



SOCIAL SCIENCES

Production and profitability of diversified agricultural systems

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Abstract: Diversified crop rotation is an option for expanding producer incomes, and its adoption has presented a series of agronomic advantages compared to less diversified crop rotation systems. In this context, the objective of this study was to verify if higher-diversified crop rotation systems perform economically better than low-diversified ones. To this end, we conducted an experiment in no-tillage crop areas in Londrina, in south of Brazil, for the years 2014/15 to 2016/17. The experiment design was randomized blocks, with six treatments, consisting of crop rotation systems with different levels of diversification, and four replications. We observed that higher-diversified crop rotation systems yield higher revenues and profits. Only these systems, specifically the ones that included canola-corn, crambe-corn, and safflower-soybeans, or wheat-corn+brachiaria, canola-corn, and edible beans-soybeans were economically feasible. Despite higher cost, diversified systems with a greater number of commercial crops in winter presented higher profits. However, diversified systems with a high proportion of cover crops in winter are economically infeasible because their net return is negative.

Key words: crop rotation, cost analysis, investment analysis, agricultural economy, conservation agriculture.

INTRODUCTION

In areas planted with temporary crops in Brazil, production systems with less diversification predominate, particularly those where soybeans are grown in the summer followed by corn or wheat grown in the winter, depending on the soil and climate conditions of the production region (Galvão et al. 2014, Freitas & Mendonça 2016). However, such systems that specialize in only few crops go against what is recommended from a technical-agronomic perspective and what is recommended by conservation agriculture (CA) (Telles et al. 2019, Kassam et al. 2009). Crop systems with less diversification exhibit relative fragility in relation to pests, diseases, weeds, and nematodes, and face conservation challenges related to inadequate soil management, which can result in erosion and

decreased organic material (Hunt et al. 2019). In addition, the excessive use of natural resources and agrochemicals in such systems cause soil degradation. As a result, less diversified crop rotation systems are becoming increasingly inefficient and unsustainable, due to stagnation in yields and increasing production costs (Wang et al. 2019).

The CA promotes more diversified production systems based on crop rotation (Cárcer et al. 2019). Such systems can be argued to be the more appropriate agricultural practice when performed continuously, highly diversified crop rotation results in structural and physical-chemical improvements in the soil (Bortoluzzi et al. 2010, Castro et al. 2011) and guarantees soil conservation by controlling soil erosion. Depending on the choice of varieties, the

sequence of crops adopted, and the duration of plant residues and their effects on the soil, crop rotation increases organic carbon and nitrogen levels in the soil and the quantity of nutrients readily available for the plant and yield stability (Dias et al. 2015, Gaudin et al. 2015). In addition, crop rotation interrupts pest and disease cycles, and in turn reduces the use of chemical products (Selim 2019).

Crops for commercialization should have preferential consideration in crop rotation planning, mainly due to the commercial potential of the grains (Fuentes-Llanillo et al. 2018). In some cases, the crop rotation should also include non-marketed crops whose purpose is soil recovery, such as cover crops (Calegari et al. 2007). Whenever possible the choice should be by regionally adapted cover crops that produce large quantities of dry material and develop rapidly (Machado & Assis 2010) such as *Brachiaria ruziziensis* and rye (Oliveira et al. 2019, Rheinheimer et al. 2019). Therefore, crop rotation planning should not always rely exclusively on income-generating crops, given that certain plants instead serve to reduce input costs and generate high yields for subsequent crops (Favarato et al. 2016).

In the state of Paraná, the second-largest soybean and corn producer in Brazil, less diversified crop rotation systems also predominate. According to the 2017 Agricultural Census, 6.2 million hectares of temporary crops were planted in Paraná, of which 5.2 million hectares were summer soybeans and 2.2 million hectares were winter corn. Northern Paraná, specifically, also hosts production systems with little diversification, which specialize in growing only a few crops that include corn in the winter and soybeans in the summer (Johann et al. 2012).

