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Economic gains from crop-livestock integration in relation to conventional systems

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ABSTRACT - The objective with this study was to calculate the total cost of maize production and beef cattle in permanent pasture activities in separate production systems (conventional) and integrated systems (maize production plus beef cattle), as well as to verify economic gains explained by the economy of scope. The first step for the development of the research was to obtain field experimental data. Six experimental treatments were studied: corn grain production, beef cattle in permanent pasture, and four integrated systems based on different crop and pasture sowings. The second step consisted in the collection, calculation, and allocation of variable and fixed costs to estimate costs of production in the systems. The crop-livestock integration showed economic gains in relation to conventional systems, which can be explained by the dilution of fixed costs and the presence of shareable inputs, resulting in economy of scope. It was also possible to demonstrate that total unit costs of both crop and livestock were lower in crop-livestock integration, showing that integrated systems resulted in economic benefits as compared with conventional ones.

Keywords: economic analysis, economy of scope, integrated systems

Introduction

Monoculture is the prevailing system of plant and animal production in Brazil, which is based on the intense use of natural resources, chemical formulas, and nonrenewable energy. However, in the face of an imminent scarcity of natural resources, integrated production systems need to be reconsidered. There is a growing number of studies that propose methodologies to measure environmental impact and evaluate different production system settings that allow minimizing ecosystem impact (Herrero et al., 2015). In this context, crop-livestock integration (CLI) has been addressed as a promising food production system.

Different studies have demonstrated benefits of integrated systems in relation to soil properties (Franzluebbers and Stuedemann, 2008), decreased fertilizer use (Entz et al., 2002), and nutrient cycling (Hendrickson et al., 2008). Thus, it is possible to state that integrated systems can be a promising tool in face of environmental challenges (Lemaire et al., 2014). The economic efficiency of integrated systems, however, has yet to be demonstrated (Wilkins, 2008).

In the economic theory, eventual economic gains obtained by the diversification of production systems are justified by the so-called “economy of scope”, which occurs when the cost for producing two items in a given production system is lower than that when the same items are produced separately (Panzar and Willig, 1981). However, measuring and demonstrating the economy of scope in production systems are not that simple (Gameiro et al., 2016), probably due to the difficulty in calculating the cost of production of an integrated system, especially for farmers. That can be explained because there is no "default protocol" for estimating the cost of an integrated system, which means there are several manners to conceptualize costs concerning nature-related production systems.

The different possibilities of CLI system settings in relation to the implemented cultures and managements performed are challenged to demonstrate the economic advantages of this system. Although integration between maize and grass of the genus *Brachiaria* has been explored, there are not many studies exploring the type of system implementation method that leads to better productive and economic advantages. Most of the results refer to the simultaneous implementation of corn and grass seeds. However, other possibilities, such as grass sown during maize crop cover fertilization, have been little discussed in literature.

We aimed to calculate the total cost of production of crop (maize grains) and livestock (fattening of beef cattle in Marandu grass pasture) in monoculture production systems and crop-livestock integrated systems to verify eventual integrated system economic gains explained by the economy of scope.

Material and Methods

The use of the animals in the experiment was approved by the local Ethics Committee on the Use of Animals (case no. 4306220617).

The first step of the study consisted in the implementation and carrying out of a field experiment called the "base project", which originated the data to perform it. The experiment was conducted in Sertãozinho, São Paulo, Brasil, (21°08'16" S latitude, 47°59'25" W longitude, and mean altitude of 548 m), from December 2015 to December 2016.

The experimental design consisted of three randomized blocks and six treatments, two of which represented conventional systems and four represented CLI. In the treatments, maize (*Zea mays*) for grain production (crop) and *Brachiaria brizantha* cv Marandu were used for fattening beef cattle in pasture (livestock). The treatments that represented CLI were, respectively: CLI1: maize plus Marandu grass seeded simultaneously; CLI2: maize plus Marandu grass plus Nicosulfuron; CLI3: maize plus Marandu grass seeded in maize cover fertilization; and CLI4: maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron. Nicolsufuron is a systemic herbicide used in the control of grass, and it was used at a subdosis of 200 mL/ha in treatments CLI2 and CLI4, aiming to verify if it would be possible to control the growth of *Brachiaria brizantha* cv Marandu, thus diminishing its completion with maize.

