Europ. J. Agronomy xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Pasture grazing intensity and presence or absence of cattle dung input and its relationships to soybean nutrition and yield in integrated crop–livestock systems under no-till

Francine Damian da Silva[a,*], Telmo Jorge Carneiro Amado[a], Christian Bredemeier[b], Carolina Bremm[c], Ibanor Anghinoni[b], Paulo Cesar de Faccio Carvalho[b]

[a] Department of Agricultural Engineering, Federal University of Santa Maria, Campus Universitário, Centro de Ciências Rurais, Prédio 42, 3° piso, CEP 97105-900 Santa Maria, RS, Brazil
[b] Faculty of Agronomy, Federal University of Rio Grande do Sul, Av. Bento Gonçalves 7712, CEP 91540-000 Porto Alegre, RS, Brazil
[c] Fundação Estadual de Pesquisa Agropecuária do Estado do Rio Grande do Sul, Centro Estadual de Meteorologia, Gonçalves Dias 570, Menino Deus, CEP 90130-060 Porto Alegre, RS, Brazil

ARTICLE INFO

Article history:
Received 28 February 2013
Received in revised form
24 September 2013
Accepted 31 October 2013

Keywords:
Cattle rise
Grain production
Nutrients cycling
Organic manure
Soil fertility

ABSTRACT

In integrated soybean–beef cattle systems, the pasture grazing intensity affects the grain crop performance in succession. In addition, the dung cattle input influences the soil nutrients distribution in the field affecting the grain crop yield. This experiment aims to evaluate the effects of winter pasture heights and cattle dung input in soybean crop performance in succession. Main soil macronutrient content, soybean plant population, dry shoot biomass, plant height, plant nutrient content, soybean yield and yield components were assessed in the 10th experimental year. The experiment was conducted in the state of Rio Grande do Sul, Southern Brazil, in a long-term integrated crop–livestock systems implemented in 2001. Treatments were arranged in a split plot design with four pasture heights (0.10, 0.20, 0.30, and 0.40 m) and two levels of dung input (with or without). For all the variables analyzed, there was no interaction between pasture heights and cattle dung input ($P > 0.05$). The pasture height management had only effect in soil P content, soybean dry biomass production, plant height and number of grains per pod. The increase in grazing intensity was associated to the rise in soybean plant height and dry mass production but was without effect on grain yield. The presence of grazing animals in the integrated soybean–beef cattle systems, and the resultant augmentation of dung input increased by 122% and 38% the availability of soil K and P, respectively in relation to the absence. Thus, the content of such nutrients in the plant were increased in 41% and 7%, respectively. The improvement in soybean nutrition increases the amount of pods per plant by 20%, and resulting in a 23% increase in soybean yield. These results indicate that cattle dung input resulting from grazing animals in the pasture phase increased soybean grain yield due to better plant nutrition. Although, the occurrence of cattle dung was very concentrated in some spots of the field and thus future studies should address strategies to improve spatial distribution of cattle dung input.

1. Introduction

The challenge of achieving high yields in soybean [*Glycine max* (L) Merr.] depends on a complex combination of environment conditions, crop management factors, and soil quality with an emphasis in plant nutrient supply. Among nutrients, N and K are required in greatest quantity for soybean (Fageria et al., 2011). Moreover, to each ton of soybean grain yield the legume demands 83, 15 and 38 kg of N, P_2O_5 and K_2O, respectively. The soybean harvest results in an exportation of 61, 65 and 53% of N, P_2O_5 and K_2O, respectively, uptake by plants (EMBRAPA, 2008). The soil N and K availability is markedly influenced by pasture and cover crops nutrient cycling in conservation tillage systems (Santi

Abbreviations: a.i., active ingredient; SY, soybean yield variation; WG, weight of 1000 grains; NPP, number of pods per plant; NGP, number of grains per pod; NPA, number of plants per area; DM, dry shoot biomass at the R2 stage; PH, plant height at the R2 stage; NP, N content in the plant; PP, P content in the plant; KP, K content in the plant; PS, P content in the soil; KS, K content in the soil; HPM, height of pasture management; DAS, days after seeding.

* Corresponding author. Tel.: +55 55 3320 8916.
E-mail addresses: frandamian@hotmail.com (F.D. da Silva), telmo.amado@cnpq.br (T.J.C. Amado), bredemeier@ufrgs.br (C. Bredemeier), carolina.bremm@yahoo.com.br (C. Bremm), ibanghi@ufrgs.br (I. Anghinoni), paulocfc@ufrgs.br (P.C.d.F. Carvalho).

1161-0301/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.eja.2013.10.009

et al., 2003). These authors reported that black oat (*Avena strigosa* Schreb.), with adequate N supply, was very efficient in cycling K. The N soybean is partly provided by the soil (25–35%) and mainly by symbiotic fixation of atmospheric N_2 (65–85%) (Gerahty et al., 1992). In Brazil, *Bradyrhizobium* inoculation has successfully replaced the use of mineral N fertilizer on soybean (Mendes et al., 2003). These authors reported that even under input of high C/N residues in no-till systems, which causes temporary N immobilization, there was no need of mineral starter soybean N fertilization. The winter pasture in integrated crop–livestock managed under no-till greatly reduces soil erosion and the runoff loss of P (García-Préchac et al., 2004). Also, the winter pasture could restore soil organic matter and therefore decrease the P fixation by clay minerals of Oxisol (Amado et al., 2006). Therefore, the long-term crop–livestock system with balanced fertilization can increase the soil P availability even in Oxisol's, which are characterized by low content of P.

Integrated systems of grain production and grazing cattle can bring benefits to grain crops, pasture, and soil quality by providing weed control, interrupting insect and disease cycles, as well as increasing plant productivity, which is often due to improvements in soil structure and nutrient cycling (Bullock, 1992; Entz et al., 2002; Franzluebbers, 2007; Humphreys, 1994; McKenzie et al., 1999; Tracy and Zhang, 2008). These benefits depend on proper pasture management, which allows for satisfactory animal performance, ensures sufficient plant residue for soil protection and allows for pasture regrowth (Carvalho et al., 2010). According to Anghinoni et al. (2011), the adjustment of grazing intensity results in an improvement in the pasture ratio of root/shoot and a positive effect on soil organic matter content in integrate systems.

The negative effects of higher pasture grazing intensities on soybean yield generally are noted during the establishment of the integrated crop–livestock systems, when the system is not yet stable (Cassol, 2003). After the initial phase, the soybean yield is less sensible to winter pasture grazing intensity (Ferreira et al., 2011; Flores et al., 2007; Lopes et al., 2009). The reduction in the quantity of pasture residue returned to soil in the integrated livestock–crop systems is compensated by an improvement in nutrient cycling associated to cattle dung and overall positive effects of the diversification on agro ecosystem (Carvalho et al., 2010; Vieira, 2004).

