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The economic value of sustainability of the integrated crop-livestock system in relation to conventional systems

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ABSTRACT - The objective of this study was to evaluate the potential of improving the economic value of integrated crop-livestock systems (ICLS) compared to conventional systems specialized in monoculture. The experimental area was 16.02 ha, divided into 18 paddocks of 0.89 ha each, organized in a randomized block design, with three replicates and six models of production systems: crop system [corn (*Zea mays*) grain production], livestock system (beef cattle under grazing conditions), and four ICLS, identified as: ICLS-1, corn integrated with Marandu palisadegrass [*Urochloa brizantha* (Hoechst. ex A. Rich.) R.D. Webster cv. Marandu (syn. *Brachiaria brizantha* cv. Marandu] sown simultaneously without herbicide; ICLS-2, corn and Marandu palisadegrass sown simultaneously with herbicide; ICLS-3, corn and Marandu palisadegrass with lagged sowing; and ICLS-4, corn and Marandu palisadegrass sown simultaneously, with herbicide in rows and between-rows of corn. We demonstrated the economic impact analysis combined with the risk optimization and discounted cash flow techniques based on Monte Carlo simulation, considering price and productivity uncertainties. The indicators of added value and return on investment of ICLS had an economic advantage compared with conventional systems. It was also found that ICLS needed a smaller operational area than conventional systems for the economic break-even point. Integrated systems provide lower financial and operational risk levels and greater economic value per hectare compared with conventional systems specialized in monoculture.

Keywords: agriculture, beef cattle, economy, intercropping

1. Introduction

A conventional system (CS) is based on the intense use of agricultural machinery, supply of nutrients and pest control trough chemical products, and non-renewable energy sources to achieve high crop productivity (Foley et al., 2011). Although CS has provided satisfactory crop gains and food security (Foley et al., 2011; Reis et al., 2020), this type of system has been linked to biodiversity decline and negative environmental impacts on ecosystems around the world, questioning the feasibility of alternative agricultural production models (Hunt et al., 2016; Moraine et al., 2016; Branca et al., 2021).

Research has addressed possibilities for measuring environmental problems, as well as different settings of agricultural systems that can decrease those impacts, while still producing sufficient food at viable economical returns (Herrero et al., 2015; Reis et al., 2020). The integration of plants and animals are focused by science as an alternative for producing sustainable and economically viable food (Gil et al., 2015; Florindo et al., 2020; Branca et al., 2021).

Research has already shown benefits of integrated crop-livestock systems (ICLS), when compared to CS, concerning physical, chemical, and biological soil properties (Olson et al., 2017; Ryschawy et al., 2017), nutrient cycling, natural control of invasive plants, and, consequently, the lesser dependency of chemical products (Tully and Ryals, 2017; Schuster et al., 2019). Thus, there is potential of ICLS to help mitigate environmental impacts, demonstrating the sustainability and resilience of this type of system (Ryschawy et al., 2013; Lemaire et al., 2014). However, there is an information gap: proof of the economic efficiency of ICLS (Wilkins, 2008; Rego et al., 2017; Rosa-Schleich et al., 2019; Sneessens et al., 2019; Reis et al., 2020).

We aimed to examine the effects of diversifying the production with an ICLS on production risk compared to the CS. The productive and market risks were controlled using a Monte Carlo simulation. With the discounted cash flow (DCF) method, we determined net present value, return on investment, and the break-even point (Nordblom et al., 2021). This methodological approach expands on recent results obtained in other studies (Mendonça et al., 2020; Reis et al., 2020), indicating that the economic benefits and conditions of production systems are viable.

2. Material and Methods

2.1. Experimental period and site description

The experiment was conducted from November 2015 to January 2018 in Sertãozinho, São Paulo state, Brazil (21°8'16" S and 47°59'25" W). The average local altitude is 548 m. The regional climate, according to the Köppen classification, is Aw, characterized as humid tropical, with a rainy season in summer and dry season in winter. The soil of the experimental area is classified as very clayey dystrophic Red Latosol (Santos et al., 2018), equivalent to the Oxisol under the United States Department of Agriculture soil classification (Soil Survey Staff, 2014). The production areas were not irrigated.

2.2. Production systems models

The experimental area was 16.02 ha, divided into 18 paddocks of 0.89 ha each, organized in a randomized block design, with three replicates and six models of production systems: crop system [corn (*Zea mays*) grain production], livestock system (beef cattle under grazing conditions), and four ICLS, identified as: ICLS-1, corn integrated with Marandu palisadegrass [*Urochloa brizantha* (Hoechst. ex A. Rich.) R.D. Webster cv. Marandu (syn. *Brachiaria brizantha* cv. Marandu] sown simultaneously without herbicide; ICLS-2, corn and Marandu palisadegrass sown simultaneously with herbicide; ICLS-3, corn and Marandu palisadegrass with lagged sowing; and ICLS-4, corn and Marandu palisadegrass sown simultaneously, with herbicide in rows and between-rows of corn. All production systems were implanted in December 2015 under no-tillage systems.