Highly diversified, no-tillage crop rotation production systems have been recognized from a technical standpoint as a necessary means

for successful development of CA (Lal 2015). The concept of CA is based on three principles: minimal soil disturbance, diversified crop species and crop residue for maintenance of a permanent soil cover (Kassam et al. 2019). The CA reduces soil degradation, mitigates the effect of droughts, increase crop productivity, and reduces production costs (Lahmar et al. 2012). In addition, more diversified crop rotation is an alternative for expanding income for grain producers, given that the adoption of other crops into a production system can generate gains when marketed, which consequently reduces some of the economic risk inherent in agriculture (Fontaneli et al. 2000). Nonetheless, producers have adopted production systems with a low degree of crop diversification, presuming that such systems generate greater economic returns, particularly in the short term. (Dury et al. 2012, Volsi et al. 2020).

Despite the well-reported technical benefits regarding highly diversified crop rotation systems (Malézieux et al. 2009), studies that analyze their economic benefits are incipient (Gentry et al. 2012, Grassini et al. 2014, Al-Kaisi et al. 2015, 2016), particularly studies regarding Brazil (Santos et al. 1996, Leal et al. 2005). We hypothesize that with the increase in species diversification, crops will perform better and will become more profitable and economically feasible. Therefore, the objective of this study is to verify if more diversified crop rotation systems perform economically better.

MATERIALS AND METHODS

The experimental area is located at the headquarters of the Instituto Agrônômico do Paraná in the municipality of Londrina, in the state of Paraná, in the south of Brazil (Figure 1). The area is geographically situated at 23°22'S