In all experimental treatments, except for CLI3, the crops were sown simultaneously. The experiment was implemented in no-tillage system in December 2015. The area destined for each experimental treatment covered 0.89 ha, with a total experimental area of 16.02 ha. The terms "crop", "livestock", and "crop-livestock integration" refer to maize grain crop production, a beef cattle fattening cycle, and the production of a maize grain crop plus a cattle-fattening cycle, respectively. For the calculation of crop yield, the quantity of kilograms of grains per hectare, with 13% moisture, was converted into bags of maize containing 60 kg each. Livestock productivity was calculated from the final weight of the animals, considering 50% carcass yield. The second step was the allocation of fixed and variable costs of the experimental treatments. The crop variable cost was calculated by the addition of maize seed, planting fertilizer, cover fertilizer, preparation herbicide, other herbicides, maize seed treatment, insecticide, grain harvest, and diesel. The livestock variable cost was made up of the pasture management (cover fertilizer and diesel) and animal production (animal purchase, mineral salt, and medication). The fixed costs considered were depreciation of physical assets, labor, opportunity cost of fixed asset, and opportunity cost of land, in addition to pasture exhaustion (considering a useful life period for pasture) in the case of livestock activity.

To allocate crop-livestock integration costs, the costs of planting fertilizer and herbicide preparation were divided between the two activities, since these two inputs were necessary for the production of both. Allocation of costs between crops and livestock was essential for the calculation of the unit cost per activity in CLI systems. The cost allocation proposed is described in Table 1.

The database source to obtain production factor prices (in Brazilian currency, Real) was the Instituto de Economia Agrícola (IEA), considering a historical series (July 2007 to August 2017). Prices not found in this database were obtained in agricultural supply stores in the region of Sertãozinho. All series prices were adjusted to the inflation effect for August 2017, using the General Price Index (IGP - DI/FGV) as reference.

To calculate depreciation, an inventory of the machinery, implements, and improvements used in each experimental treatment was developed. The linear method was used to calculate depreciation, which could be accepted because of the analysis referred to one year of the production cycle, so that there is no need to consider the effect of the depreciation variation during the years; also in addition, the Brazilian Federal Government accepts the linear method for fiscal and managerial purposes of an enterprise. The IEA was the source of data to calculate labor costs. To calculate the opportunity cost of fixed asset, the corrected initial value of all production assets listed in the inventory was multiplied by a 0.5% interest rate per month and extended to a period. The opportunity cost of land was the leasing value for sugarcane activity (the most significant crop in the municipality of Sertãozinho and surrounding area), according to the IEA.

Table 1 - Allocation of production costs between treatments representing crop, livestock and crop-livestock integration (CLI)

Cost	Crop	Livestock	Crop + Livestock (CLI)
Fixed costs (US$)	Labor	Pasture exhaustion	Pasture exhaustion
	Depreciation	Grass seed	Grass seed
	Income	Planting fertilizer	Planting fertilizer (1/2)
	Opportunity cost of fixed asset	Preparation herbicides	Preparation herbicide (1/2)
	Opportunity cost of land	Diesel (pasture implementation)	Diesel (pasture implementation)
		Labor	Labor
		Depreciation	Depreciation
		Income	Income
		Opportunity cost of fixed asset	Opportunity cost of fixed asset
		Opportunity cost of land	Opportunity cost of land
Variable costs (US$/bag, US$/kg)	Cost of maize crop	Pasture management	Cost of maize crop
	Maize seed	Cover fertilizer	Maize seed
	Planting fertilizer	Diesel (fertilizer application)	Planting fertilizer (1/2)
	Cover fertilizer	Animal production	Preparation herbicide (1/2)
	Preparation herbicide	Animal purchase	Cover fertilizer
	Other herbicides	Mineral salt	Other herbicides
	Maize seed treatment	Medication	Maize seed treatment
	Insecticide		Insecticide
	Grain harvest		Grain harvest
	Diesel		Diesel (maize management)
			Pasture management
			Cover fertilizer
			Diesel (fertilizer application)
			Animal production
			Animal purchase
			Mineral salt
			Medication

