus, the 22% increase in soybean yield production in dung patches were not enough to overcome the differences between systems. However, our study contributes on investigation about the underlying mechanisms of CLT dynamics. Combining information of spatiotemporal patterns created by cattle, such as dung and urine distribution pattern (the latter still with scarce information), with the nutrients release patterns from residues (plant and animal) will help to define effective system fertilization strategy to improve the system's overall performance and efficiency.

Conclusions

The presence of cattle dung in the integrated crop–livestock systems increased the availability of phosphorus and potassium in the soil. By contributing to the increase in the levels of these nutrients in the plant, as well as S, it favored the yield components of the soybean crop, directly affecting productivity.

The soybean yield was higher in the crop–livestock without trees compared to the crop–livestock with mature tree systems. Light restriction, competition for nutrients with trees, periods of drought, are factors to be considered to explain the difference in productivity between these two integrated systems.

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