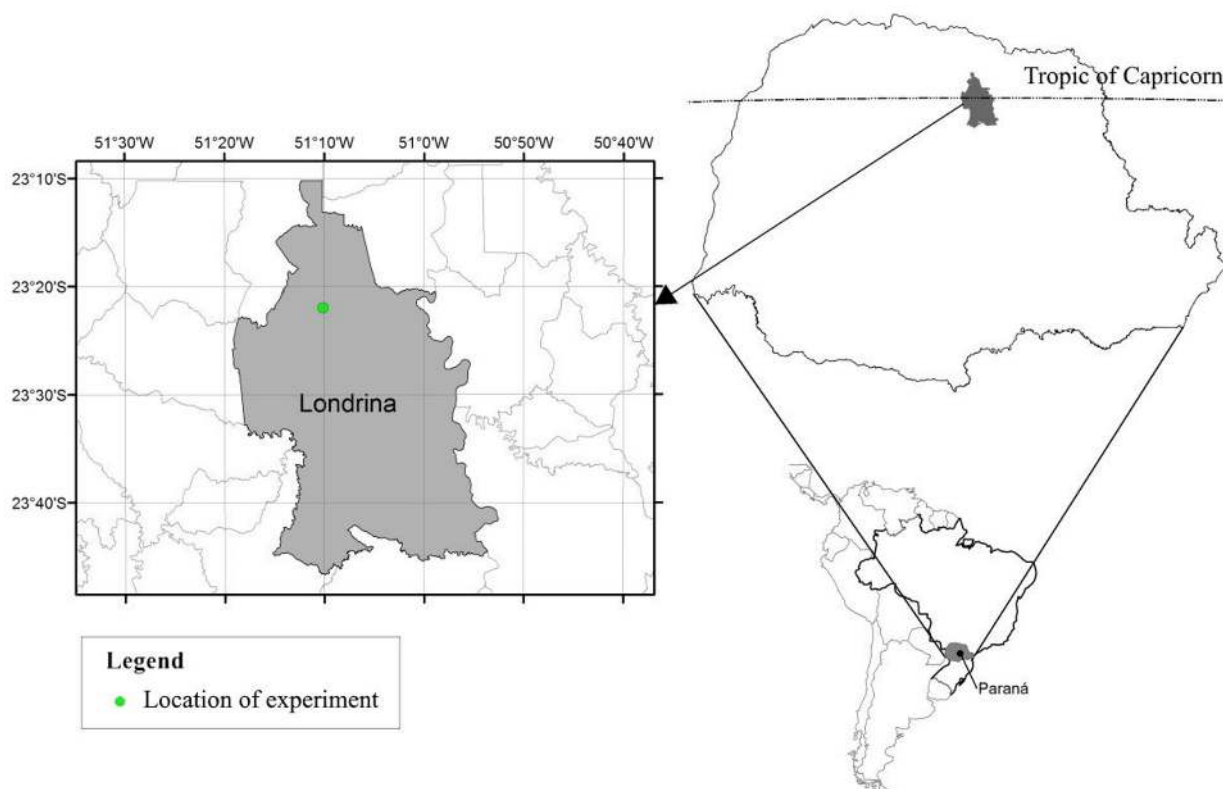


Figure 1. Location of experimental area.

and 51°10'W, and at an altitude of 585 meters. The soil is classified as a typical eutrophic red latosol, with a clay texture and a mild, undulating relief (Santos et al. 2013).

The climate of the region, according to the Köppen classification, is of type Cfa (humid subtropical), with an average annual temperature of 21.1°C and average annual precipitation of approximately 1,523 mm. To reference the climate conditions of the crop years 2014/15 through 2016/17, we calculated the average minimum and maximum temperatures (Figure 2a) and the ten-day water balance (Figure 2b) using spreadsheets from Rolim et al. (1998).

The experiment design involved randomized blocks that included six treatments and four replications. The treatments were composed of six agricultural systems: five highly diversified crop rotation systems and one less diversified crop rotation system, in a three-year cycle (Table

1). The area of each experimental plot was 15 x 20m (300 m²), with a 10-meter spacing between plots to maneuver equipment. Prior to setting up the experiment, the area had served for 11 years as a no-tillage production area, with winter growing of black oats and summer production of alternating corn and soybeans.

Each production system served a distinct purpose. Considering that a diversified system has at least three different crops during the year (Kassam et al. 2019), C-C represented the less diversified crop rotation system. It consists of successive soybean and corn planting and is adopted by the majority of grain producers in northern Paraná. WO-R-W involved a more diverse system in relation to C-C, where white oats, rye, and wheat took the place of corn as a winter crop in the three years, respectively. To obtain maximum straw cover, O-BO-BR produced oats and rye, black oats and forage

