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Comparison of an integrated crop–livestock system with soybean only: Economic and production responses in southern Brazil

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Abstract

In Brazil, as well as globally, land use has been increasingly addressed for environmental impacts and economic improvements. Integrated crop–livestock systems (ICLSs) are a potential strategy to optimize use of land, increase total production and reduce economic risk through diversification. We compared production and economic outcomes of a soybean-only system with ICLS differing in sward management. The study area was managed since 2001 using no-till in southern Brazil. Soybean [*Glycine max* (L.) Merr.] was rotated with a mixture of black oat (*Avena strigosa* Schreb) and ryegrass (*Lolium multiflorum* Lam) either for: (i) grazing (ICLS) or (ii) cover crops as cropping system only (CS) with no livestock grazing. Four sward height management methods (10, 20, 30 or 40 cm) were evaluated under put-and-take stocking. Across years, soybean yield ($2516 \pm 103\,\mathrm{kg\,ha^{-1}}$) was not affected by treatment, but was affected by year ($P < 0.001$), due to rainfall during crop development. Cattle average daily gain, gain per hectare (GPH) and gross margin were affected by treatments ($P < 0.001$). Average daily gain was lower when pasture was managed at 10 cm than between 20 and 40 cm. With increasing sward height, a gradual reduction in cattle GPH was observed ($P < 0.05$). Overall gross margin was lower in CS than in ICLS. Economic return with ICLS was greatest when sward height management was between 10 and 20 cm. Our study indicates that ICLS could be considered an alternative management strategy that improves economic performance and promotes balanced production in the long term.

Key words: mixed systems, sward management, financial analysis, no-tillage

Introduction

Management of grassland ecosystems has been the focus of research on food production, livelihoods and ecosystem services[1], with a goal of reducing environmental impact and improving economic value of these systems. Among alternative systems, one strategy is an integrated system of crop and livestock production. Integrated crop–livestock systems (ICLSs) are a challenge for farmers because of the difficulties in managing complex interactions between grain and livestock production during different seasons in a single area. In addition to maximizing interactions between crop and livestock production, ICLSs benefit the environment by enhancing nutrient cycling[2,3], and are considered a good way to achieve sustainable intensification of agricultural systems[4].

During the 1990s, research in Europe on integrated systems focused mainly on crop production, where the use of crop rotation was successfully implemented to reduce fertilizer and pesticide use[5,6]. Recent studies have shown that the integration of cattle and pasture with a grain crop rotation increases the quantity and quality of soil organic matter in comparison to continuous cropping[7,8].

In many regions of Brazil, there are degraded pastures that could benefit from integrated systems to increase agricultural output. Southern Brazil has 6.4 million hectares annually cultivated with soybean [*Glycine max* (L.) Merr.], maize (*Zea mays* L.) and rice (*Oryza sativa* L.)[9]. In the past few years, approximately 1.1 million hectares have been cultivated with winter crops such as wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.) and barley (*Hordeum vulgare* L.)[9]. The remaining area (i.e. 5.3 million hectares) without crops in the autumn and winter seasons, represents potential income with soil being exposed or simply seeded to cover crops[10]. An ICLS is a potential strategy to increase production in these areas and reduce financial risk for farmers through diversification. Producers make decisions about adopting alternative systems based on the price outlook for products, which can fluctuate both in the short and long term. Nevertheless, farmers are generally most concerned about deviations in yield below the mean or other target values[11,12]. Therefore, investigating ICLSs using both economic and production values is a key step to assess the performance of integrated systems over specialized systems.

When a farmer decides to adopt ICLS, a relevant factor is the use of adequate grazing intensity during the pasture phase, which is a key management variable influencing sward structure. Grazing intensity affects animal performance by influencing herbage intake through modifications in sward structure[13], as well as possibly affecting crop development by physically altering surface soil or changing nutrient recycling[10].

In general, farmers often use high grazing intensities and set stocking rates greater than pasture carrying capacity, which can negatively affect both pasture and crops in the rotation[10]. Determination of an optimum stocking rate must be balanced from trade-offs among several potential outputs that may conflict[14]. There is evidence that grazing management promoting higher individual animal production (i.e. moderate grazing)[15] can also foster positive environmental outcomes[16].