The third step consisted in calculating the total cost of production of each experimental treatment so that the total unit cost of the crop and livestock could be subsequently calculated. For the calculation of the total cost of production, it was necessary to define a representative area for the extrapolation of costs related to depreciation. If this extrapolation had not been carried out, the costs of production would have been overestimated, since experimental implementation improvements would not be justifiable for a productive area such as experimental plots.

The definition of the representative area was based on the possession of a tractor similar to the one used in the base project (100 hp), since this machine is an essential production factor for a production system to be developed. The defined representative area of 75 ha was based on the Agricultural Census of 2017, which allowed to identify that, in the municipality of Sertãozinho, farms that have the largest number of 100-hp tractors are the ones that have crop areas between 50 and 100 ha (average of 75 ha).

Variable costs were calculated per hectare according to inputs used in the base project, and were extended to a 75-ha area. After this extrapolation, variable costs were added to fixed costs, resulting in the total cost of production (absorption costing method).

To verify the occurrence of the economy of scope, the following equation (1) suggested by Panzar and Willig (1975) was used:

$$C\,(a, b) < C\,(a, 0) + C\,(0, b), \qquad (1)$$

in which $C\,(a, b)$ represents the cost of production of hypothetical products (a and b) in a multi-product enterprise (crop-livestock integration), and $C\,(a, 0)$ and $C\,(0, b)$ represent the cost of production of the same products separately (conventional systems).

To calculate the total unit of cost of production (per bag of maize and per kilogram of cattle), it was necessary to adopt an apportionment criterion that would allow the calculation of the average fixed cost. The criterion for fixed cost apportionment was the quantity of final product produced (in kg). Thus, the total fixed cost of crop, livestock, and CLI treatments was divided, respectively, by the total maize yield (100% moisture), total live weight of animals (without considering a 50% yield), and the addition of total maize and live animal weight. As the objective was to verify economic gains explained by the economy of scope and this theory is based on cost of production, the revenues are not explored in this paper.

The Tukey test ($P<0.05$) was performed for the comparison of total costs and unit cost of production among treatments, based on the experimental design (three randomized blocks and six treatments). The significant level of 5% was set in all statistical analyses. Statistical analysis was performed using SAS (Statistical Analysis System, version 5.1).

Results

The analysis showed no significant difference between means of production of maize grain bags per hectare. In livestock, the results related to weight gain were more satisfactory in crop-livestock integration systems than in conventional system (Table 2). The results of crop treatment are based on just one maize production cycle and after grain harvesting, no sowing was performed. In some regions of Brazil (Southeast and Mid-west) it is possible to sow maize in March to be harvested in August (winter crop). In the present study, there would not be enough time for animal performance, in case the winter maize crop would be performed. When the objective is to make the integration crop-livestock, it is necessary that the agriculture and livestock schedule be adjusted so that both activities may occur in the same agricultural year.

The grazing period was longer in the livestock system compared with CLI. In the livestock treatment, pasture is formed faster, since there is no competition with other species. Thus, pasture was ready for animal production before, when compared with CLI systems, while in the CLI systems, it was necessary to wait for the harvest of the maize to obtain the pasture formation. It is important to emphasize that, in the CLI systems, the formation of pasture does not occur concomitantly to the maize production, since there is competition between the crops. Yet, the pasture days for livestock and CLI treatments could be explained by low nocturnal temperatures, short photoperiod, and low precipitation, which were determinant to limit the forage accumulation after the grain harvesting.