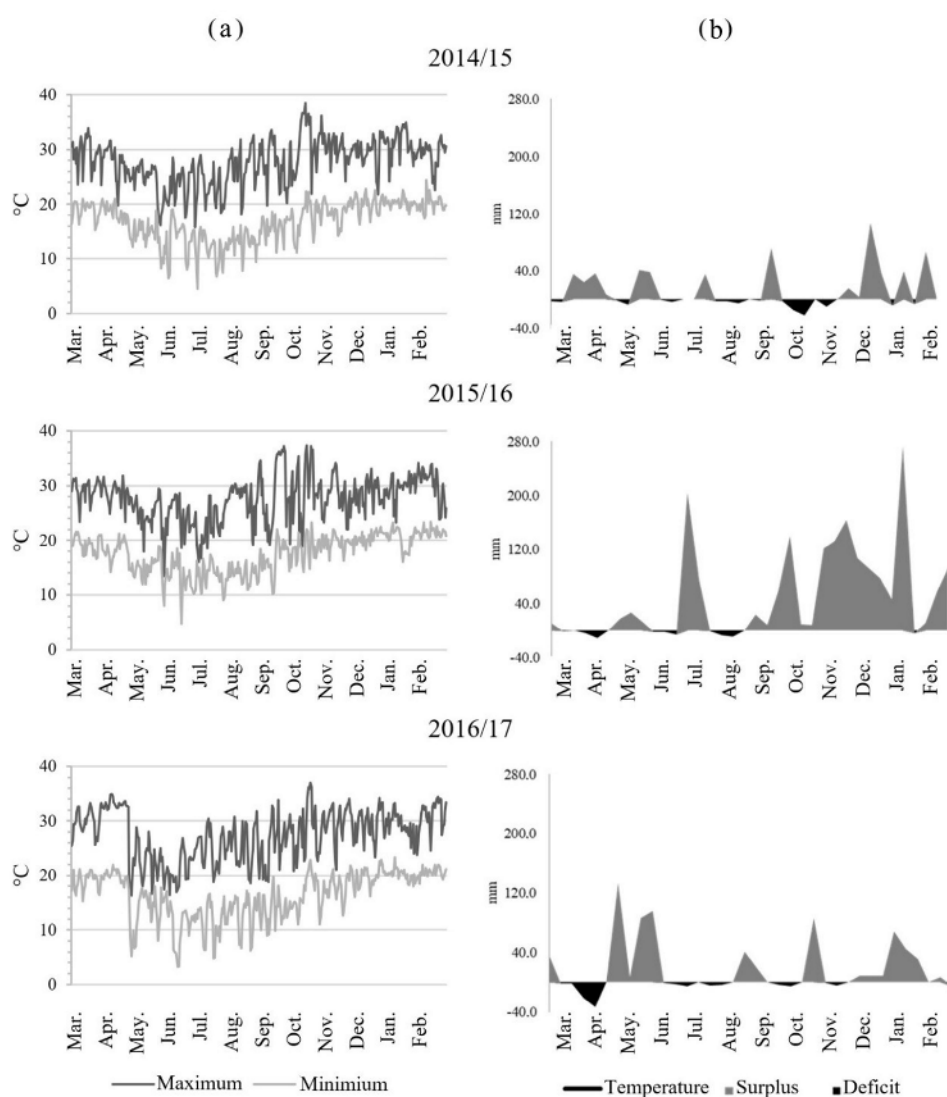


Figure 2. (a) Minimum and maximum daily temperatures and (b) ten-day water balance (water storage capacity = 80 mm), Londrina, Paraná, for the 2014/15 to 2016/17 crop years. Developed based on data from the Instituto Agrônômico do Paraná.

turnip, and brachiaria grass as the winter crops during the three years, respectively. CL-CR-SF served to produce crops related to agroenergy such as canola, crambe, and safflower, while the winter crops under BW-EB-BW included little-studied crops with commercial potential such as edible beans and buckwheat. Finally, W-CL-EB presented the greatest crop diversification of all systems, because of the higher numbers of species grown.

To perform the economic analysis, we considered all services and inputs used in each production system. In addition, we calculate

the remuneration of capital invested in variable costs and land, indicators for opportunity cost analyses. According to Kay et al. (2014), opportunity cost can be defined as the revenue that could be obtained if the producer invested his money in other activities and rented his property to third. To calculate cost remuneration, we considered an investment with an annual interest rate of 7.5%, and to calculate land remuneration, we used a value of 18 soybeans bags of 60 kg per hectare, which is the value of land rent used in the region where the experiment took place. To calculate the costs involved in agricultural

Table I. Crop rotation systems and their respective planting dates, conducted in three-year cycle.

Agricultural system	2014/15		2015/16		2016/17	
	Winter	Summer	Winter	Summer	Winter	Summer
C-C	C (19/03/14) ¹	S (20/10/14)	C (20/03/15)	S (07/10/15)	C (14/03/16)	S (10/10/16)
WO-R-W	WO (05/05/14)	S (24/10/14)	R (10/04/15)	C (06/10/15)	W (02/05/16)	S (10/10/16)
O-BO-BR	O+R (05/05/14)	S (24/10/14)	BO+FT (10/04/15)	C (06/10/15)	BR (16/03/16)	S (10/10/16)
CL-CR-SF	CL (06/05/14)	C (24/10/14)	CR (14/04/15)	C (06/10/15)	SF (15/03/16)	S (10/10/16)
BW-EB-BW	BW/FT (24/03/14) (01/06/14)	C (24/10/14)	EB (02/04/15)	S (07/10/15)	BW/O (14/03/16) (07/07/16)	S (10/10/16)
W-CL-EB	W (05/06/14)	C+BR (24/10/14)	CL (27/05/15)	C (06/10/15)	EB (15/03/16)	S (10/10/16)