The presence of grazing cattle during pasture phases could be beneficial to the following grain crop, since it influences nutrient cycling indirectly and directly (Whitehead, 2000). In the indirect effect, the cattle intake of pasture stimulates plant growth and soil nutrient uptake. In the direct effect, the cattle dung and urine inputs drive the nutrient cycling in integrated crop–livestock systems (Cantarutti et al., 2001; Dubeux et al., 2007; Whitehead, 2000). N and K are mostly excreted through urine (70–90%), being K in the ionic form, which is water soluble and readily available for plant uptake, while P is deposited with the dung (95%), as organic and inorganic P, depending on the amount and type of forage ingested (Haynes and Williams, 1993; Mathews et al., 1996). The cattle's excreta were generally concentrated in areas which attract animals such as watering, resting and salting areas (Auerswald et al., 2009; Bailey et al., 2001; Haynes and Williams, 1993; Hirata et al., 1987; Tate et al., 2003; White et al., 2001). The result was an unequal distribution of excreta infield (Teixeira et al., 2012; White et al., 2001) affecting in some level the following crop performance.

This experiment was designed to test the hypothesis that in long-term integrated crop–livestock systems a range of grazing intensities, which do not spoil the soil quality, has a minor effect on following crop performance, but on the contrary the cattle dung input drives the soybean nutrition and yield.

2. Materials and methods

2.1. Local characteristics, experimental design and treatments

The present study was conducted at Espinilho farm (28°56′ S, 54°20′ W, 425 m high) in the state of Rio Grande do Sul, Southern Brazil. The soil is classified as Rhodic Haplorthox (Oxisol), deep and well drained. The soil textural values were clay 540 g kg^{-1}, silt 270 g kg^{-1}, and sand 190 g kg^{-1} (0–0.20 m layer). The climate type is Cfa, humid subtropical, according to Köppen's Classification. Soil chemical properties at the beginning of the experiment were 11.5 mg dm^{-3} of available P, 180 mg dm^{-3} of available K, both were extracted using the Mehlich-I extracting solution, 0.45 $cmol_c$ dm^{-3} of exchangeable Al, 39 g kg^{-1} of organic matter and a pH of 4.8 in water in the 0–0.10 m soil layer.

After 10 years of continuous soybean in succession with black oat as the cover crop and with most of the residue returning to soil, the experiment was established in 2001. Since then, the area has been managed within an integrated crop–livestock systems using no-till. Soybean has been rotated with a mixture of black oat and italian ryegrass (*Lolium multiflorum* Lam.) for winter grazing. During the pasture phase, four grazing intensities were applied by managing pastures at 0.10, 0.20, 0.30 or 0.40 m using continuous stocking of animals with put-and-take as proposed by Mott and Lucas (1952) in order to maintain the intended pasture heights. The animals used were crossbreed steers aging 10 months on average.

The experimental data collected in this study only refers to the 10th pasture–crop rotation year. Black oat was sown in rows with 45 kg ha^{-1} of seeds in the end of April 2010. Italian ryegrass originated from natural reseeding. Forty-five days after sowing, 45 kg N ha^{-1} was applied in the form of urea ($CO(NH_2)_2$) (45% of N). The pasture height was monitored every 15 days, using the sward stick method (Barthram, 1986).

The statistical arrangement was a split plot design with four grazing intensities (pasture heights of 0.10, 0.20, 0.30 and 0.40 m) and two cattle dung input treatments (presence and absence). The treatments were replicated 6 times totaling to 48 plots (Fig. 1).

The grazing period in the 10th year occurred between July 6th and November 3rd, a period in which cattle dung input was georeferenced 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 ArcView GIS 3.2 software. The cattle dung distribution in previous experimental years was not evaluated, but considering that the congregation of cattle dung was associated to the proximity of fences, watering, salt spots and resting areas that were not changed during the 10-year period, it was assumed that the spatial distribution of the 10th year (Fig. 1) was valid for the entire experimental period.

Prior to the soybean establishment in the 10th year, the plots were demarcated according to the dung spatial distribution digital map in each pasture height management treatment as represented in Fig. 1. Each plot consisted of 3 soybean rows, 1.5 m in length, spaced 0.45 m apart, and totaling to 2.025 m^2. This size of plots was defined based on the dung cattle congregation, i.e., with visual presence or absence of dung in the plots according the treatment. The total size of paddocks was 0.9, 1.3, 1.6 and 2.2 ha for the treatments 0.10, 0.20, 0.30 and 0.40 m of pasture height management, respectively.

Rainfall that occurred during the soybean growing season (Fig. 2) was monitored *in situ*, whereas other climatic data were collected from the Meteorological Station of the Meteorology National Institute (INMET). The region had an average rainfall of 857 mm (climate normal 1961–2010), for the examined months (INMET, 2011).

Please cite this article in press as: da Silva, F.D., et al., Pasture grazing intensity and presence or absence of cattle dung input and its relationships to soybean nutrition and yield in integrated crop–livestock systems under no-till. Eur. J. Agron. (2013), http://dx.doi.org/10.1016/j.eja.2013.10.009

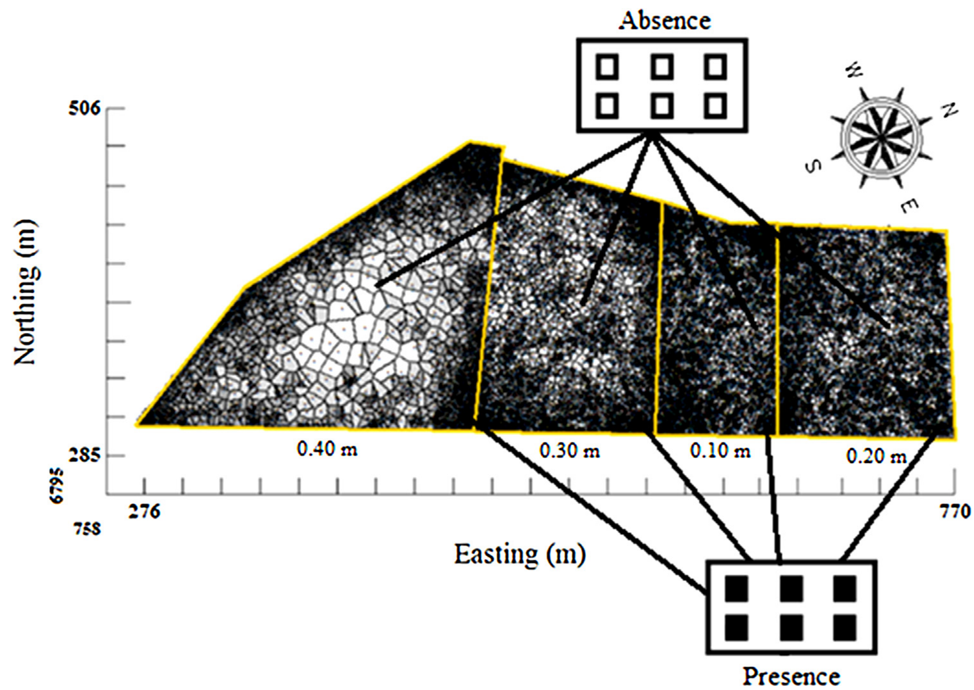

Fig. 1. Map indicating presence and absence of dung in different areas and different heights of pasture management. Dark gray represents areas with large amount of dung, whereas white indicates areas without dung. Axes *X* and *Y* with UTM coordinates (in meters).

2.2. Soybean management

Two days before sowing, the area was dessicated with glyphosate herbicide (2.5 L ha^{-1} of [N-(phosphonomethyl) glycine] active ingredient (a.i.)) and ethyl 2-(4-chloro-6-methoxypyrimidin-2-ylcarba moylsulfamoyl) benzoate (150 g ha^{-1} a.i.).