The crop-livestock integration in Brazil has corn production as one of the main alternatives for this system (Gil et al., 2016). In addition, the country is the largest exporter and the third-largest global producer of corn (FAOSTAT, 2019), which reinforces the importance and representativeness of the scope of products (corn and beef) in this research.

In the crop system, Pioneer P2830H corn was sown at 75 cm spacing between-rows, at a seeding density of 70,000 plants ha^{-1}. At the time of sowing, 32 kg ha^{-1} N (as urea), 112 kg ha^{-1} P_2O_5 (as simple superphosphate), and 64 kg ha^{-1} K_2Cl (potassium chloride) were applied. In addition, 80 kg ha^{-1} N (as urea) and 80 kg ha^{-1} K_2Cl (potassium chloride) were applied to corn, 20 days after sowing (second fertilization). Corn was planted in two consecutive years (December 2015 and December 2016), providing two harvests of corn grains (May 2016 and 2017). The field was left fallow between harvests.

For the livestock system, Marandu palisadegrass was sown at 37.5 cm spacing between-rows, at a seeding density of 5 kg ha^{-1} (76% viable seeds). Marandu palisadegrass seeds were then mixed within the fertilizer: 32 kg ha^{-1} N (as urea), 112 kg ha^{-1} P_2O_5 (as simple superphosphate), and 64 kg ha^{-1} K_2Cl (potassium chloride). In addition, 40 kg ha^{-1} N (as urea), 10 kg ha^{-1} P_2O_5 (as simple superphosphate), and 40 kg ha^{-1} K_2Cl (potassium chloride) were applied to the pasture in October 2016 and March 2017. Ninety days after sowing, animals started the grazing period (March 2016), where three continuous stocking cycles were performed: the first cycle between March and April 2016 (30 days), the second between August and October 2016 (78 days), and the third between November 2016 and December 2017 (370 days).

For the integrated systems, the same cultivars, row spacings, seeding densities, and fertilizers as for crop system and livestock system were used. For ICLS-1, Marandu palisadegrass was sown simultaneously with corn in the sowing row. For ICLS-2, simultaneous sowing was also performed, but 20 days after corn germination, 200 mL ha^{-1} of the herbicide nicosulfuron (8 g ha^{-1} of active ingredient) were applied. For ICLS-3, Marandu palisadegrass was sown 20 days after corn had been sown (lagged sowing). For ICLS-4, Marandu palisadegrass and corn were sown simultaneously, but with the grass seed sown within and between corn rows, resulting in 37.5 cm row spacing. Exclusively for this system, the fertilizer and grass seeds were mixed and applied in the row and between rows of corn, to guarantee an equal mixture of grass seed and fertilizer in the entire system. In addition, 200 mL ha^{-1} of the herbicide nicosulfuron (8 g ha^{-1} of active ingredient) was also applied 20 days after corn germination for this system. In all integrated systems, corn was harvested in May 2016, and 90 days after harvest, animals started the grazing period, where two continuous stocking cycles were performed: the first cycle between August and October 2016 (78 days), and the second cycle between November 2016 and December 2017 (370 days).

For the economic analyses, two years of data were used, considering the results of the first corn harvest (in 2016), weight of the animals, and stocking rate of the first and second grazing cycles (August to October 2016 and November 2016 to December 2017, respectively).

2.3. Animals

The continuous stocking method with a variable stocking rate (put and take) was used, according to Mott (1960), in the livestock system and all integrated systems. Caracu beef steers (14 months old; 335±15 kg live weight) were used, and carcass yield was considered 50% (Canesin et al., 2006) for the economic analyses. The Caracu breed (*Bos taurus taurus*) was introduced in Brazil during the 17th century and is considered the most adapted taurine breed to the Brazilian tropical climate (Pires et al., 2019). It is one of the main taurine breeds in Brazil and, even though it is not the most expressive breed in production systems, its use in the central region of the country is relevant (Souza et al., 2022). We chose this breed for this research because of its great potential to produce meat, excellent rusticity, and qualitative meat characteristics differentiated from other common breeds (Queiroz et al., 2005).

Different studies have demonstrated that the Caracu breed can present a productive performance similar to other species, including Nelore, the main breed in Brazil (Mendonça et al., 2021; Resende et al., 2014). Economic information regarding the results of this breed in the country is scarce (Mendonça et al., 2020). Exploring the productive and economic results of different bovine breeds is important to expand the volume of information on the multiple possibilities of production systems, including to value the diversification necessary for a continental country with structural and environmental differences in its regions (Souza et al., 2022).