W: wheat. S: soybeans. O: oats. BO: black oats. C: corn. WO: white oats. EB: edible beans. FT: forage turnip. R: rye. CR: crambe. SF: safflower. CL: canola. BW: buckwheat. BR: brachiaria grass. ¹The information in parentheses refers to the planting dates of each crop. ¹ Represents crops grown individually, one after the other.

operations, such as equipment and labor, we considered the area of a medium-scale farm, which represents the majority of rural properties in northern Paraná. According to the Law No. 8,629 (Brasil 1993), in the study region, a medium-scale farm has an area between 48 hectares and 180 hectares.

In our cost analysis, we used costs related to production (i.e. variable costs), following the methodological theory and procedures presented by Kay et al. (2014). To establish the operational costs of seeding, spraying, and harvest, including labor, we used the technical coefficients of the experimental station where the experiment was conducted. The values for agricultural operations (manual and mechanical) and inputs were given in hectares.

To perform an opportunity cost representative of the region where the study was developed and to provide information that would allow for planning and control of future operations for each type of rural activity, we took

care with cost records as to not distort data that could serve as a basis for decision-making and activity efficiency analysis. Therefore, to obtain both agricultural operational costs and input costs, we conducted a survey regarding the average values paid and received by producers in the month of June in the years 2014, 2015, and 2016, based on the information obtained from at least three cooperatives and companies from the Londrina region, in Paraná.

For the economic analysis, we used the relation between revenue and cost, or net return, for each production system. We obtained revenues by multiplying production volumes by the respective selling price at harvest. Meanwhile, we obtained yields by weighing the grains harvested from the useful area of the plots, given in kg ha⁻¹, and by correcting humidity to 13% on a wet basis (w.b.).

We corrected all economic indicators to December 2019 values using the Extended National Consumer Price Index (IPCA), the

official inflation index in Brazil, for the purpose of converting nominal values into real values to make comparisons exemplified from effects related to inflation during the study period. The values were converted to US dollars based on the current exchange rate.

RESULTS AND DISCUSSION

Crop yield

Table II presents the yield results for each crop rotation system during the three crop years of the experiment. Some moments demonstrated periods of water deficit (Figure 2), which occurred in the summer of 2014/15 between the months of October and November, in the winter of 2015/16 in the months of April and August, and were most pronounced in the winter of 2016/17, between March and April. Water deficits can often limit the growth and development of

the plant, particularly when they occur while a plant is flowering or during grain fill (Fioreze et al. 2011, Santos et al. 2012).

An additional factor limiting plant growth and development is low temperatures. Frost, in addition to interfering with the development of the species, can cause plant damage and even mortality (Sereia et al. 2012). During the period under study, we observed only one frost event, in July of 2016/17, with a minimum temperature of 3.2°C (Figure 2a). Frost damage begins with air temperatures below 3°C (Silva & Sentelhas 2001). During the winter that the frost event in our study occurred, buckwheat, corn, and edible bean yields were, respectively, 32%, 58%, and 60% lower than the average yields for the crops in previous years. In the case of wheat, yields greatly benefitted from the dry and cold weather during this period and were higher that year.

Regarding to soybeans, the highest yields occurred in the 2016/17 crop year, for the most

Table II. Production system yields, for the crop years of 2014/15, 2015/16, and 2016/17.