The objectives of this paper were: (i) to compare production and economic outcomes from a soybean cropping system with and without cattle grazing; and (ii) to analyze different sward management strategies for ICLSs, to determine optimal sward height.

Materials and Methods

Study area

The study was conducted at Espinilho Farm (28°56′14.00″S, 54°20′45.61″W) in the state of Rio Grande do Sul, southern Brazil, between May 2001 and April 2012. The climate type is Cfa according to Köppen, humid subtropical with hot and humid summers and cool and humid winters[17]; similar climates are found in the USA, primarily in the southeast. Climate data (Table 1) were taken from a nearby station maintained by the Agricultural and Livestock Research Foundation of Rio Grande do Sul, Brazil.

The soil at Espinilho Farm is classified as Rhodic Hapludox (Oxisol) with 540, 270 and 190 g kg^{-1} of clay, silt and sand, respectively, at 0–20 cm depth. The experimental area was managed since 2001 as an ICLS using no-till. Soybean [*G. max* (L.) Merr.] was rotated with a mixture of black oat (*Avena strigosa* Schreb) and ryegrass (*Lolium multiflorum* Lam) with or without grazing. After inoculation and treatment of soybean seeds with 5,6-dihydro-2-methyl-1,4-oxathi-ine-3-carboxanilide (75 ml ha^{-1} a.i.), methyl benzimidazol-2-yl-carbamate + 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.), soybean was sown at a density of 35 seeds m^{-2} with 0.45 m between rows. Black oat was sown in rows with 45 kg ha^{-1} of seeds, while ryegrass originated annually from natural reseeding. Fertilizers were applied to both soybean and pastures annually. In areas with inoculated soybean, phosphorus and potassium were applied both before and after establishment to achieve a goal of 4 t ha^{-1} of grain yield. In the pasture phase, 45 kg N ha^{-1} of urea was applied 40 days after pasture was sown (Table 2), with the objective of developing between 4 and 7 t ha^{-1} of dry matter (DM).

Treatments and experimental design

Soybean was planted in five treatments. Cropping system only (CS) was defined as a non-grazed area, whereas ICLS consisted of four sward management heights of 10 (G-10), 20 (G-20), 30 (G-30) and 40 cm (G-40) using put-and-take stocking. This method consisted of using three tester animals per experimental unit (permanent) and a variable animal number with periodic adjustment in an attempt to maintain desired sward height[18]. Sward height was measured at 100 randomized points in paddocks every 15 days using a sward stick[19].

The experimental design was randomized blocks with three replicates, totaling 22 ha. The experimental unit areas ranged from 0.8 to 3.6 ha, according to treatments. Grazing start date generally occurred in July (Table 2) and was defined as the time when herbage mass reached 1500 kg ha^{-1} of DM. Animals used in the pasture phase were crossbreed steers that were approximately 10 months old and averaged 210 kg initial live weight. The strategy for the grazing period was for steers to graze until early November of each year, then steers were weighed [final live weight (LW)], and hauled to a commercial packing plant, where they were slaughtered for meat production.

Management of crop and livestock

Soybean yield (kg DM ha^{-1}) was determined at the R8 stage (harvest maturity) according to phenology scale developed by Fehr et al.[20]. All plants from six samples of 2 m of rows in each paddock were collected. Plant samples were air-dried, and grain was threshed and weighed.

To evaluate livestock production with ICLS under different grazing intensities, average daily gain (ADG, kg d^{-1}) and gain per hectare (GPH, kg ha^{-1}) were calculated. The ADG was obtained by measuring the difference between the initial and the final individual LW of three tester animals throughout the grazing period.

Table 1. Rainfall and mean air temperature recorded near the experiment (2001–2012).