2.4. Economic analyses

The economic analyses were performed using the DCF, the most traditional and robust method for analyzing investments in the agricultural context (Rezende and Richardson, 2015; Faleiros et al., 2018; Montoro et al., 2019). Among the primary techniques, the DCF better reflects the financial impact of investment decisions during a specific time (Danthine and Donaldson, 2014). Thus, from the DCF analysis structure, it is possible to build different indicators, such as net present value (NPV), internal rate of return (IRR), return on investment (ROI), payback, break-even-point (BEP), among others. These indicators are addressed to different types of investments and information needs (Faleiros et al., 2018). In the current study, we calculated NPV, ROI, BEP, and annualized cash flows (ACF), to allow for long-term analyses. The calculations are in the sequence from the DCF structure (Equation 1).

$$DCF = \sum_{j=1}^{n} \frac{ACF_j}{(1+i)^t} \quad (1)$$

in which i = interest and t = time.

In this study, we calculated the free cash flow (FCF) to allow the flow structure to be adapted to the Brazilian tax context (Faleiros et al., 2018, Farinelli et al., 2018).

(+) Gross revenue

(-) Taxes on income

(=) Net revenue

(-) Variable costs

(=) Contribution margin (CM)

(-) Fixed costs

(=) Earn before taxes, interest, depreciation, and amortization (EBTIDA)

(-) Depreciation

(=) Profit before taxes (PBT)

(-) Tax

(+) Depreciation

(=) Operational cash flow (OCF)

(-) Investment flow

(=) Free cash flow

The operational and productive parameters and market information were used to construct cash flow variables. The study extrapolated the results to a 75 ha-property, which is the modal profile of the study region (Faleiros et al., 2018; Farinelli et al., 2018). The study controlled for uncertainties in price and productivity of corn and beef using the Monte Carlo simulation, considering 10,000 possibilities for each production system (Oliveira and Medeiros Neto, 2012), and the assumptions regarding the volatility of these variables (Table 1). The researchers consulted all commercial values related to costs and investments with companies in the area and compared them with market information consolidated by IEA (2019).

The prices and movement of corn and beef were based on the Brazilian Stock Market and Futures Exchange (B3) numbers from January 2004 to December 2016, with recorded values combined to give an average value of R$ 38.14 for a 60-kg bag of corn, and R$ 152.31 for each arroba (15 kg carcass weight), with 17.32 and 9.33% being the respective coefficients of variation (CV). These values reflect the reality of the country, as B3 is the only futures exchange in Brazil.

Table 1 - First and second year production results for the empirical study system field trials

System[1]	Year 1					Year 2				
	Corn (t/ha)			Beef (arroba)		Corn (t/ha)			Beef (arroba)	
	Mean	Min	Max	Mean	CV (%)	Mean	Min	Max	Mean	CV (%)
Crop	12.02	9.93	14.53	NA	NA	9.02	7.45	10.90	NA	NA
Livestock	NA	NA	NA	46.02	5.33	NA	NA	NA	98	29.00
ICLS-1	11.01	9.52	12.49	33.13	7.15	NA	NA	NA	100	5.67
ICLS-2	12.46	10.88	14.04	29.07	9.40	NA	NA	NA	100	4.40
ICLS-3	11.10	8.80	13.54	30.50	8.27	NA	NA	NA	103	8.43
ICLS-4	12.16	9.68	14.68	30.12	6.31	NA	NA	NA	100	6.22

CV - coefficient of variation; NA - not avaliable.

[1] Crop system: corn grain production; livestock system: beef cattle under grazing conditions; ICLS-1: corn and Marandu palisadegrass sown simultaneously, without herbicide; ICLS-2: corn and Marandu palisadegrass sown simultaneously, with herbicide; ICLS-3: corn and Marandu palisadegrass in lagged sowing; ICLS-4: corn and Marandu palisadegrass simultaneously sown in corn rows and between-rows, with herbicide.

The possibilities of corn and beef prices and beef productivity were generated using a normal distribution pattern, following identification of normality via a Jarque-Bera test (P-value > 0.05). A discrete distribution pattern was used for corn productivity using the average, minimum, and maximum values from the crop system, ICLS-1, ICLS-2, ICLS-3, and ICLS-4 systems. It should be noted that the volatilities used were considered independent, since the correlation between price variations of corn and beef was 0.27 and without statistical significance (P-value < 0.05).