Even with the grazing period being shorter in the CLI treatments, when compared with livestock treatment, highest animal weight gains in CLI could be observed (Table 2). The reasons for higher weight of animals are due to the better quality of pasture available to the animals and to the residue of the maize harvesting (straw and corn loss, cob, derived from harvesting).

It was possible to observe that, in the treatments that represent CLI, the pasture exhaustion cost was lower when compared with the treatment that represents conventional livestock, which can be explained by the fact that the cost of preparation herbicides and planting fertilizer were apportioned among integrated system activities. The depreciation cost differed between treatments due to machine and implement particularities. A difference observed in relation to the depreciation between crop and other treatments was observed, mainly due to the physical structure required for livestock management (fixed fence, drinking troughs, and management cattle pens), which greatly impacted fixed costs in all treatments. The sum of crop total fixed costs and livestock total fixed costs resulted in a higher value than that of the total fixed costs of CLI treatments (Table 3), indicating a significant advantage of combining the two activities in a CLI system.

Table 2 - Indicators used to measure the productivity of activities

Indicator	Unit	Crop/Livestock	CLI1[1]	CLI2[2]	CLI3[3]	CLI4[4]
Harvest	bags/ha	199.53a	183.00a	201.00a	190.17a	197.67a
Stocking	animals/ha	3	2	2	2	2
Initial average weight	kg	364	417	395	412	403
Duration	days	300	50	50	50	50
Final average weight	kg	431b	456a	436ab	448a	452a
Gain per day	kg/day	0.22b	0.78a	0.82a	0.72a	0.98a

Crop: average production of maize grain bags per hectare per experimental treatment. Livestock: stocking, average initial weight, days of pasture, and final average weight per experimental treatment.
[1] Maize plus Marandu grass seeded simultaneously.
[2] Maize plus Marandu grass plus Nicosulfuron.
[3] Maize plus Marandu grass seeded in maize cover fertilization.
[4] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
a,b - Different letters mean statistically different results ($P<0.05$) by Tukey's test.
One bag of maize grain = 60 kg.

Table 3 - Items that made up the total fixed cost (US$) per experimental treatment

	Crop	Livestock	CLI1[1]	CLI2[2]	CLI3[3]	CLI4[4]
Pasture exhaustion	-	2,469.87	1,412.22	1,412.22	1,412.22	1,446.37
Depreciation	7,162.47	11,073.41	11,350.40	11,350.40	11,273.29	11,256.13
Labor	9,880.99	7,897.31	9,768.71	9,768.71	9,768.71	9,768.71
Land[5]	28,071.00	28,071.00	28,071.00	28,071.00	28,071.00	28,071.00
Capital[6]	7,725.64	10,302.05	10,973.47	10,973.47	10,894.22	10,876.58
Total FC[7]	52,840.10b	57,343.77b	60,163.58a	60,163.58a	60,007.22a	59,972.42a

[1] Maize plus Marandu grass seeded simultaneously.
[2] Maize plus Marandu grass plus Nicosulfuron.
[3] Maize plus Marandu grass seeded in maize cover fertilization.
[4] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
[5] Opportunity of land cost.
[6] Opportunity of fixed asset cost.
[7] Total fixed cost.
a,b - Different letters mean statistically different results ($P<0.05$) by Tukey's test.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

Seed and fertilizer were the costliest items in the treatment of the crop. In the treatments that represent CLI, the cost of planting fertilizer was lower as compared with that of conventional system, since it was divided between crop and livestock activities. Costs such as cover fertilizer, seed treatment, herbicides, and insecticides were similar among treatments, and variations were attributed to total production of maize bags. The cost of grain harvesting was the same in all treatments, once a percentage per bag was established for the payment of this service (Table 4).