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Study mean	55-yr mean
							Rainfall (mm)							
Jan	240	149	77	246	33	196	95	79	93	555	99	57	160	116
Feb	86	67	213	55	42	8	228	152	110	223	190	101	123	119
Mar	80	144	121	60	218	82	125	71	59	32	165	58	101	115
Apr	248	160	184	171	58	27	42	112	14	125	128	52	110	113
May	40	170	30	148	177	186	162	102	123	113	60	49	113	102
Jun	84	112	185	125	38	93	177	192	71	107	123	NE	119	117
Jul	88	213	148	120	66	87	187	37	66	209	227	NE	132	105
Aug	40	107	70	47	182	122	155	99	195	25	136	NE	107	121
Sep	121	276	100	129	145	87	217	38	273	346	46	NE	162	138
Oct	42	415	195	106	315	59	210	374	84	49	123	NE	179	135
Nov	45	174	198	147	85	116	112	85	439	59	45	NE	137	112
Dec	15	198	370	46	39	165	95	38	173	146	15	NE	118	107
Total	1129	2185	1891	1402	1400	1231	1805	1380	1702	1989	1358	NE	1588	1400
							Mean air temperature (°C)							
Jan	22.6	27.8	24.0	23.9	24.9	26.8	23.5	24.3	22.8	24.0	25.1	24.4	24.5	23.7
Feb	27.3	24.5	23.3	22.3	23.9	25.4	22.1	23.5	24.0	25.0	23.6	26.0	24.2	23.3
Mar	28.4	28.0	22.1	22.7	23.2	24.3	24.4	22.4	23.1	23.3	22.0	23.0	23.9	22.0
Apr	22.1	25.5	19.1	21.4	19.2	20.5	26.6	19.3	21.2	19.5	20.3	19.4	21.2	19.1
May	15.9	21.9	16.5	14.8	17.7	15.6	14.7	15.6	17.7	15.8	15.8	17.9	16.7	15.8
Jun	16.1	17.0	16.0	15.1	17.0	17.0	16.0	12.8	12.0	14.6	12.9	NE	15.1	13.7
Jul	15.9	16.0	13.8	11.8	13.6	16.4	11.4	16.0	11.5	13.3	13.2	NE	13.9	13.6
Aug	19.4	17.0	13.1	14.0	16.6	12.5	13.1	15.1	15.6	14.1	14.2	NE	15.0	14.4
Sep	18.2	16.3	16.3	16.7	13.9	16.1	18.7	14.6	15.8	16.5	16.3	NE	16.3	16.1
Oct	23.1	19.9	19.8	17.7	18.5	19.8	19.9	18.6	18.2	19.3	19.4	NE	19.5	18.4
Nov	23.7	21.3	21.3	19.3	21.9	21.4	20.2	22.1	24.2	20.7	21.8	NE	21.6	20.7
Dec	24.6	22.6	21.5	22.4	22.1	23.7	23.8	23.3	23.9	22.9	22.5	NE	23.0	22.6
Mean	21.4	21.5	18.9	18.5	19.4	19.9	19.5	19.0	19.2	19.1	18.9	NE	19.6	18.6

NE, not evaluated.

The GPH was obtained by multiplying the ADG by the number of animals per hectare each day.

Economic data and analysis

Monthly soybean prices (R\$ 60 kg^{-1}) and live cattle prices (R\$ kg^{-1}) in Rio Grande do Sul during May 2001 through May 2012 were obtained from the Management Planning Division (Rio Grande do Sul Emater/Ascar). Prices of inputs and operations were obtained from market places in Rio Grande do Sul. For crop inputs, the price survey was collected in November of each year, while May was used for harvesting. For livestock inputs, all values were collected in May. All information was converted into constant R\$. Domestic price series were converted from current prices in R\$ into constant R\$ using the General Price Index (averaged across Brazil cities and all items, from Fundação Getúlio Vargas). To compare the values in US\$ the long-term average conversion was made using current R\$/US\$ exchange rates (daily averages by month obtained from the Central Bank of Brazil/BACEN).

Economic performance was assessed from the five treatments on the basis of gross margin, which is widely used in economics to estimate the production potential of a farm[4,21]. This represents the net revenue (excluding fixed costs) at the farm level[22]. In both phases, gross margin per hectare was calculated as follows:

$$\text{Overall gross margin} = \sum \text{yearly products} - \sum \text{yearly costs},$$

$$\sum \text{yearly products} = \sum \text{crop products} \times (\text{soybean grains sales}) + \sum \text{livestock products} \times (\text{animal sales}),$$

$$\sum \text{yearly costs} = \sum \text{crop operating costs (desiccant} + \text{soybean seed} + \text{sowing} + \text{fertilizer} + \text{herbicide} + \text{fungicide} + \text{insecticide} + \text{application} + \text{harvesting)} + \sum \text{livestock operating costs (black oat seed} + \text{sowing} + \text{fertilizer} + \text{animal purchase} + \text{parasite control} + \text{application} + \text{holding cattle).}$$

Table 2. ICLS dates from the experiment in Rio Grande do Sul, Brazil.