The current study divided total costs into fixed and variable costs. Fixed costs included labor, management, insurance, maintenance of machinery, and taxes and fees (a guide to the breakdown of these costs can be found in Mendonça et al., 2020). Variable costs of corn production included expenses with soil preparation, planting, crop management, and harvesting activities. Variable costs for meat production included expenses with purchase of animals, veterinary care, and drugs. Non-financial costs, such as depreciation, were treated separately, to avoid impact on cash flow and obtain the tax benefit allowed under the Brazilian law.

For all analytical economic criteria, it was necessary to determine the annual cash flow of each production system, using the DCF determined in the two years of results. Equation 2 shows the annual cash flow calculation based on a current value.

$$ACF = \frac{DCF \times i}{1 - (1 + i)^{-t}} \tag{2}$$

Net present value determination used investment profiles specific to each production system. Thus, land value was not considered in the analysis for three reasons: land cost is not financial, thereby it does not impact the cash flow, and its use biases the analysis by the DCF methodology; the investment in land constitutes a sunk cost, so the analyzes must be guided in the choice of the production system that maximizes the value for this investment; and as the land size is the same for the production systems, there are no marginal differences. The calculation is shown in Equation 3 (Farinelli et al., 2018):

$$NPV = \sum_{j=1}^{n} \frac{OCF_j}{(1 + i)^t} - I_0 \tag{3}$$

The strategy to quantify each production system was the perpetuity valuation. The calculation is shown in Equation 4:

$$Valuation = \frac{ACF}{i} \tag{4}$$

The added value represents the surplus obtained by a producer who decides to invest in one of the studied production systems. It considers all the necessary investments, including land. For the calculation of the added value of each production system, Equation 5 was used:

$$Added\ value = Valuation - Total\ investment \tag{5}$$

As investment decisions in productive assets in agriculture do not have the exact requirements as for assets traded in enormously efficient markets, such as liquidity, information symmetry, dispersion between agents with supply and demand for capital, it was considered appropriate to analyze not only the added value, but the inclusive profitability of each investment. This allowed for comparison with other investment opportunities (Nordblom et al., 2021). Therefore, ROI was used as an indicator, using Equation 6 (Farinelli et al., 2018).

$$ROI = \frac{Annual\ OCF}{Total\ investment} \tag{6}$$

The proposed cash flow calculation structure allows the calculation of the break-even point for the operation area of each production system (Equation 7) (Farinelli et al., 2018). This indicator has been generally ignored in agribusiness economic feasibility studies. However, besides being highly relevant to producers, it can help to indicate the viability of forms of investment that require less use of land and can contribute to a reduction in the process of land concentration and, consequently, increase the sustainability of small- and medium-scale rural producers (Faleiros et al., 2018).

$$BEP = \frac{\sum_{j=1}^{n} \frac{Fixed\ costs_j}{(1+i)^t} + Total\ investment}{\sum_{j=1}^{n} \frac{Contribution\ margin\ per\ ha_j}{(1+i)^t}} \tag{7}$$

The BEP becomes an essential tool for small farmers in the planning process of their production system. Producers need to know if their production area is capable of making the chosen system viable. When the decision process ignores this information, the lack of economic viability causes liquidity problems supported by debt or partial or total sale of the land.

When determining production system discount rates, it was decided that rates should express the risk inherent to each system (as is generally modeled in the literature). Accordingly, the Capital Assets Pricing Model (CAPM) calculation structure was performed using Equation 8 (Montoro et al., 2019).

$$CAPM = i = R_f + \beta_s(R_m - R_f) \tag{8}$$

in which R_f = risk-free rate, β = systematic risk, and R_m = return on market portfolio.

For the risk-free rate, the Selic rate that backs Brazil's national treasury bills for January 2019 was used (when net remuneration was estimated at 6.4% per year). The historical difference used by market analysts of 8.2% per year for the Brazilian market premium ($R_M - R_f$) was used (Fernandez et al., 2019).

The risk of each production system was estimated considering the historical volatility of corn and meat prices on the crop and livestock system, respectively. In contrast, for the ICLS, the risk was calculated based on the risk of a portfolio, in which returns also vary, according to Equation 9 (Farinelli et al., 2018).

$$\sigma_{m,b} = \sqrt{\{[(w_m^2 \times \sigma_m^2) + (w_b^2 \times \sigma_b^2) + 2 \times w_m \times w_b \times COV_{m,b}]\}} \tag{9}$$

in which w = weight of each asset (corn or beef) within the total system revenue; and σ = risk, measured by the standard deviation in price changes for each product (corn and/or beef).