The soybean strain, Nidera A6411 RR, was sown on November 27 (2010) after inoculation and treatment of seeds with 5,6-dihydro-2-methyl-1,4-oxathi-ine-3-carboxanilide (75 mL ha^{-1} a.i.), methyl benzimidazol-2-ilcarbamato + methanal (30 mL ha^{-1} a.i.) molybdenum 10% + cobalt 1% + zinc 1% (75 mL ha^{-1} a.i.), and fipronil + thiophanate-methyl + pyraclostrobin (50 g ha^{-1} a.i.), being fungicide, fertilizer and insecticide, respectively. Seeds were sown at a density of 35 seeds m^{-2} spaced 0.45 m between rows, and 240 kg ha^{-1} of the commercial formula 0–25–25 (N–P–K) was applied.

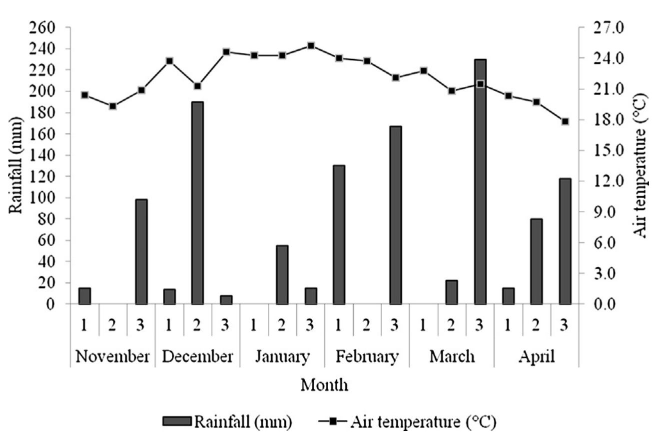

Fig. 2. Average rainfall and air temperature during the experimental period (2010/2011).

2.3. Sampling procedures

Soil samples were collected at 0–0.10 m depth using an auger with three replications per plot in order to analyze the content of nutrients. The soil samples were randomly and cautiously collected so that no samples were contaminated with dung.

Fifty days after the soybean were sown, at the V8 growth stage on the Fehr and Caviness (1977) scale, the initial plant population was evaluated. Five random plants were measured using a graduated ruler. The measurement was taken from the surface of the ground to the apex of the main stem. In order to determine the dry shoot biomass, five other plants were selected and cut above the ground surface. Then samples were dried in an air forced-draught oven at 50 °C, so that they could reach constant weight. Sixty-five days after the soybeans were sown; another measurement of plant height and dry shoot biomass was carried out, at the R2 growth stage on the Fehr and Caviness (1977) scale. Once dried the plant samples were weighed, ground, and analyzed for N, P and K content, according to the methodology described by Tedesco et al. (1995).

Evaluations of soybean yield and the final plant population were conducted at the R8 stage (harvest maturity). Before soybean harvest, all plants present in the 48 plots were counted and cut. Once harvested, ten random plants were separated, while the rest were railed, dried and weighed. The ten separated plants had their total number of pods counted in order to determine the average of pods per plant. Then the grains were threshed, divided into three groups of 100, and weighed. Subsequently, the weight of 1000 grains was calculated by the determined average.

The number of grains per pod was estimated by dividing the number of grains by the number of pods in the sample. In order to determine the number of pods per unit area, the final plant population was multiplied by the number of pods per plant. The grain weight was then adjusted for a moisture content of 130 g kg^{-1}.

2.4. Statistical analysis

The data was submitted to an analysis of variance (ANOVA) with fixed effects for pasture height, cattle dung input, the pasture height × cattle dung input interaction, and the random effects for plots. When differences were detected ($P < 0.05$), treatment means were compared using Tukey's HSD test at 5% of significance level, through the MIXED procedure of SAS (SAS Institute, 2008).

A path analysis, using the JMP v.8.2 statistical program (SAS Institute, 2008), identified the variable (s) that best explained the soybean yield variation (SY). For such analysis, the variables considered as direct effects were: weight of 1000 grains (WG), number of pods per plant (NPP), number of grains per pod (NGP), and number of plants per area (NPA). Whereas the variables considered as indirect effects include: dry shoot biomass at the R2 stage (DM), plant height at the R2 stage (PH), N, P, and K contents in the plant (NP, PP, KP), P and K contents in the soil (PS, KS), and height of pasture management (HPM). The effect of the set of variables excluded from the diagram (residual) upon soybean yield was represented by the letter U.

3. Results

For all soybean attributes and soil fertility variables evaluated, there was no significant interaction between heights of winter pasture management and cattle dung input (Table 1). For this reason the effects of pasture height management and cattle dung input on soybean performance were analyzed separately.

The initial and final population of soybean plants did not differ among heights of pasture management (Table 2) or among areas with cattle dung input (Table 3). Soybean plants height at V8 growth stage (50 days after seeding (DAS)), as well as at R2 (65 DAS), showed significant differences ($P < 0.05$) as a function of heights of winter pasture management (Fig. 3a). Therefore, areas managed during winter with pasture heights of 0.10 and 0.20 m presented taller soybean plants when compared to plants in pasture height of 0.40 m (Fig. 3a). On the other hand, plant height in areas with or without dung did not differ significantly at the V8 ($P = 0.9509$) and R2 ($P = 0.7139$) soybean growth stages (Table 3). Concerning dry shoot biomass at V8, there was no difference in relation to distinct heights of winter pasture management (Table 2) and areas with or without dung (Table 3). At R2 growth stage, dry shoot biomass of soybean was higher in areas managed during winter with pasture heights of 0.10 and 0.20 m than in areas managed at 0.40 m ($P < 0.05$; Fig. 3b), whereas there was no significant difference for areas with or without dung input ($P = 0.7139$) (Table 3).

Soybean plant N content did not differ among heights of winter pasture management (Table 2) as well as among areas with or without dung input (Table 3) at V8 and R2. Soybean plant P content, on the other hand, was significantly affected by height of winter pasture management at V8, but not at R2 (Table 2). However, the opposite occurred in areas with dung input, where P content was not affected at V8, but rather was affected at R2 soybean growth stage (Table 3). Soybean plant K content differed among areas with or without dung input (Table 3) at V8 and R2 growth stages, but was not affected by heights of winter pasture management (Table 2).

Management of pasture height also did not influence soybean grain yield (Table 2). However, areas with dung input presented higher soybean grain yield compared to areas without this organic fertilizer (Table 3). The soybean yield components concerning the number of pods per area and 1000-grains weight, were not affected by heights of winter pasture management or by the presence of dung (Tables 2 and 3). In contrast, the number of pods per plant was higher in areas with cattle dung input (Table 3). Nevertheless, this component was not affected by the height of winter pasture management (Table 2). The number of soybean grains per pod was affected by the height of winter pasture management (Table 2), i.e., the pasture managed at 0.20 m resulted in a higher number of grains per pod than the paddock managed at 0.10 m, whereas pastures at 0.30 and 0.40 m were similar. On the other hand, this variable was not affected by cattle dung input (Table 3).