Among the items that made up the total variable cost of livestock, animal purchase cost was the highest (Table 5). This can be explained by the initial weight of the animals in the base project. Although it is conventional to show pasture maintenance costs per hectare, these were presented here per unit (US$/kg), since this was the object of the cost in question.

Table 4 - Items of crop variable cost (US$/bag of maize grain), total production of maize grain, and crop total variable cost per production system

Harvest cost	Unit	Crop	CLI1[1]	CLI2[2]	CLI3[3]	CLI4[4]
Prepartion herbicides	US$/bag	0.24	0.13	0.12	0.13	0.12
Seed	US$/bag	1.15	1.26	1.14	1.23	1.17
Planting fertilizer	US$/bag	1.13	0.61	0.56	0.60	0.57
Cover fertilizer	US$/bag	0.94	1.03	0.93	1.00	0.95
Seed treatment	US$/bag	0.07	0.08	0.07	0.08	0.07
Other herbicides	US$/bag	0.03	0.03	0.05	0.03	0.05
Insecticides	US$/bag	0.38	0.41	0.38	0.41	0.39
Diesel	US$/bag	0.31	0.16	0.18	0.15	0.18
Grain harvest	US$/bag	0.80	0.80	0.80	0.80	0.80
Variable cost (VC)	US$/bag	5.05	4.52	4.24	4.42	4.30
Total production	bags	14,965	13,725	15,075	14,263	14,825
Total VC	US$	75,573.25a	62,037.00a	63,918.00a	63,042.46a	63,747.50a

[1] Maize plus Marandu grass seeded simultaneously.
[2] Maize plus Marandu grass plus Nicosulfuron.
[3] Maize plus Marandu grass seeded in maize cover fertilization.
[4] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
Different letters mean statistically different results (P<0.05) by Tukey's test.
One bag of maize grain = 60 kg.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

Table 5 - Items of livestock variable cost (US$/kg), total production of kilograms, and total livestock variable costs per production system

Cost item	Unit	Livestock	CLI1[1]	CLI2[2]	CLI3[3]	CLI4[4]
Cover fertilizer[5]	US$/kg	0.19	0.29	0.30	0.29	0.29
Diesel[5]	US$/kg	0.01	0.02	0.02	0.02	0.02
Animals[6]	US$/kg	2.15	2.50	2.48	2.51	2.43
Mineral salt	US$/kg	0.04	0.04	0.04	0.04	0.04
Medication	US$/kg	0.01	0.01	0.02	0.01	0.01
Total VC[7]	US$/kg	2.41	2.86	2.86	2.88	2.79
Total kg[8]	kg	48,487.50	34,200.00	32,703.75	33,750.00	33,885.00
Total VC[9]	US$	116,854.88a	97,812.00b	93,532.73b	97,200.00b	94,539.15b

[1] Maize plus Marandu grass seeded simultaneously.
[2] Maize plus Marandu grass plus Nicosulfuron.
[3] Maize plus Marandu grass seeded in maize cover fertilization.
[4] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
[5] Pasture management.
[6] Animal purchase.
[7] Total variable costs per kilogram.
[8] Total production of kilograms.
[9] Total variable cost.
a,b - Different letters mean statistically different results (P<0.05) by Tukey's test.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

The total cost of production of the treatments that represent crop and livestock differs statistically from each other, in addition to differing from the total cost of production of other treatments. The difference of the total cost of production between the treatments may be explained by the superior fixed costs, as well as by the variable costs, since for the development of the integrated system, there were varied costs related to the vegetable and animal production. Statistically, the total cost of production of the livestock was inferior compared with the total cost of production of the CLI systems, but superior, when compared with the crop. The highest variable costs of livestock treatment may be explained by the purchase of animals.

From the total cost of production, it is possible to validate the hypothesis that CLI showed economic gains in relation to conventional systems. These gains can be justified by the theory of the economy of scope, since the sum of the total cost of production of treatments that represented conventional systems (crop + livestock) resulted in a higher value than that of the total cost of production of any of the CLI treatments (Table 6).