Equation 9 allowed the determination of risk for each production system (even for those with more than one product). This enabled the evaluation of the effect of diversification of the system on the risks involved, which aggregates the effects of covariance between corn and beef individual risks. From this, the risk for each system was related to the Ibovespa-based risk, in which β = 1, enabling to estimate β values of each system using Equation 10. It should be noted that this procedure was performed as a proxy to identify the risk in each production system, which is expressed in the DCF model by the discount rate (i), and appears directly in the calculations of equations 1, 2, 3, 4, and 7.

$$\beta_s = \frac{\sigma_s}{\sigma_m} \quad (10)$$

in which β_s = overall production system risk (s), σ_s = risk for each production system, and σ_m = market portfolio risk (Ibovespa).

In agribusiness-related literature, a risk-free rate is frequently used as a discount rate for investment projects (Faleiros et al., 2018; Montoro et al., 2019). However, its use contradicts a theoretical assumption in finance literature in which investments must be related to a rate that expresses its risk, considering the risk/return ratio inherent to each investment (Farinelli et al., 2018; Montoro et al., 2019). Therefore, the treatment of risk in this research is in line with the CAPM model, which assumes that each asset or asset portfolio has specific β. Each asset or combination of assets has different sensitivities to systematic risk or market risk (Danthine and Donaldson, 2014).

Financial values were updated using the official Brazilian inflation index from January 2019, expressed in the local currency (Real; R$). The average exchange rate between the Real and the United States dollar in January 2019 was R$ 3.74 = U$ 1.00.

3. Results

Mean present value consolidated results (Equation 2) for cash fow variables in each of the production systems analyzed (Table 2).

Net revenues generated by the ICLS were greater than those generated by CS, possibly due to better land use. To calculate the current value of each variable, the discount rate (i) of each production system was used, and these were calculated using equations 8, 9, and 10 (Table 3).

The economic risk of the ICLS expressed as a discounted rate showed a high level of diversification. This scenario was due to the weak price correlation between a bag of corn and beef cattle arroba (0.27), which increased the natural hedge of these production systems, in which the response was shown in the associated interest rates. Annual OCF is equivalent to OCF per year; this indicates more clearly the differences among the net operating results of each production system when risks involved are considered. Even though the ICLS financial results are greater than those of the CS, the impact of risk diversification for each system and the different fixed investment requirements must be comparatively evaluated. This means that the differences in requirements for machinery, equipment, tools, installations, and utensils must be considered in such calculations. Accordingly, we show the main

Table 2 - Averaged current cash flow values for different production systems in 75 ha

Cash flow variables[1]	Production system[2]					
	Crop	Livestock	ICLS-1	ICLS-2	ICLS-3	ICLS-4
(=) Net revenue	803,918	1,480,380	1,848,407	1,906,637	1,916,328	1,877,192
(-) Variable costs	428,304	1,219,894	1,315,642	1,319,218	1,368,167	1,304,326
(=) CM	375,614	260,485	532,764	587,418	548,160	572,865
(-) Fixed costs	193,610	154,796	159,399	159,205	159,443	159,426
(=) EBTIDA	182,004	105,690	373,365	428,213	388,717	413,439
(-) Depreciation	143,311	127,014	137,485	137,317	136,737	136,374
(=) PBT	38,693	−21,324	235,880	290,896	251,980	277,066
(-) Income tax	23,421	16,249	68,559	84,780	72,507	81,211
(+) Depreciation	143,311	127,014	137,485	137,317	136,737	136,374
(=) OCF	158,583	89,441	304,805	343,433	316,210	332,228
(=) OCF by year	93,491	49,130	168,034	189,560	174,274	183,354

[1] CM - contribution margin; EBTIDA - earn before taxes, interest, depreciation, and amortization; PBT - profit before taxes; OCF - operational cash flow.
[2] Crop: crop system (corn grain production); Livestock: livestock system (beef cattle under grazing conditions); ICLS-1: corn and Marandu palisadegrass sown simultaneously, without herbicide; ICLS-2: corn and Marandu palisadegrass sown simultaneously, with herbicide; ICLS-3: corn and Marandu palisadegrass in lagged sowing; ICLS-4: corn and Marandu palisadegrass sown simultaneously in corn rows and between-rows, with herbicide.

economic results produced by the DCF method developed in this study (Table 4). Once the financial results were built from extrapolation of the empirical, experimental results (Table 1), applied in the context of a model property in the region where the experiment was conducted, it was necessary to annualize all investment-related information using Equation 2. Additionally, current value annualized OCF was used to calculate the production system value (Equation 5).