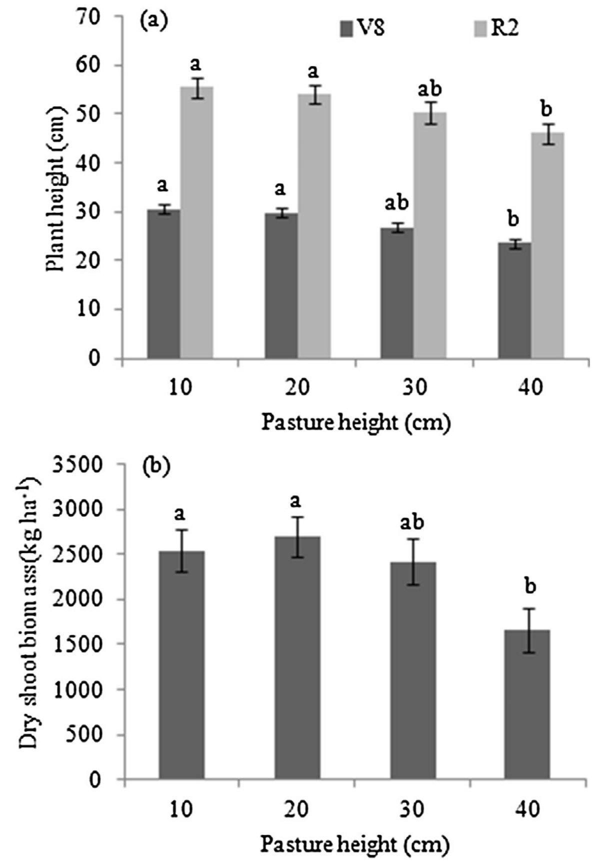

Fig. 3. Height of soybean plants at the V8 and R2 stages (a) and dry shoot biomass at R2 (b), in relation to heights of pasture management (2010/11 harvest). Averages followed by distinct letters differ according to Tukey's test, at 5% of significance.

P and K contents available in the soil differed among areas with or without dung input (Table 3), being higher under the presence of dung input. It is noteworthy to mention that soil P content increased according to winter pasture grazing intensity (Table 2).

Fig. 4 shows only the variables of considerable direct and indirect effects, as well as the coefficients of correlation among these variables in relation to soybean grain yield, with the 1000-grains weight variable excluded. In this figure, unidirectional arrows indicate the direct effect (path coefficient) of each explanatory variable, while bidirectional arrows represent the interdependence of two explanatory variables.

4. Discussion

In the 10th experimental year, different heights of winter pasture management preceding soybean crop sowing did not influence initial and final soybean plant population (Table 2). Flores et al. (2007) previously in the same experiment it was also reported that pasture grazing intensity had no effect on the following soybean plant population. Moreover, Carvalho et al. (2010) in the same experimental area that our study did not find negative effect on soybean yield of winter pasture grazing intensity during a five year period. In our study, carried out in 10th year of the experiment, we confirmed the same trend of which pasture grazing

Table 1
Analysis of variance for plant parameters and nutrient contents in plant and soil in relation to pasture height and cattle dung input.

Causes of variation	Parameters																		
	IPP	FPP	PHV8	PHR2	SBV8	SBR2	PNV8	PNR2	PPV8	PPR2	PKV8	PKR2	GY	PA	1000-GW	PP	GP	SP	SK
Pasture height	ns	ns	*	*	ns	*	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	*	*	ns
Cattle dung input	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	ns	ns	*	ns	*	*
Pasture height *vs.* cattle dung input	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns: not significant; *$P < 0.05$; IPP: initial plant population (n° m^{-2}); FPP: final plant population (n° m^{-2}); PHV8:plant height at V8 (cm); PHR2: plant height at R2 (cm); SBV8: shoot biomass V8 (Mg ha^{-1}); SBR2: shoot biomass R2 (Mg ha^{-1}); PNV8: plant N at V8 (g kg^{-1}); PNR2: plant N at R2 (g kg^{-1}); PPV8: plant P at V8 (g kg^{-1}); PPR2: plant P at R2 (g kg^{-1}); PKV8: plant K at V8 (g kg^{-1}); PKR2: plant K at R2 (g kg^{-1}); GY: grain yield (Mg ha^{-1}); PA: pods per area (n° m^{2}); 1000-GW: 1000-grain weight (g); PP: pods per plant (n°); GP: grains per pod (n°); SP: soil P (mg dm^{-3}); SK: soil K (mg dm^{-3}).

Table 2
Plant parameters and nutrient contents in plant and soil in relation to height of pasture management in integrated soybean–beef cattle system under no-till.

Parameter	Pasture height (m)				Average	*P*
	0.10	0.20	0.30	0.40		
Initial plant population, n° m^{-2}	39.3	39.5	41.1	34.2	38.5	0.1450
Final plant population, n° m^{-2}	37.8	37.6	40.5	34.9	37.6	0.3128
Shoot biomass V8, Mg ha^{-1}	1.48	1.44	1.27	1.04	1.31	0.0835
Plant N at V8, g kg^{-1}	33.25	34.32	33.12	36.66	34.26	0.1648
Plant N at R2, g kg^{-1}	30.62	30.21	29.86	30.80	30.20	0.9544
Plant P at V8, g kg^{-1} [a]	1.67 ab	1.52 b	2.00 a	2.05 a	1.78	0.0081
Plant P at R2, g kg^{-1}	1.39	1.51	1.62	1.70	1.54	0.1674
Plant K at V8, g kg^{-1}	22.43	21.42	22.60	26.77	22.64	0.1929
Plant K at R2, g kg^{-1}	20.10	22.46	21.45	24.45	21.58	0.2244
Grain yield, Mg ha^{-1}	3.58	3.43	3.63	3.71	3.57	0.2024
Pods per area, n° m^{2}	1528.40	1340.91	1467.50	1613.86	1471.98	0.3423
1000-grain weight, g	146.79	149.01	144.89	144.92	146.76	0.4309
Pods per plant, n°	38.8	36.1	35.8	46.0	39.0	0.1122
Grains per pod, n° [a]	1.86 b	2.00 a	1.91 ab	1.99 ab	1.94	0.0178
Soil P, mg dm^{-3} [a]	12 a	10 ab	8 b	8 b	9	0.0087
Soil K, mg dm^{-3}	333	348	288	287	298	0.6748

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

intensity had no effect on soybean yield ($P = 0.2024$) (Table 2). Averaged across the different pasture heights the soybean yield was 3.57 Mg ha^{-1}, ranging from 3.43 to 3.71 Mg ha^{-1} to 0.20 and 0.40 m pasture height, respectively. This result confirms that soybean is a rustic crop that has some elasticity to adapt to different grazing strategies during the winter since the soil quality was not severely depleted. It is noteworthy that climatic conditions in our study were favorable to crop grain performance (Fig. 2), with accumulated precipitation above the average for the last 49 years. Conte et al. (2007) demonstrated that the increase of grazing intensity on winter pastures increases soil penetration resistance but did not negatively affect the following soybean crop performance.

Contrarily, to previous study investigated Lunardi et al. (2008) reported that the pasture grazing intensity reduced the number of pods per soybean plant resulting in 51 and 39 pods for low and moderate pasture grazing intensities, respectively. In our study the grazing intensity did not affect the number of soybean pods ($P = 0.1122$), ranging from 39 to 46 for high and low pasture grazing intensities, respectively (Table 2).

Table 3
Plant parameters and nutrient contents in plant and soil in relation to the presence or absence of dung in integrated soybean-beef cattle system under no-till.