ICLS period	Pasture sowing date[1]	Start grazing date	Finish grazing date	Grazing duration (days)	Soybean planting date	Soybean harvest date	Soybean growth duration (days)
2001/2002	18 May	24 Jul	05 Nov	104	10 Dec	06 May	147
2002/2003	13 May	16 Jul	13 Nov	120	17 Dec	01 May	135
2003/2004	19 May	21 Jul	07 Nov	109	NA	NA	NA
2004/2005	10 May	12 Jul	14 Nov	125	05 Dec	30 Apr	146
2005/2006	04 May	05 Jul	13 Nov	131	02 Dec	05 May	154
2006/2007	11 May	29 Jun	08 Nov	132	15 Dec	12 May	148
2007/2008	12 May	14 Jul	09 Nov	118	18 Dec	17 May	151
2008/2009	17 May	17 Jul	15 Nov	121	NA	NA	NA
2009/2010	17 May	17 Jul	30 Oct	105	17 Dec	17 Apr	121
2010/2011	30 Apr	06 Jul	02 Nov	119	27 Nov	26 Mar	119
2011/2012	19 Apr	10 Jun	07 Nov	150	16 Nov	16 Apr	152
Mean	08 May	09 Jul	08 Nov	121	09 Dec	28 Apr	141

NA, not available.
[1] The sowing date of black oat. Ryegrass originated from natural reseeding.

Crop, livestock and economic data in percentage terms

Mean values over the study period were calculated for ADG, GPH, soybean yield and gross margin. Mean values for each treatment were then transformed into percent deviation from the overall mean.

Statistical analysis

Analysis of variance was performed using mixed models (SAS Institute Inc., Cary, NC) with fixed effects for sward management, years (repeated measurements) and the interaction between sward management and year and random effects for blocks (paddocks). When differences between means were detected, treatments were compared using Tukey's HSD test at a significance level of 5%. Pearson correlation analysis was performed between climate data during crop development (December to April) and soybean yield ($P<0.05$).

Results

Total annual rainfall and its distribution varied greatly during the experimental period in comparison to the long-term average. The long-term mean annual rainfall was 1400 mm (55 years) and the study mean was 1588 mm, with a peak between September and October in both periods (Table 1). Two extreme years were 2010, with the greatest rainfall during the summer, and 2012, with the lowest rainfall. March was the driest month during the study period, with an average of 101 mm of rainfall, ranging from 32 (2010) to 218 mm (2005). The minimum and maximum average monthly temperatures during the experimental period were 13.9 and 24.5°C in July and January, respectively.

Crop phase

No difference ($P>0.05$) was observed in soybean yield between cropping system only and ICLS, nor among grazing intensities ($2516\pm103\,kg\,ha^{-1}$). There was also no interaction between sward management and experimental years ($P>0.05$). Soybean yield was affected by experimental years ($P<0.001$; Fig. 1), where higher values were observed in 2002/2003 ($3738\pm82\,kg\,ha^{-1}$), 2006/2007 ($3586\pm82\,kg\,ha^{-1}$) and 2009/2010 ($3417\pm85\,kg\,ha^{-1}$) and smallest value in 2011/2012 ($311\pm82\,kg\,ha^{-1}$). Variation in soybean yield was positively correlated with rainfall ($r=0.82$; $P<0.001$).