As there were no statistical differences between the total costs of production of the treatments that represented CLI to demonstrate the other results, the CLI4 treatment was chosen to represent the integrated systems for the demonstration of other results to focus the discussion of the present study on its central issue: monoculture versus crop integration. The CLI4 treatment was selected because it provided better results related to pasture production and growth during the evaluated period.

The average fixed cost demonstrates the cost to produce one kilogram of the product of interest (whether maize grain or fat cattle). This cost was lower in the crop treatment, since the total fixed cost of this treatment was also lower. Although the total fixed cost of CLI4 was higher compared with the livestock treatment, the average fixed cost of this treatment was lower, since the total amount of CLI4 produced was higher (maize and cattle) (Table 7).

Table 6 - Fixed costs (FC), variable costs (VC), and total cost of production (TC) per experimental treatment (US$)

Cost	Crop	Livestock	CLI1[1]	CLI2[2]	CLI3[3]	CLI4[4]
FC	52,840.10	57,343.77	60,163.58	60,163.58	60,007.22	59,972.42
VC_C[5]	75,614.85	-	61,986.38	63,851.70	63,037.08	63,810.06
VC_L[6]	-	116,731.34	97,766.43	93,464.83	96,784.82	94,653.17
TC	128,454.95c	174,075.11b	219,916.39a	217,480.11a	219,829.12a	218,435.64a

[1] Maize plus Marandu grass seeded simultaneously.
[2] Maize plus Marandu grass plus Nicosulfuron.
[3] Maize plus Marandu grass seeded in maize cover fertilization.
[4] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
[5] Total crop variable cost.
[6] Total livestock variable cost.
a-c - Different letters mean statistically different results ($P<0.05$) by Tukey's test.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

Table 7 - Total fixed cost (US$), total maize and cattle production (kg), and average fixed cost (US$/kg) per experimental treatment

Item	Unit	Crop	Livestock	CLI4[1]
Total FC[2]	US$	52,840.10	58,588.86	61,350.98
Maize production[3]	kg	1,032,052	-	1,022,431
Cattle production[4]	kg	-	96,975.00	67,800.00
Total production	kg	1,032,052	96,975.00	1,090,231
Average FC[5]	US$/kg	0.05	0.60	0.06

[1] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
[2] Total fixed cost.
[3] Total maize production (100% moisture).
[4] Total cattle production.
[5] Average fixed cost.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

Table 8 - Average fixed cost, variable cost, and total unit cost of the crop and livestock in the conventional system and crop-livestock integration (CLI)

Unit	Conventional		CLI4[1]	
	Crop	Livestock	Crop	Livestock
	US$/bag	US$/kg	US$/bag	US$/kg
Average FC	3.00	0.60	3.60	0.06
VC[2]	5.05	2.41	4.30	2.79
Average TC	7.91a	3.61a	7.61b	2.85b

[1] Maize plus Marandu grass seeded on maize rows and interrows plus Nicosulfuron.
[2] Variable cost. To calculate the average fixed cost per bag, the average fixed cost per kilogram was multiplied by 60 considering the weight of the maize bag.
a,b - Different letters mean statistically different results (P<0.05) by Tukey's test.
One bag of maize grain = 60 kg.
The exchange rate of US$ 0.3119 = R$ 1.00 is suggested.

The costs of production of a maize bag and a kilogram of beef were statistically lower in the CLI than in the conventional system (Table 8).

Discussion

The lack of homogeneity in the methodological procedures for the calculation of cost of production is a challenge for studies that propose to compare production systems based on economic evaluations (Gameiro, 2009). In this sense, one of the most relevant contributions of this study was the demonstration of a model for the calculation of the cost of production of both crop and livestock, when these activities are practiced in an integrated way.