Parameter	Dung		Average	*P*
	Presence	Absence		
Initial plant population, n° m^{-2}	38.3	38.7	38.5	0.8448
Final plant population, n° m^{-2}	37.4	38.0	37.6	0.7559
Plant height at V8, cm	27.6	27.7	27.6	0.9509
Plant height at R2, cm	51.9	51.1	51.4	0.7139
Shoot biomass V8, Mg ha^{-1}	1.26	1.36	1.31	0.4376
Shoot biomass R2, Mg ha^{-1}	2.36	1.36	2.33	0.8243
Plant N at V8, g kg^{-1}	35.42	33.25	34.26	0.0901
Plant N at R2, g kg^{-1}	31.42	29.32	30.20	0.1043
Plant P at V8, g kg^{-1}	1.90	1.71	1.78	0.1218
Plant P at R2, g kg^{-1} [a]	1.68 a	1.43 b	1.78	0.0197
Plant K at V8, g kg^{-1} [a]	27.83 a	18.79 b	22.64	<0.0001
Plant K at R2, g kg^{-1} [a]	25.90 a	18.33 b	21.58	<0.0001
Grain yield, Mg ha^{-1} [a]	3.94 a	3.23 b	3.57	<0.0001
Pods per area, n° m^{2}	1578.32	1397.02	1471.98	0.0994
1000-grain weight, g	145.65	147.16	146.76	0.4598
Pods per plant, n° [a]	42.7 a	35.6 b	39.0	0.0278
Grains per pod, n°	1.95	1.94	1.94	0.8116
Soil P, mg dm^{-3} [a]	11 a	8 b	9	0.0010
Soil K, mg dm^{-3} [a]	433 a	195 b	298	<0.0001

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

Please cite this article in press as: da Silva, F.D., et al., Pasture grazing intensity and presence or absence of cattle dung input and its relationships to soybean nutrition and yield in integrated crop–livestock systems under no-till. Eur. J. Agron. (2013), http://dx.doi.org/10.1016/j.eja.2013.10.009

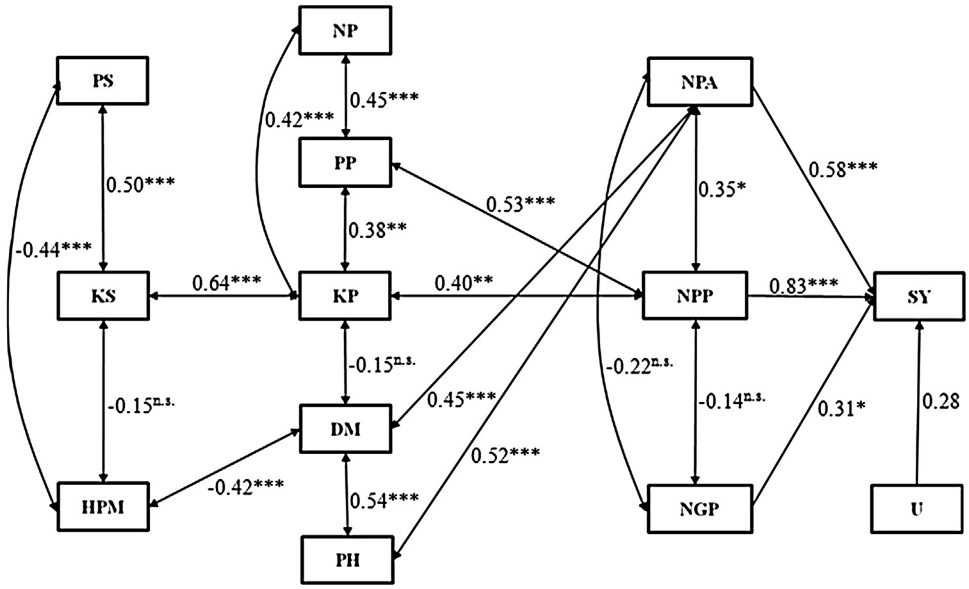

Fig. 4. Diagram presenting coefficients of correlation among variables of direct and indirect effects upon soybean yield. n.s.: not significant. $^{*}P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$.

Significant correlations between the variables NPA × PH ($r=0.52$; $P<0.001$), NPA × DM ($r=0.45$; $P<0.001$), and DM × PH ($r=0.54$; $P<0.001$) were observed in our study (Fig. 4). Thus, the increase in soybean plant height, due to a search for improvement in sunlight interception (Board and Kahlon, 2011; Shibles and Weber, 1965), resulted in greater dry shoot biomass. In our study, pasture height management at 0.40 m resulted in shorter soybean plants (Fig. 3a) with less shoot biomass when compared to heights management of 0.10, 0.20 and 0.30 m (Fig. 3b). This response may be caused by the lower microbial biomass and by lower soil basal respiration associate to lower grazing intensities (0.30 and 0.40 m of pasture height) in relation to high grazing intensity (0.10 m) (Souza et al., 2010). Moreover, for higher winter pasture grazing intensities (0.10 and 0.20 m of height) there was less mulch accumulation in relation to low grazing intensities, which results in faster nutrient cycling as a consequence of higher soil-residue contact and higher microbial activity (Souza et al., 2010). Therefore, the initial development of soybean at lower pasture grazing intensities is compromised, possibly reducing soybean plant height and dry shoot biomass (Carvalho et al., 2010). In the 10th year this experimental confirmed the trend observed in previous experimental years, adding to the increase in soybean plant height which resulted in a significant increase of NPA. This yield component was positively associated to SY (Fig. 4).

Furthermore, there was a negative correlation between PS and HPM ($r=-0.44$; $P<0.001$) (Fig. 4), meaning that high soil P values were associated with high grazing intensities (Table 2), probably due to the higher stocking rate, which is necessary to maintain a short pasture height. The higher stocking rate results in further cattle excreta having a positive effect on soil biology and nutrient cycling.

In plots with a presence of dung input, soybean average yield was 3.94 Mg ha^{-1}, while in plots with an absence, soybean average yield was 3.23 Mg ha^{-1}, both yield values were above the state's (Rio Grande do Sul) and Brazil's national grain averages for the 2010/2011 growing season (CONAB, 2011), which were of 2.80 Mg ha^{-1} and 3.10 Mg ha^{-1}, respectively. Therefore, the presence of cattle during the pasture phase can boost the soybean crop performance in succession. Some studies reported that the presence of cattle enhances soil nutrient cycling (Hati et al., 2006; Maughan et al., 2009; Sulc et al., 2005; White et al., 2001) resulting in a maintenance or even an increase in the grain crop productivity in crop–livestock systems (Entz et al., 2002; Lunardi et al., 2008; Sulc and Tracy, 2007).

Considering that the dung input increases the soybean yield by 23% in relation to the absence of dung input, an in depth analysis was carried out to identify which yield components were most affected. The three yield components that directly affected SY in our study were NPA ($r=0.58$; $P<0.001$), NPP ($r=0.83$; $P<0.001$) and NGP ($r=0.31$; $P<0.05$) (Fig. 4). Therefore, the NPP and NPA had the strongest relationship with SY. This result was not unexpected, since the number of pods per plant is the yield component which most frequently influences soybean yield (Iqbal et al., 2003; Machikowa and Laosuwan, 2011; Rezaizad et al., 2001). Nogueira et al. (2012) reported that the number of pods had correlations ranging from 0.77 to 0.85 with soybean yield, the upper limit of this range is similar to found in our study ($r=0.83$) (Fig. 4). In our study, we found the presence of dung input increased the number of pods per soybean plant by 20% (Table 3).