Livestock phase

The variables of ADG and GPH showed interactions between sward management and experimental year ($P<0.001$; Table 3). The interaction for ADG was mainly due to no differences among treatments in 2001, 2002, 2005, 2007, 2008 and 2009, and lower ADG with lower sward heights in 2003, 2004, 2006, 2010 and 2011. Considering the mean values from the study period, ADG was lower when pasture was managed at 10 cm in comparison to sward heights between 20 and 40 cm. The interaction for GPH represented a difference in magnitude of treatment effects among years, in which the strongest decline of GPH with increasing sward height occurred in 2001, 2005 and 2009. In the mean of the study period, with increasing sward heights, a gradual reduction in GPH was observed ($P<0.05$). Treatment G-10 was the least stable during the 11 years of the study, ranging between 0.663 and 1.072 $kg\,day^{-1}$ and between 314 and 612 $kg\,LW\,ha^{-1}$ for ADG and GPH, respectively. Treatment G-20 had intermediate variation, while treatments G-30 and G-40 were most stable, presenting similar values for ADG and GPH among years.

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Table 3. ADG and GPH in the long-term ICLS experiment in Rio Grande do Sul, Brazil.

ICLS period	Average daily gain ($kg\,day^{-1}$)*				Gain per hectare ($kg\,LW\,ha^{-1}$)*			
	Sward management							
	G-10	G-20	G-30	G-40	G-10	G-20	G-30	G-40
2001	0.89ABa	1.03ABa	1.11Aa	1.09Aa	480ABa	311Cb	231Abc	121Ac
2002	0.92ABa	1.22Aa	1.19Aa	1.07Aa	541ABa	537Aa	301Ab	154Ab
2003	0.73Bb	1.01ABab	1.14Aa	1.12Aa	540ABa	440ABCa	268Ab	153Ab
2004	0.73Bb	1.14ABa	1.24Aa	1.21Aa	530ABa	490ABa	321Ab	202Ab
2005	0.96ABa	1.24Aa	1.13Aa	1.10Aa	515ABa	385ABCab	288Abc	167Ac
2006	0.76ABb	1.05ABab	1.08Aab	1.15Aa	612Aa	496ABa	328Ab	175Ab
2007	0.69Ba	1.02ABa	0.95Aa	1.00Aa	428BCa	501ABa	356Aa	185Ab
2008	0.74Ba	0.94ABa	0.97Aa	0.92Aa	495ABa	419ABCa	233Ab	156Ab
2009	0.83ABa	0.89Ba	0.96Aa	1.10Aa	529ABa	390ABCab	337Abc	178Ac
2010	0.66Bb	1.01ABab	1.17Aa	1.15Aa	314Cab	375ABCa	318Aab	175Ab
2011	1.07Aab	0.82Bb	1.21Aab	1.23Aa	459ABCa	343BCab	324Aab	230Ab
Mean ± SE	0.82 ± 0.03b	1.03 ± 0.03a	1.10 ± 0.02a	1.10 ± 0.02a	495 ± 15.6a	426 ± 14.8b	300 ± 10.1c	172 ± 6.2d

Values followed by different upper-case letters in the column and lower-case in letters the row differ significantly according to the Tukey test ($P < 0.05$). *($P < 0.001$) for interaction treatment × year. Grazing at 10 cm (G-10), grazing at 20 cm (G-20), grazing at 30 cm (G-30), grazing at 40 cm (G-40).

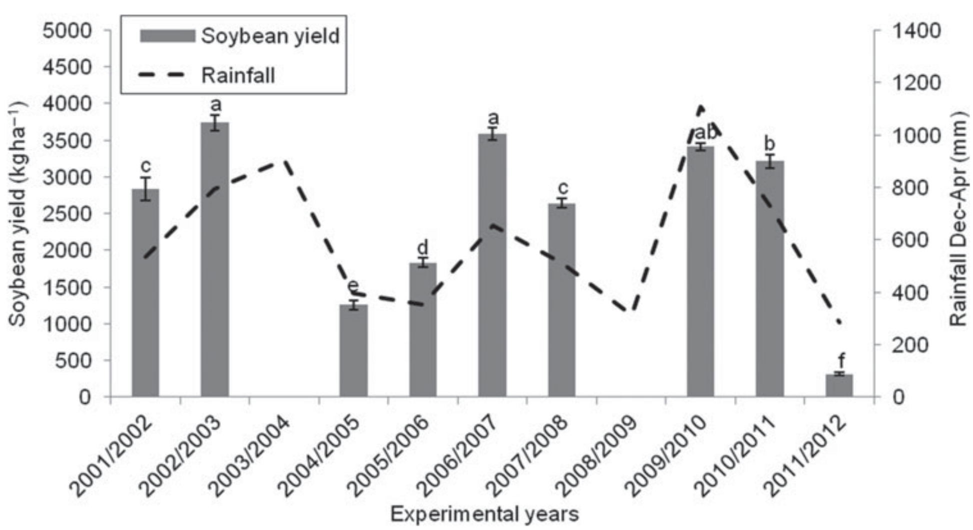

Figure 1. Soybean yield ($kg\,ha^{-1}$) and rainfall from December to April in long-term ICLS experiment in Rio Grande do Sul, Brazil.