The proposal to share the cost of production between crop and livestock was an essential step to calculate the cost of the activities separately in integrated systems. It was suggested that the cost resulting from the factors of production that benefit both systems be divided among the activities. In the present study, these production factors were preparation herbicides and planting fertilizers, since the application of these supplies aims at the improvement of soil quality, which, consequently, would benefit the crops implemented in the location

Among the crop variable costs, maize seed and planting and cover fertilizers were the most expensive items. This result is in agreement with that found by Garcia et al. (2012) in an economic analysis of maize grain yield associated with forages in a no-tillage system. Among the variable costs of livestock, the purchase of animals for fattening was the item with the greatest impact, as demonstrated by Sartorello et al. (2018).

It was possible to demonstrate the economic gain of the CLI systems as contrasted to conventional system by the economy of scope, because the sum of the total cost of production of treatments that represented conventional systems (crop + livestock separated) resulted in a higher value than that of the total cost of production of any of the CLI treatments. According to literature, economy of scope is observed when added unit costs of production are lower than when there is separate production (Panzar and Willig, 1981; Teece, 1982; Leathers, 1992; Chavas and Kim, 2007).

The dilution of fixed costs was one of the items of the economy of scope detected in this study, since the physical structure (depreciation cost and opportunity cost of fixed asset), labor, and productive area (opportunity cost of land) were used for the production of maize grain and cattle in the experimental treatments that represented CLI. In crop and in livestock treatment, the total fixed cost is paid by the income generated by grains and animal production, respectively, while in CLI, this cost is covered by the income generated by two products of commercial interest, which means that this cost is diluted between the activities. Baumol et al. (1982) and Chavas and Kim (2007) mentioned the occurrence of fixed costs as a necessary condition for the economy of scope to occur.

Leathers (1992) argued that fixed costs can only be a source of short-term economies of scope, assuming that all costs are variable in the long run. It is postulated, therefore, that in the long term, the economic benefit of CLI would continue to be justified by the economy of scope, based on the so-called "technical complementarity" source. This source of the economy of scope occurs because, in integrated systems, agriculture and livestock have shared technologies, which results in the dilution of costs between activities. Baumol et al. (1982), Gorman (1985), and Leathers (1992) mentioned technical complementarities as sources of economies of scope. Planting and cover fertilizers can be cited as examples of shareable inputs as they benefit both maize and pasture. The allocation of planting fertilizer and preparation herbicide costs were different between conventional and CLI treatments (Table 1), which is an example of technical complementarity source. This allocation of production costs was determinant for the sum of the total cost of production of conventional treatments to have a higher total production cost than CLI treatments. The mutual benefit could be demonstrated by the fact that maize production did not differ statistically between monoculture and integrated treatments.

Land is an important example to demonstrate empirically the economy of scope in the present study. Although the opportunity cost of land was equal for all treatments, in the CLI, the same area was used for agriculture and livestock production, demonstrating an economic advantage when compared with conventional systems. Land could be mentioned as a source for the dilution of fixed costs and technical complementarity, the two main sources of economy of scope (Baumol et al., 1982; Gorman, 1985; Leathers, 1992; Chavas and Kim, 2007).

Although long-term effects have not been evaluated in this study, it is possible to suggest the existence of eventual environmental gains mentioned as CLI long-term benefits (Russelle et al., 2007; Sanderson et al., 2013; Lemaire et al., 2014). These can be an important source of economies of scope, such as nutrient cycling, as evidenced by Gameiro et al. (2016). Corn straw, which remains in the system after the grain is harvested, as well as animal excrement, are important sources of nutrients, which will contribute to the improvement of soil fertility in the long run. The improvement of the chemical, physical, and biological quality of the soil represents the possibility of increased crop productivity, reduced fertilizer use (Lemaire et al., 2014; Salton et al., 2014), and lower expenditure on non-renewable energies (Russelle et al., 2007), which results in a lower cost of production.