A significant correlation between the NGP and SY was also observed in our study (Fig. 4). This result was not expected, since the NGP was projected to present less variation in response to crop management (Thomas and Costa, 2010).

The soybean nutrient uptake (PP and KP) and the plant attributes (DM and PH) affected, to some degree, the yield components (Fig. 4). The PP and KP showed correlations of $r=0.53$ ($P<0.001$) and $r=0.40$ ($P<0.05$) with the main soybean yield component, i.e. the NPP, respectively. Moreover, there was no significant correlation of NP to NPP. This latter result was probably associated to soybean capacity of symbiotic atmospheric N fixation. Therefore the soybean when efficiently inoculate with *Bradyrizobium* is less dependent on N fertilizer input (Mendes et al., 2003) as organic N (cattle excreta).

The P in plant is particularly important in the reproductive organs of leguminous, such as soybean, since they contain high levels of this nutrient (Kovacevic et al., 2011). According to Hrustic et al. (1998), the uptake of P in plants is intense in the early plant growth stages as well as during the formation of reproductive organs. In our study, the PP had a strong correlation with NPP. In some degree this result was explained by the high demand for P during advanced growth stages development when more than 60% of P uptake ends up in the pods and seeds (INPI, 1998).

Please cite this article in press as: da Silva, F.D., et al., Pasture grazing intensity and presence or absence of cattle dung input and its relationships to soybean nutrition and yield in integrated crop–livestock systems under no-till. Eur. J. Agron. (2013), http://dx.doi.org/10.1016/j.eja.2013.10.009

The K in plant is the second nutrient demanded in higher amount for soybean. This nutrient plays an important role in various physiological processes (photosynthesis, assimilate transport, water relations and protein metabolism), which have a positive relationship with grain yield and quality (Pettigrew, 2008). Johnston and Milford (2009) reported the occurrence of N and K interactions affecting crop growth and yield. Moreover, the main interaction of these nutrients occurs during the process of plant growth at cellular level. In our study we found a correlation of NP and KP (r = 0.42; P < 0.001). The latter nutrient is responsible for the stimulation of NO_3^- uptake and transport within the plant, as K^+ serves as the accompanying counter cation (Blevins et al., 1978a,b; Pettigrew, 2008). In addition, K stimulates leaf protein synthesis resulting in an improvement of the efficiency in plant N use (Pettigrew, 2008).

As shown in Fig. 4, there was significant correlation between NP × PP (r = 0.45; P < 0.001) and, PP × KP (r = 0.38; P < 0.01), since these are essential elements for soybean development and that of the symbiotic bacteria associated with it. The N and P contents in the plant increased by 7.1% and 17.5%, respectively under dung presence in relation to absence (Table 3). For K content in the plant this increment was as high as 41.3%. These results are similar to the previous report by Mahmoodabadi et al. (2011), which reported the positive effect of sheep manure on soybean nutrition. Among the yield components affected by K fertilization, the number of pods per plant (Bharati et al., 1986; Coale and Grove, 1990; Jones et al., 1977; Nelson et al., 1945) and the weight of seeds (Bharati et al., 1986) are emphasized. In our study, the NPP was affected by KP (r = 0.40; P < 0.05). However, there was no increase in the weight of grains (P = 0.4598) or number of grains per soybean pod (P = 0.8116) by dung input (Table 3).

The PS and KS were well correlated (r = 0.50; P < 0.001) (Fig. 4); this result, at least in areas with dung input, was expected since these nutrients return to the soil through animal excreta (Teixeira et al., 2012). Thus, the K content in the soil in cattle dung input plots were increased by 122% (238 mg dm^{-3}) in relation to absence (Table 3). While, to P content in the soil this increment was 37.5% (3 mg dm^{-3}). The cattle dung in contact with soil decomposed as a result of physical (rain and trampling) and biological processes (microorganisms and epifauna), thus releasing the nutrients. Cattle dung can be incorporated into soil within 24 h after input by beetle activity (Monteiro and Werner, 1997). Therefore, the cattle dung input in the grazing pasture phase should have the nutrients released during soybean phase. The KS was well correlated with KP (r = 0.64; P < 0.001) (Fig. 4). In our study the K content in the soil under dung input was as high as 433 mg dm^{-3} (more than 4 folds higher than the critical level). When K supply was well above the level necessary to produce maximum yields a luxury consumption is noted (Sale and Campbell, 1986). These authors reported correlations between mean yield and oil, protein and K concentrations, over a wide range of K inputs, were 0.97, −0.94 and 0.98, respectively.

The dung cattle input resulted in higher K and P contents in the soil, which reflected higher K and P content in soybean plants (Table 3). This in turn affected the NPP and ultimately the SY (Fig. 4). Therefore, these results suggest that the dung cattle input improved the soil nutrient cycling since the mineral fertilizer input (56 kg ha^{-1} of K_2O) was the same for the presence and absence of dung input; the nutrient exportation by soybean harvest was higher in the presence (3.94 Mg ha^{-1} × 0.20 kg of K Mg^{-1} of soybean harvest = 79 kg ha^{-1}) than in the absence (3.23 Mg ha^{-1} × 0.20 kg of K Mg^{-1} of soybean harvest = 65 kg ha^{-1}) (Table 3). Therefore, based on the soybean yield of the 10th experimental year there was a budged of −23 and −9 kg ha^{-1} of K_2O in the plots with presence and absence of cattle dung input, respectively. The soil nutrient content at 10th year was 433 and 195 mg dm^{-3} in areas with and without dung, respectively. In relation to the beginning of the experiment, K content in the plots with dung input had an increase of 141% and the plots with absence an increase of only 8%. The difference in K content due its magnitude was attributed to the long-term effect of cattle dung input and not just from the 10th year. In a similar way, the P budget considering the P_2O_5 fertilizer input and P exported by harvest was +17 and +24 kg ha^{-1} in the presence and absence of dung input, respectively. As the P was maintained in the presence of dung input and decrease in 30% in the absence in relation to the beginning P soil content. These results highlight the role of dung input as a K source to soil and plant.

5. Conclusions

There was no interaction of grazing intensity and cattle dung input on soybean yield and components. In a range of grazing intensity that did not spoiled the soil quality the soybean yield was not affect by pasture height management. The presence of free-range cattle and their spontaneous dung in integrated soybean–beef cattle systems increased the soil availability of P and K in such areas reflecting an improvement in nutrient cycling. Thus, the content of these nutrients in the plant was positively affected, increasing the number of pods per plant by 20% and the soybean grain yield by 23% in plots with presence of dung input in relation to absence.

Acknowledgements

The authors wish to express sincere thanks to CNPq for the scholarships, Agropecuária Cerro Coroado for funding provided for this study, Leonardo Minussi, Jonas and Jhon Lennon for field support. We are also grateful to Jean Mezzalira, Lidiane Fonseca, Dorothy Menefee and Carolyn Fox for support during the writing up of this work.

References

Amado, T.J.C., Bayer, C., Conceicao, P.C., Spagnollo, E., De Campos, B.H.C., Da Veiga, M., 2006. Potential of carbon accumulation in no-till soils with intensive use and cover crops in southern Brazil. J. Environ. Qual. 35, 1599–1607.