The differences in investments in fixed capital demonstrated that the ICLS required greater levels of expenses on long-term resources. This comes from the need to develop more than one agricultural activity in the same area, which reinforces the need for an economic analysis of the viability of this investment. The livestock system was not economically viable. Even with the lowest risk involved, it presented the lowest rate of return and, in effect, the lowest probability of having a positive NPV across 10,000 simulations. The crop system was the one that showed the most significant risk as a result of greater combined volatility of prices and productivity; this was directly reflected in a greater discount rate. However, as the investment value was the lowest among all production systems analyzed, the NPV of this system was positive. On the other hand, when these indicators were evaluated via SC and ICLS, it was evident that greater efficiency in the use of resources allowed operating cash flow generation to be much greater than the highest investment level, thereby increasing the levels of profitability of the property (ROI) and resulting in positive NPV, with a high occurrence probability (> 90%).

For the integrated treatments, the enhanced cash flow generation capacity positively impacted the area necessary to make each system viable, as can be seen in the break-even points calculated in Equation 7. All systems showed a positive contribution margin, but, due to the value that each system generated across the different investment profiles, the ICLS had a lower BEP. Per hectare production system valuation, which is the perpetuity calculation for the capacity of each production system to generate free cash flow to the investor (Equation 4), is given in the final column of Table 4. This is the intrinsic value of the entire production structure established per hectare, according to the premises

Table 3 - Effect of operational diversification on the discount rate (i) of each treatment

System[1]	Risk free (%)	With crop (%)	With beef cattle (%)	Risk (%)	Beta	Real discount rate (%)
Crop	6.40	100	0	6.97	1.16	11.72
Livestock	6.40	0	100	2.98	0.50	6.51
ICLS-1	6.40	25.09	74.91	3.19	0.53	6.76
ICLS-2	6.40	27.50	72.50	3.25	0.54	6.85
ICLS-3	6.40	24.51	75.49	3.17	0.53	6.74
ICLS-4	6.40	27.29	72.71	3.25	0.54	6.84

The calculated rate of inflation was 3.75% per year.
[1] Crop: crop system (corn grain production); Livestock: livestock system (beef cattle under grazing conditions); ICLS-1: corn and Marandu palisadegrass sown simultaneously, without herbicide; ICLS-2: corn and Marandu palisadegrass sown simultaneously, with herbicide; ICLS-3: corn and Marandu palisadegrass in lagged sowing; ICLS-4: corn and Marandu palisadegrass sown simultaneously in corn rows and between-rows, with herbicide.

Table 4 - Comparison of economic result means of production systems

System[1]	Annualized fixed capital investment (R$)	NPV (R$)	Probability of positive NPV (%)	ROI (%)	BEP (ha)	Production system value/ha (R$)
Crop	71,595	154,429	65.33	3.38	172	5,833
Livestock	94,895	–132,268	39.30	1.71	383	–614
ICLS-1	105,598	653,611	90.91	5.77	82	21,660
ICLS-2	105,467	771,936	93.63	6.48	73	25,572
ICLS-3	104,787	674,415	90.31	5.97	75	23,042
ICLS-4	104,536	733,586	92.73	6.28	75	24,496

The NPV averages were statistically different using the two-tailed t test, with a 5% confidence level.
NPV - net present value; ROI - return on investment; BEP - break-even point.
[1] Crop: crop system (corn grain production); Livestock: livestock system (beef cattle under grazing conditions); ICLS-1: corn and Marandu palisadegrass sown simultaneously, without herbicide; ICLS-2: corn and Marandu palisadegrass sown simultaneously, with herbicide; ICLS-3: corn and Marandu palisadegrass in lagged sowing; ICLS-4: corn and Marandu palisadegrass sown simultaneously in corn rows and between-rows, with herbicide.

of corporate finance (Danthine and Donaldson, 2014; Farinelli et al., 2018). The ICLS demonstrated economic results that were statistically more robust than the SC.

At longer terms, differences existed in the potential for value creation among the production systems, especially when grossly comparing ICLS to CS. However, these values were below the area values for land acquisition (mean per hectare was R$ 30,608; IEA, 2019). This difference may result from the asymmetry among agents in the land market and the possible overvaluation of land prices.

4. Discussion

Although economic feasibility analyses are critical for producers to make effective decisions, there is a knowledge gap in this study area for ICLS (Ryschawy et al., 2012). One reason may be the difficulty of the required analyses, given the complexity of management of the systems involved, as reported by Wilkins (2008). Additionally, viability analyses of livestock systems require studies over longer time frames than does crop production, which further complicate evaluations (Moraes et al., 2014; Romanzini et al., 2020). In this context, our study contributes to the analysis of comparative ICLS/CS economic viability, considering, in addition to the different impacts on cash flow, the effects of diversification in terms of long-term economic evaluation. Moreover, the different treatments used and the possibility of including market and production uncertainties allowed for a more robust economic analysis to be conducted.