Poffenbarger et al. (2017) compared, from an economic point of view, specialized grain production systems and integrated systems (grains plus livestock) in the Corn Belt area (USA) between 2008 and 2015. The authors concluded that initial investments in integrated systems were higher, which can be accounted for by animal production and labor costs. However, in the long run, these systems showed a more satisfactory economic return than monoculture systems, which could be explained by an increase in crop productivity in association with the environmental benefits obtained by this type of system.

It could be considered that studies of this nature should be carried out for more than one productive year, since crop and livestock results are related to soil and climate, which may vary between years of production. However, the results of this study are an initial approach, which allows a first argument about the economic benefits of CLI systems in relation to conventional systems. Longer-term experiments should be encouraged.

The apportionment of fixed costs (Table 7) was a necessary step for the calculation of the total cost per bag of maize and per kilogram of cattle produced. The difficulty in relation to fixed cost estimates, as well as their apportionment, is the reason why fixed costs are ignored or partially considered in many economic analyses, as in the study by Retallick et al. (2013). No study has been found in the literature comparing different methods of apportioning fixed costs in agricultural activities. The criterion of apportionment by the quantity of kilograms produced seems a feasible alternative, since it demonstrates the allocation of the total fixed cost according to the productivity capacity of each system.

The calculation of unit costs per maize bag and kilogram of beef (Table 8) was a fundamental step so that the economic benefits of CLl could be justified. Without a detailed demonstration of the costs related to each of the activities involved in the integration, the claim that CLI systems are economically viable may be misleading, once the economic advantage of one of the activities may conceal the economic inefficiency of an activity integrated to it. In the present study, both the cost of cultivation and of cattle raising were lower in the CLI as compared with the cost of the same activities in a conventional system.

There was no statistical difference between crop yield (bags/ha) in crop and CLI treatments. However, the livestock indicator (gain of kg/day) indicated better performance of CLI treatment compared with the livestock treatment. Thus, it is possible to claim that the yield is a relevant indicator; however, this indicator is not sufficient to conclude that there is an economic advantage of such activity on commercial farms, and this indicator must be analyzed together with cost of production.

Finally, due to the theoretical referential covered in this study (economy of scope), the analysis variable is the cost of production. Therefore, it was considered that when costs were lower (which was demonstrated in the results, in relation to CLI systems) in a *ceteris paribus* condition (which means all other variables were kept constant), independently of eventual differences of prices and of revenues, it may mention “economic gain”.

Conclusions

Crop-livestock integration shows economic gains in relation to conventional systems, which can be explained by the dilution of fixed costs and the presence of shareable inputs, which result in economies of scope. In addition, it has been demonstrated that the total unit costs of the crop, as well as livestock, are lower in CLI, reinforcing the idea that integrated systems result in economic benefits as compared with conventional systems. It is possible that CLI economic gains, as compared with conventional systems, have been underestimated in this study, considering the short evaluation period. It is recognized that for more conclusive results, longer periods of evaluation are necessary. However, the results of this study are the first indicators of the economic advantages related to the CLI systems. In addition, the present study contributes by suggesting a method of analysis to demonstrate the economy of scope theory in Animal Science.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: G.G. Mendonça and A.H. Gameiro. Data curation: F.F. Simili. Formal analysis: F.F. Simili. Funding acquisition: F.F. Simili. Investigation: G.G. Mendonça, F.F. Simili and A.H. Gameiro. Methodology: F.F. Simili and A.H. Gameiro. Project administration: G.G. Mendonça, F.F. Simili, J.G. Augusto, P.M. Bonacim and L.S. Menegatto. Software: G.G. Mendonça. Supervision: F.F. Simili and A.H. Gameiro. Validation: G.G. Mendonça, F.F. Simili, J.G. Augusto, P.M. Bonacim and L.S. Menegatto. Writing-original draft: G.G. Mendonça, F.F. Simili and A.H. Gameiro. Writing-review & editing: G.G. Mendonça, F.F. Simili and A.H. Gameiro.

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