Anghinoni, I., Assmann, J., Martins, A., Costa, S., Carvalho, P., 2011. Nutrient Cycling in Integrated Crop–Livestock Systems. Synergismus Scyentifica UTFPR, http://revistas.utfpr.edu.br/pb/index.php/SysScy/article/view/1431

Auerswald, K., Mayer, F., Schnyder, H., 2009. Coupling of spatial and temporal pattern of cattle excreta patches on a low intensity pasture. Nutr. Cycl. Agroecosys. 88, 275–288.

Bailey, D.W., Welling, G.R., Miller, E.T., 2001. Cattle use of foothills rangeland near 17 dehydrated molasses supplement. J. Range Manage. 54, 338–347.

Bharati, M.P., Whigham, D.K., Voss, R.D., 1986. Soybean response to tillage and nitrogen phosphorus, and potassium fertilization. Agron. J. 78, 947–950.

Barthram, G.T., 1986. Experimental techniques: the HFRO sward stick. In: HFRO Biennial Report 1984–85., pp. 29–30.

Blevins, D.G., Barnett, N.M., Frost, W.B., 1978a. Role of potassium and malate in nitrate uptake and translocation by wheat seedlings. Plant Physiol. 62, 784–788.

Blevins, D.G., Hiatt, A.J., Lowe, R.H., Leggett, J.E., 1978b. Influence of potassium on the uptake translocation and reduction of nitrate by barley seedlings. Agron. J. 70, 393–396.

Board, J.E., Kahlon, C.S., 2011. Soybean yield formation: what controls it and how it can be improved. In: El-Shemy, H.A. (Ed.), Soybean Physiology and Biochemistry. InTech, Croatia, pp. 1–36.

Bullock, D.G., 1992. Crop rotation. Crit. Rev. Plant Sci. 11, 309–326.

Carvalho, P.C.F., Anghinoni, I., Moraes, A., Souza, E.D., Sulc, R.M., Lang, C.R., Flores, J.P.C., Lopes, M.L.T., Silva, J.L.S., Conte, O., Wesp, C.L., Levien, R., Fontaneli, R.S., Bayer, C., 2010. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. Nutr. Cycl. Agroecosys. 88, 259–273.

Cantarutti, R.B., Nascimento Jr., D., Costa, O.V., 2001. Impacto animal sobre o solo: compactação e reciclagem de nutrientes. In: Mattos, W.R.S. (Ed.), A produção animal na visão dos brasileiros. FEALQ, Piracicaba, pp. 826–837.

Cassol, L.C., 2003. Relações solo-planta-animal num sistema de integração lavoura-pecuária em semeadura direta com calcário na superfície. Universidade Federal do Rio Grande do Sul (Thesis).

Coale, F.J., Grove, J.H., 1990. Root distribution and shoot development in no-till full season and double-crop soybean. Agron. J. 82, 606–612.

CONAB, 2011. Safra: Décimo levantamento 2010/2011, Available at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/11_07_15_11_03_18_boletim_julho_-_2011.pdf (accessed 19.12.12).