The literature refers to two main economic benefits of ICLS. The first is the scope of the economics, which occurs when the cost of producing two products in the same production system is lower than if the same products were produced separately (Panzar and Willig, 1981). In other words, it is how much is saved due to the scope of the production unit (Mendonça et al., 2020). This is one of the hypotheses that explains the increase in the cash-generating capacity of the ICLS systems (Table 2). The second benefit is the risk reduction associated with the activity, enabling byproduct diversification (Russelle et al., 2007; Hendrickson et al., 2008; Wilkins, 2008; Ryschawy et al., 2012; Gameiro et al., 2016, Mendonça et al., 2020).

The crop system was found to have a greater activity risk value (6.97%) than the livestock system (2.98%), while for ICLS, the risk was 50% lesser than the CS (6.04%) and greater than the livestock system. As a result, it was possible to assert the benefits of combining livestock with an agricultural system, supporting the findings of Wilkins (2008), Vermersch (2007), and Russelle et al. (2007). The greatest risk of conventional, monoculture-based agriculture is the variation of climatic factors on market values, which influences prices of agricultural inputs, grains, applied technologies, and natural resources. Nevertheless, the results of the current study showed that, overall, livestock is the activity with the lowest risk.

The risk reduction in agricultural activities when ICLS is adopted has also been reported by Ryschawy et al. (2012). A risk analysis study by Lazzarotto et al. (2010) found that diversification of ICLS products was beneficial. However, the system was more complex, since it required the producer to have a broader technical and market knowledge of agricultural and livestock-based activities. Additionally, ICLS was considered less vulnerable to variations in operational and market factors.

The combination of agricultural and livestock activities reduced non-systematic risks, which are the specific risks associated with the activities making up the systems. In the study by Ryschawy et al. (2012), a greater gross margin was observed for ICLS compared with a crop system, with greater independence of the studied farm to reduce total costs. Moreover, volatility analysis with Monte Carlo simulation showed that, unlike CS, ICLS were less likely to be affected by fluctuations in the price of agricultural inputs and sales, because of diversification. Thus, in addition to generating a higher margin, the integrated systems allow for a smaller fluctuation in the revenue stream and, consequently, a lower risk of operating cash flow. One of the differences in this study compared with the others regarding risk diversification is that, via CAPM, it was possible to target this risk reduction in terms of the discount rate, a practice not generally used in feasibility studies of agricultural systems (Farinelli et al., 2018).

The discount rate was the greatest for the crop system (11.72%) and the lowest for livestock system (2.98%). For ICLS, risks cannot be calculated simply with a weighted average, as they are diversified, but instead, must include the effect of the correction between them (Equation 9). Accordingly, the ICLS betas can lie very close to the livestock system level, directly influencing the discount rate. The lower the discount rate, the greater the added economic value, and, thus, the reduction in production system risk must be reflected in the interest rate and contribute objectively to creating a system value.

The use of Monte Carlo simulations allowed the inclusion in the analytic model of uncertainties related to productivity and the market value of prices. As with the ICLS, in addition to generating a greater level of cash flow, they also had no significant positive correlation. This contributed to a lower level of system cash flow volatility, and, consequently, a greater level of probability of positive NPV for the ICLS (+/- 91.90%), followed by crop (65.33%) and livestock (39.30%) systems. These results reinforce the economic viability of the ICLS and indicate that the confidence level for this result is high. It should be noted that this result is estimated for a property of 75 ha.

The ICLS systems performed better in all the indicators used in the study. The presence of a positive NPV means that the sum of all discounted cash inflows during the operational time of the project is more significant than for discounted cash outflows, which would make the project viable. Additionally, the indicator showed that the ICLS systems were financially more viable than the CS. In the current study, SC and ICLS productivity results were the same for both corn and livestock production (Table 1). This result shows that it is possible, by adopting ICLS, to obtain satisfactory productivity and generate competitive revenues, which ends with a positive NPV using ICLS.

The negative NPV of livestock system can be explained by the greater expenses with the cost of livestock, such as purchase of animals, mineral salt, medicines, and maintenance of pasture. These costs were nearly equal to revenue, negatively impacting the cash flow of this system. However, it is possible that, under other operational approaches, the livestock system could show satisfactory economic results, for example, in the case of breeders who operate complete production cycles (rearing, growth, and finishing phases). Although the investments and costs may be greater in these operations, there is also the potential for greater revenues, generating greater net cash flows. Furthermore, the production of different categories of livestock within the property represents a diversification strategy, resulting in greater revenue generation flexibility (sale of calves, lean cattle, fat cattle, and breeding stock).