Economic data

An interaction ($P < 0.001$) between treatments and experimental years was observed for gross margin (Table 4). There was great variability in gross margin during the study period, with higher values observed in 2002/2003, 2006/2007 and 2007/2008 and smaller values in 2004/2005, 2005/2006 and 2011/2012 (Table 4).

Considering means of the study period (Table 5), gross margin was lower in CS than ICLS ($P < 0.05$). When comparing grazing intensities, greater gross margin was observed in G-10 and G-20 than in G-30 and G-40 ($P < 0.05$). During the crop phase there were no differences in any of the economic factors among treatments. Treatment G-10 had the greatest overall operating cost per ha due to livestock operating costs ($P < 0.05$), whereas CS had the lowest overall operating cost. Regarding revenue, overall and livestock phases showed similar behavior. Livestock gross margin was superior in treatments G-10 and G-20.

Variations in treatments relative to overall mean

In percentage terms, all treatments were similar for soybean yield (Fig. 2). For GPH, treatments G-10 and G-20 had values superior to the overall mean of the long-term experiment. For ADG, treatment G-10 was inferior

Table 4. Gross margin in the long-term ICLS experiment in Rio Grande do Sul, Brazil.

	Gross margin (Brazilian real ha^{-1})*				
	Treatment				
ICLS period	G-10	G-20	G-30	G-40	CS
2001/2002	1677BCDa	1021CDEa	1354ABa	1056Aa	NA
2002/2003	2985Aab	3053Aa	2214Aab	2217Aab	1910Ab
2003/2004	NA	NA	NA	NA	NA
2004/2005	987CDEa	318DEab	−28Cab	−154Cb	−298Bb
2005/2006	623DEa	135Ea	262BCa	112BCa	−203Ba
2006/2007	2050ABCa	2119ABa	1697Aa	1621Aa	1219Aa
2007/2008	2568Aba	2451ABa	2084Aab	1948Aab	1288Ab
2008/2009	NA	NA	NA	NA	NA
2009/2010	1770BCDa	1952BCa	2095Aa	1575Aa	1146Aa
2010/2011	1418BCDa	1568BCDa	1740Aa	1958Aa	1460Aa
2011/2012	222Eab	826DEa	−117Cab	−145BCab	−434Bb

Values followed by different upper-case letters in the column and lower-case letters in the row differ significantly according to the Tukey test ($P<0.05$). * ($P=0.007$) for interaction treatment × year. 1 US$ = 2.27 Brazilian real. Grazing at 10 cm (G-10), grazing at 20 cm (G-20), grazing at 30 cm (G-30), grazing at 40 cm (G-40) and CS (cropping system only). NA, not available.

Table 5. Economic analysis in the long-term ICLS experiment in Rio Grande do Sul, Brazil.

	Financial data (Brazilian real ha^{-1})				
	Treatment				
	G-10	G-20	G-30	G-40	CS
Overall operating costs	4916a (158)	3898b (108)	3037c (89)	2276d (59)	1325e (54)
Crop operating costs	960a (50)	962a (50)	961a (53)	974a (47)	971a (39)
Livestock operating costs	3956a (126)	2936b (82)	2076c (71)	1301d (41)	354e (16)
Overall gross revenue	6466a (326)	5362b (285)	4268c (250)	3412d (209)	2071e (258)
Crop gross revenue	1953a (201)	1974a (205)	1943a (199)	2102a (209)	2071a (258)
Livestock gross revenue	4519a (186)	3382b (151)	2323c (113)	1306d (59)	–
Overall gross margin	1569a (190)	1518a (202)	1256b (188)	1133b (189)	760c (202)
Crop gross margin	994a (176)	1020a (174)	989a (167)	1135a (182)	1061a (220)
Livestock gross margin	572a (102)	407ab (85)	285b (60)	12c (44)	–