Conte, O., Levien, R., Trein, C.R., Cepik, C.T.C., Debiasi, H., 2007. Draft requirement in direct drilling in crop and cattle rotation systems using different grazing pressures and its relation to soil compactness status. Eng. Agric. 27, 222–228.
Dubeux Jr., J.C.B., Sollenberger, L.E., Mathews, B.W., Scholberg, J.M., Santos, H.Q., 2007. Nutrient cycling in warm-climate grasslands. Crop Sci. 47, 915–928.
EMBRAPA, 2008. Circular Técnica 62. In: Fertilidade do solo e nutrição mineral da soja. Centro Nacional de Pesquisa de Soja, Londrina-PR, pp. 1–8.
Entz, M.H., Baron, V.S., Carr, P.M., Meyer, D.W., Smith Jr., S.R., McCaughey, W.P., 2002. Potential of forages to diversify cropping systems in the Northern Great Plains. Agron. J. 94, 240–250.
Fageria, N.K., Baligar, V.C., Jones, C.A., 2011. Growth and Mineral Nutrition of Field Crops, 13th ed. CRC Press, Boca Raton.
Fehr, W.R., Caviness, C.E., 1977. Stages of soybean development. In: Iowa Agricultural and Home Economics Experiment Station Special Report., pp. 3–11.
Ferreira, E.V.O., Anghinoni, I., Andrighetti, M.H., Martins, A.P., Carvalho, P.C.F., 2011. Potassium cycling and balance and soybean yield in an integrated crop–livestock system under no-tillage. Rev. Bras. Cienc. Solo 35, 161–169.
Flores, J.P.C., Anghinoni, I., Cassol, L.C., Carvalho, P.C.F., Leite, J.G.D.B., Fraga, T.I., 2007. Soil physical attributes and soybean yield in an integrated livestock–crop system with different pasture heights in no-tillage. Rev. Bras. Cienc. Solo 31, 771–780.
Franzluebbers, A.S., 2007. Integrated crop–livestock systems in the Southeastern USA. Agron. J. 99, 361–372.
García-Préchac, F., Ernst, O., Siri-Prieto, G., Terra, J.A., 2004. Integrating no-till into crop–pasture rotations in Uruguay. Soil Till. Res. 77, 1–13.
Gerahty, N., Caetano-Anollés, G., Joshi, P.A., Gresshoff, P.M., 1992. Anatomical analysis of nodule development in soybean reveals an additional autoregulatory control point. J. Plant Sci. 58, 1–7.
Hati, K.M., Mandal, K.G., Misra, A.K., Ghosh, P.K., Bandyopadhyay, K.K., 2006. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India. Bioresour. Technol. 97, 2182–2188.
Haynes, R.J., Williams, P.H., 1993. Nutrient cycling and soil fertility in the grazed pasture system. Adv. Agron. 49, 119–199.
Hirata, M., Sugimoto, Y., Ueno, M., 1987. Distribution of dung pats and ungrazed areas in Bahiagrass (*Paspalum notatum* Flugge) pasture. J. Jpn. Soc. Grassl. Sci. 33, 128–139.
Hrustic, M., Vidic, M., Jockovic, Dj., 1998. Soybean Institute of Field and Vegetable Crops. Novi Sad, Yugoslavia.
Humphreys, L.R., 1994. Tropical forages: Their role in sustainable agriculture. Longman Scientific & Technical, New York, Harlow.
Iqbal, S., Mahmood, T., Tahira, M., Ali, M., Anwar, M., Sarwar, M., 2003. Path coefficient analysis in different genotypes of soybean (*Glycine max* (L) Merril). Pakistan J. Biol. Sci. 6, 1085–1087.
INMET, 2011. Monitoramento das estações automáticas, Available at: http://www.inmet.gov.br (accessed 21.12.12).
INPI, 1998. Nutrient Management for Top-Profit Soybeans, Available at: http://www.ipni.net/ppiweb/ppinews.nsf/0/2aa6a1b33813f7cb8525691c005bd1ae/$FILE/98105-NRU-Soybeans.pdf (accessed 16.09.13).
Johnston, A.E., Milford, G.F.J., 2009. Nitrogen and Potassium Interactions in Crops. The Potash Development Association, PO Box 697, York YO32 5WP, UK.
Jones, G.D., Lutz, J.A., Smith, T.J., 1977. Effects on phosphorus and potassium on soybean nodules and seed yield. Agron. J. 69, 1003–1006.
Kovacevic, V., Sudaric, A., Antunovic, M., 2011. Mineral nutrition. In: El-Shemy, H.A. (Ed.), Soybean Physiology and Biochemistry. InTech, Croatia, pp. 389–427.
Lopes, M.L.T., Carvalho, P.C.F., Anghinoni, I., Santos, D.T., Aguinaga, A.Q., Flores, J.P.C., 2009. Crop–livestock integration system: effect of oat and Italian ryegrass sward height management on soybean yield. Cienc. Rural 39, 1499–1506.
Lunardi, R., Carvalho, P.C.F., Trein, C.R., Costa, J.A., Cauduro, G.F., Barbosa, C.M.P., Aguinaga, A.A.Q., 2008. Soybean yield in an animal–crop rotation system: effects of grazing methods and intensities. Cienc. Rural 38, 795–801.
Machikowa, T., Laosuwan, P., 2011. Path coefficient analysis for yield of early maturing soybean. Songklanakarin J. Sci. Technol. 33, 365–368.
Mahmoodabadi, M.R., Ronaghi, A.M., Khayyat, M., Amirabadi, Z., 2011. Effects of sheep manure on vegetative and reproductive growth and nutrient concentrations of soybean plants under leaching and non-leaching conditions. J. Plant Nutr. 34 (11).
Mathews, B.W., Sollenberger, L.E., Tritschler, J.P., 1996. Grazing systems and spatial distribution of nutrients in pastures: soil considerations. In: Joost, R.E., Roberts, C.A. (Eds.), Nutrient Cycling in Forage Systems Symposium, Vol. 1. Columbia, MO, 7–8 March 1996. Potash and Phosphate Institute and Foundation for Agronomic Research, Manhattan, KS, pp. 213–229.
Maughan, M.W., Flores, J.P.C., Anghinoni, I., Bollero, G., Fernandez, F.G., Tracy, B.F., 2009. Soil quality and corn yield under crop–livestock integration in Illinois. Agron. J. 101, 1503–1510.
McKenzie, B.A., Hampton, J.G., White, J.G.H., Harrington, K.C., 1999. Annual crop production principles. In: White, J., Hodgson, J. (Eds.), New Zeal. Pasture and Crop Scie. Oxford Univ. Press, Oxford, pp. 199–212.
Mendes, I.C., Hungria, M., Vargas, M.A.T., 2003. Soybean response to starter nitrogen and *Bradyrhizobium* inoculation on a Cerrado Oxisol under no-tillage and conventional tillage systems. Rev. Bras. Cienc. Solo 27, 81–87.
Monteiro, F.A., Werner, J.C., 1997. Reciclagem de nutrientes nas pastagens. In: Simpósio sobre manejo de pastagem, 1997, Piracicaba. Anais. . .. FEALQ, Piracicaba, pp. 55–84.
Mott, G.O., Lucas, H.L., 1952. The design, conduct and interpretation of grazing trials on cultivated and improved pastures. In: International Grassland Congress, State College, Proc. State College, Pennsylvania, State College Press, pp. 1380–1395.
Nelson, W.L., Buckhart, L., Colwell, W.E., 1945. Fruit development, seed quality, chemical compositions, and yield of soybeans as affected by potassium and magnesium. Soil Sci. Soc. Am. Proc. 10, 224–229.
Nogueira, A.P.O., Sediyama, T., Sousa, L.B., Hamawaki, O.T., Cruz, C.D., Pereira, D.G., Matsuo, E., 2012. Path analysis and correlations among traits in soybean grown in two dates sowing. Biosci. J. 28, 877–888.
Pettigrew, W.T., 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol. Plant. 133, 670–681.
Rezaizad, A., Yazdi Samadi, B., Ahmadi, M., Zeinali, H., 2001. Relationships between yield and yield components in soybean using path analysis. J. Sci. Technol. Agric. Nat. Resour. Water Soil Sci. 5, 107–115.
Sale, P.W.G., Campbell, L.C., 1986. Yield and composition of soybean seed as a function of potassium supply. Plant Soil 96, 317–325.
Santi, A., Amado, T.J.C., Acosta, J.A.A., 2003. Black oat biomass and nutrient cycling as affected by nitrogen fertilization in soil under no-tillage. Rev. Bras. Cienc. Solo 27, 1075–1083.
SAS, 2008. SAS/STAT Software Release 9.2. SAS Institute Inc., Cary, NC, USA.
Shibles, R.M., Weber, C.R., 1965. Leaf area, solar radiation interception, and dry matter production by various soybean planting patterns. Crop Sci. 6, 575–577.
Souza, E.D., Costa, S.E.V.G.A., Anghinoni, I., Carvalho, P.C.F., Oliveira, E.V.F., Martins, A.P., Cao, E., Andrighetti, M., 2010. Soil aggregation in a crop–livestock integration system under no-tillage. Rev. Bras. Cienc. Solo 34, 1362–1374.
Sulc, R.M., Moraes, A., Alves, S.J., Pelissari, A., Carvalho, P.C., Lang, C.R., 2005. Production systems to integrate livestock grazing and grain production in southern Brazil and Midwestern USA. In: O'Mara, F.P. (Ed.), Proc. 20th Int. Grassl. Congr. Dublin, Ireland. 26 June–2 July 2005. Wageningen Acad. Publ., Wageningen, The Netherlands, p. 388.
Sulc, R.M., Tracy, B.F., 2007. Integrated crop–livestock systems in the U.S. corn belt. Agron. J. 99, 335–345.
Tate, K.W., Atwill, E.R., McDougald, N.K., George, M.R., 2003. Spatial and temporal patterns of cattle feces deposition on rangeland. J. Range Manage. 56, 432–438.
Tedesco, M.J., Gianello, C., Bissani, C.A., 1995. Análises de solo, plantas e outros materiais, 2nd ed. Universidade Federal do Rio Grande do Sul, Porto Alegre.
Teixeira, V.I., Dubeux Jr., J.C.B., Mello, A.C.L., Lira, M.A., Saraiva, F.M., Santos, M.V.F., Lira, M.A., 2012. Herbage mass, herbage rejection, and chemical composition of signalgrass under different stocking rates and distances from dung pads. Crop Sci. 52, 422–430.
Thomas, A.L., Costa, J.A., 2010. Desenvolvimento da planta de soja e o potencial de rendimento de grãos. In: Thomas, A.L., Costa, J.A. (Eds.), Soja: Manejo para a alta produtividade. Evangraf, Porto Alegre, pp. 13–33.
Tracy, B.F., Zhang, Y., 2008. Soil compaction, corn yield response and soil nutrient pool dynamics within an integrated crop–livestock system in Illinois. Crop Sci. 48, 1211–1218.
Vieira, F.T.S., 2004. Producão da pastagem de inverno, rendimento animal e produtividade da soja em integração lavoura-pecuária. Universidade Federal do Paraná (Dissertation).
White, S.L., Sheffield, R.E., Washburn, S.P., King, L.D., Green Jr., J.T., 2001. Spatial and time distribution of dairy cattle excreta in an intensive pasture systems. J. Environ. Qual. 30, 2180–2187.
Whitehead, D.C., 2000. Nutrient Elements in Grassland. CABI Publishing, Wallingford.