The ICLS and livestock systems are similar in cash outflows terms. However, ICLS revenues are greater than livestock systems, which is associated with the calculated discount rate (Table 3), due to the positive NPV of ICLS. Although the crop system demonstrated a positive NPV, it was influenced by the variation in the crop production indicator of the system. This is because in the second experimental year, the production of bags of corn per hectare was lower than in the first year. Grain production may have been affected by unfavorable climatic conditions in the second harvest. This factor is related to the greater risk of agricultural activity (Table 3).

The different ICLS varied with the NPV related to sowing techniques and how the corn and pastures were implemented. Greater corn productivity was obtained in the ICLS-2 and ICLS-4 treatments (Table 1) and, consequently, net revenues obtained by these systems were greater than the others. For grain production, this result can be attributed to the use of nicosulfuron to control Marandu palisadegrass, reducing competition for water, light, and nutrients. Our results support those of Poffenbarger et al. (2017), who compared the economics of grain-specialized production systems and ICLS (grains and animal) in the United States Corn Belt over eight years (2008 to 2015). Authors concluded that the initial investments in the ICLS were greater, which can be mainly explained by the animal inclusion and labor expenses. However, at longer periods, these systems demonstrated a better economic return than CS. Authors associated the increases in crop productivity with the environmental benefits provided by this type of system.

The ROI indicator was greater (6.13%) for ICLS-1 and ICLS-4 compared with CS. Lower values were found for the crop (3.38%) and livestock (1.71%) systems. This indicator is important to show the producers the level of profitability of their investment, but it cannot be considered a complete indicator, as it functions only as a comparative indicator among activities. It is important to note that in agriculture and livestock-based activities that need differ from assets traded in markets, such as liquidity, information symmetry, the dispersion among agents with supply and demand for capital. However, it is understood that it is appropriate to analyze added value and the profitability of each investment by allowing comparison with other investment opportunities. Because of such alternative economic viability indicators, our study used the BEP indicator as a differentiated and appropriate method, based on the number of hectares required for each studied system. For crop and livestock systems, the BEP were 172 and 383 ha, respectively, while for ICLS, the mean was 76 ha. Thus, the BEP indicator showed that ICLS required a smaller area than CS to function viably. Results found were 56% smaller for ICLS than that needed for the crop system and 80% smaller for livestock system. To achieve a BEP is necessary to use CM, and because all systems have positive CM, all systems can be considered feasible, depending on the production scale required. This reinforces the importance in the analysis of segregating costs as variable and fixed, explaining the variation in results described in the literature. In this case, presenting the results per hectares ignores the effect of the size of each property with the dilution of fixed costs (Faleiros et al., 2018).

In addition to the economic importance, the BEP-related result has social dimension associated within, since, by extending the economic viability for medium-sized agricultural properties (> 76 ha), an economically viable alternative for land use was demonstrated. With that, producers have sufficient resources for the operational and economic requirements involved, such as environmental, social, and economic benefits of ICLS can contribute to better land use.

The indicator "production system value (R$)" (Table 4) was positive in all studied systems, except for livestock system, where a negative economic value indicated that the OCF generated by the system was unable to meet investment needs over time. While a positive OCF means that the production is financially viable when considering the risk involved and the investment flow required over time, the livestock system alternative became unfeasible under our experimental conditions. These results are in agreement with Peyraud et al. (2014), who demonstrated the advantages of ICLS, the possibility of high productivity, and how good agricultural yields could be guaranteed, while at the same time conserving natural resources, producing valuable ecosystem services, and providing greater sectorial resilience against climatic and economic restrictions.

Other studies have also demonstrated how ICLS maximizes land use (Tracy and Zhang., 2008; Carvalho et al., 2018). Therond et al. (2017) reported that integrated agriculture formats require the development of assessment methods at various local, regional, and global levels, with analytical capacity in the areas of social and human sciences. The authors pointed out that these methods support the innovation dynamics of new agricultural production models, but that their coexistence is likely to require the development of socioecological and transdisciplinary policies.

5. Conclusions

The ICLS are more economically viable than the existing conventional system. The management technique used for the integrated systems of intercropping corn and Marandu palisadegrass is important and directly affected the economic viability. The integrated systems had lower associated risks when compared to crop system. However, the risk with the livestock system was the lowest among all the systems studied. The area required by the ICLS to reach the break-even point is smaller than for conventional system. Thus, our results may be an essential indicator of the economic viability of agricultural production using ICLS. It is recognized that it is possible to explore other combinations of integrated systems and work with grain rotations in the same area, such as soybean-corn, thus, not restricting the exclusive production of corn. Furthermore, the short evaluation period of this study indicated that the economic gains of the ICLS are being underestimated compared with the conventional system. Therefore, we suggest using optimization tools, such as financial models, as it allows the exploration of the means of economic gains, while considering the optimal size of cultivated areas, as well as the technologies for the available resources and production objectives.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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