Values followed by different lower-case letters in the row differ significantly according to the Tukey test ($P<0.05$). 1 US$ = 2.27 Brazilian real. Grazing at 10 cm (G-10), grazing at 20 cm (G-20), grazing at 30 cm (G-30), grazing at 40 cm (G-40) and CS (cropping system only).

and the other treatments were similar to the overall mean of the experiment. Gross margin was superior to the mean of the long-term experiment in treatment G-10 and inferior in CS.

Discussion

Long-term grazing intensities did not influence soybean yield responses, contradicting the paradigm that grazing animals negatively impact soybean yield[23]. Use of no-till with constant presence of plants (soybean and pasture) promotes the stability of soil physical properties. Another study performed in this area showed that changes in soil physical properties observed in areas grazed at different sward heights and in the non-grazed area did not influence soybean establishment and yield[24]. In a study from Illinois[7], trampling and soil disturbance from cattle on cropland had no negative effect on subsequent corn yields and may have helped increase yield over continuous corn plots. A similar analysis found that winter grazing on corn residues had minimal effect on subsequent soybean yield[25].

Stability of soybean yield between sward management practices may be related to soybean reproductive plasticity and harvest index stability in response to variations in shoot biomass[26]. During soybean growth, rainfall and its distribution varied greatly over the period of this study (Table 1), and variation in annual soybean yield was associated with rainfall (Fig. 1). Similarly, in the

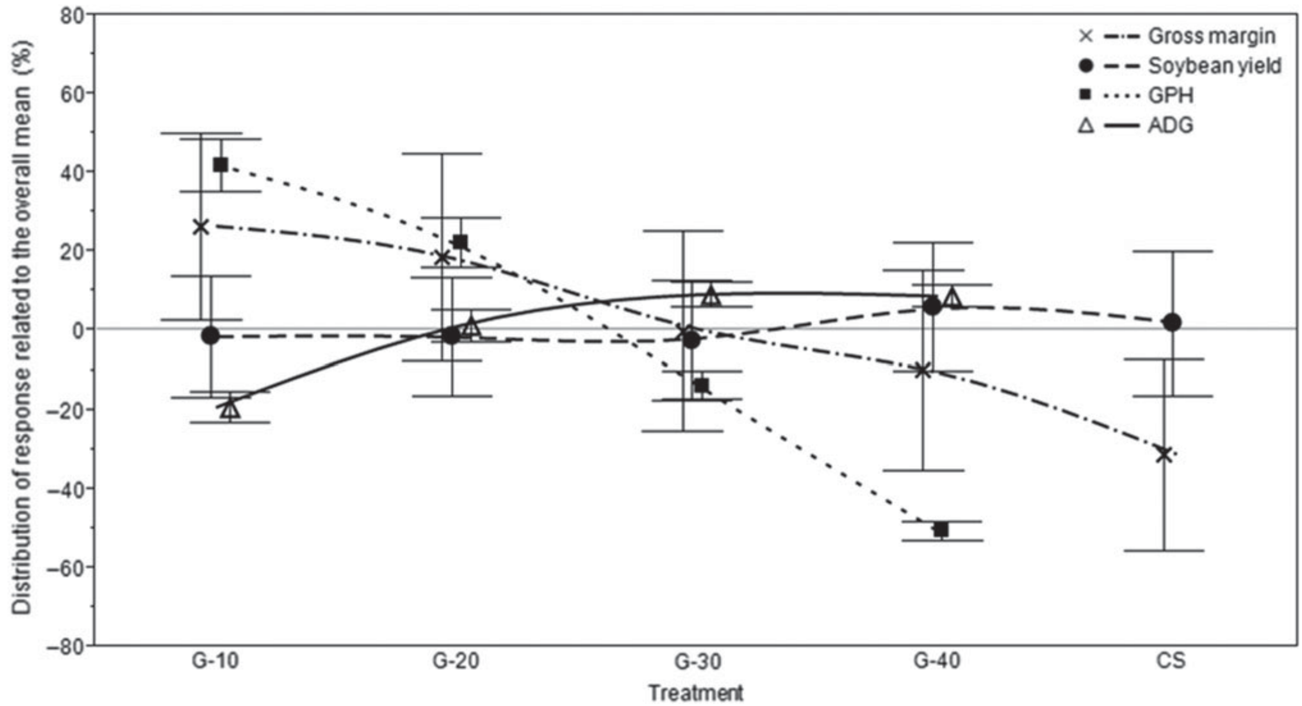

Figure 2. Influence of treatments from the overall mean (%) of gross margin, soybean yield, GPH and ADG in a long-term experiment of ICLS in Rio Grande do Sul, Brazil. Grazing at 10 cm (G-10), grazing at 20 cm (G-20), grazing at 30 cm (G-30), grazing at 40 cm (G-40) and CS (cropping system only).

main soya growing area of Argentina, soybean yield exhibited high inter-annual variation, with differences of 2000 kg ha^{-1} or more[27].

Considering livestock production, the negative relationship between ADG and stocking rate is well established[28]. Therefore, decisions concerning grazing intensity are especially important because of the close relationship between ADG and animal production per hectare[29]. When increasing grazing intensity, ADG is normally reduced, but greater beef production per unit land area is observed[30,31]. From an initial average LW of 210 kg and considering the grazing duration for each ICLS period (Table 2), G-10 had the lowest final LW (309 ± 5 kg), with increasing weights for G-20, G-30 and G-40 (average of 340 ± 5 kg). Considering the whole ICLS, it should be noted that low sward heights result in lower forage mass and therefore lower amounts of residual DM for no-till management[32]. In the other extreme, increasing sward height increases stem components and total biomass, with consequent reductions in green forage mass and nutrition value[33]. Animals can achieve greater ADG in high swards; however, GPH is significantly reduced (Table 3).

Profit is an important factor in decision making about land use, even in perception of long-term related to specific alternative practices[34]. Generally, farmers seek land use and land management to maximize profits, subject to resource constraints and subject to factors beyond their control, including input costs[22].

Land-use decision making might consider revenue from differences in yields and the probability that crop/livestock yields will be higher than specialized systems. Independent of sward height management, gross margin was greater in ICLS than cropping system only. Comparing years with rainfall during crop development (December to April) above (2002/03; 2006/07; 2009/10; 2010/11) and below (2004/05; 2005/06; 2007/08; 2011/12) the study mean (Table 1), there was a greater difference observed in gross margin between sward height treatments and CS in years with lower rainfall. Gross margin in CS was negative in three of those four years. In years with higher rainfall, gross margin in CS was positive, but still only 72 ± 11% of that in ICLS. The presence of the livestock phase was important to avoid economic loss in years with low rainfall, but important also in wet years to increase economic gain.

Mixed crop–livestock systems also generate higher economic efficiency in saving production costs through complementarities between crop and livestock[35]. The CS treatment had an operating cost with cover crop establishment (Table 5) for soil and water conservation. Therefore, ICLS may be considered a strategy to improve economic performance and promote conservation practices[36]. As for production, the combination of crops and livestock produces more food than either separately from the same area[37].

In this long-term experiment, gross margin was optimized for G-10 and G-20 treatments (Table 5), which could be considered heavy and moderate stocking rates, respectively. In Wyoming, the most profitable stocking rate in years with favorable prices was between moderate and heavy, but in years with average or unfavorable prices, the optimum stocking rate was moderate or slightly lower[38]. Environmental risks and costs increase with intensification, as does the level of disturbance and utilization of grasslands, leading to loss of soil resources which increases costs of replacing nutrients and species and in managing nutrient runoff[39].

Finally, aiming to reduce the economic dependence on single crops and specialized systems by considering grazing management in ICLS, a balance between economic and production outcomes for the system as a whole was achieved with a sward management strategy between treatments G-10 and G-20.

Conclusion

The ICLS investigated was an effective option for diversifying the soybean-cropping system. This long-term research addresses the positive influence of sward management on average daily gain, GPH and gross margin, while showing no effect on soybean yield. The optimal grazing intensity to achieve production and economic goals for this ICLS was reached at 10–20 cm sward height.

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