Agricultural system	2014/15		2015/16		2016/17	
	Winter	Summer	Winter	Summer	Winter	Summer
	----- kg ha ⁻¹ -----					
C-C	C	S	C	S	C	S
	5,895	2,965	6,536	3,241	2,737	4,030
WO-R-W	WO	S	R	C	W	S
	3,247	3,518	–	9,867	3,762	4,488
O-BO-BR	O+R	S	BO+FT	C	BR	S
	–	3,431	–	10,300	–	4,591
CL-CR-SF	CL	C	CR	C	SF	S
	1,756	11,202	1,475	9,252	1,006	4,397
BW-EB-BW	BW/FT	C	EB	S	BW+O	S
	1,161	10,630	1,984	3,006	785	4,369
W-CL-EB	W	C+BR	CL	C	EB	S
	1,833	10,532	1,142	9,591	776	4,617

W: wheat. S: soybeans. O: oats. BO: black oats. C: corn. WO: white oats. EB: edible beans. FT: forage turnip. R: rye. CR: crambe. SF: safflower. CL: canola. BW: buckwheat. BR: brachiaria grass. “–”: no grain production took place.

diversified crop rotation systems such as that of W-CL-EB (4,617 kg ha⁻¹), or in systems that practiced the extensive use of cover straw, such as in O-BO-BR (4,591 kg ha⁻¹). Meanwhile, the lowest soybean yield was found in the least diversified crop rotation system, C-C (4,030 kg ha⁻¹), which demonstrated yields that were 12.7% lower than those observed in W-CL-EB. Other studies also showed that soybean yields from more diversified crop rotation systems were higher than those of crop rotation systems with little diversification (Stanger et al. 2008, Santos et al. 2014). The primary factor in the higher yields found for the last summer under study was the substitution of seeds with higher-technology seeds. Soybeans were the crop least affected by weather complications that summer, presenting an average yield across treatments of approximately 52 bags (60 kg each) per hectare.

Economic analysis

Table III presents the revenue, variable costs, and net return per hectare for each crop rotation system during the three years of the experiment. We found that the production systems practicing a more diversified crop rotation demonstrated the highest profit and revenue, with the exception of O-BO-BR, whose winter crops were used for straw and not marketed. Specifically, we found the best revenue results for W-CL-EB (US\$ 6,466.29), followed by CL-CR-SF (US\$ 5,604.85), WO-R-W (US\$ 5,472.47), BW-EB-BW (US\$ 5,368.47), C-C (US\$ 5,341.72) and O-BO-BR (US\$ 4,380.65).

With respect to variable costs, those of W-CL-EB were the highest (US\$ 4,862.14), followed by C-C (US\$ 4,779.43), BW-EB-BW (US\$ 4,526.68), WO-R-W (US\$ 4,486.28), CL-CR-SF (US\$ 4,089.95), and O-BO-BR (US\$ 3,178.28). Although the quantification and analysis of the variables are extremely important for the decision of the rural producer (Volsi et al. 2020) the variable cost is a relative indicator

in the economic analysis, since it is possible to have a high cost that can be more than offset if the revenue is high. One of the issues that can be observed from the analysis of variable costs is to identify which component has the greatest impact. On average, inputs represent the majority of spending, accounted for approximately 53% of production costs, agricultural operations costs accounted for around 32%, and other costs, such like taxes, yield transportation and security accounted for around 15%. In general, in the years when cover crops were grown, the expenditure on inputs was considerably smaller compared to the crops that were commercialized. On average, except for treatment O-BO-BR, all systems had higher input costs in winter than in summer. In relation to the net return, an indicator of the profitability of production systems, W-CL-EB performed the best, with a net return of US\$ 1,604.15, followed by CL-CR-SF (US\$ 1,514.90), O-BO-BR (US\$ 1,202.36), WO-R-W (US\$ 985.91), BW-EB-BW (US\$ 841.79), and C-C (US\$ 562.56).

The agricultural systems that showed the best profitability results were those that were most diversified, such as the case of W-CL-EB and CL-CR-SF – systems that also had the highest revenues and highest variable costs. We should note that a high variable cost does not necessarily imply that the agricultural system is worse; instead, while a production system may present a high variable cost, this may be offset by the revenue the system generates. The crop rotation systems with higher profit were associated, among other factors, with periods of high yields and market prices. In the case of W-CL-EB, as a result of high corn yields in 2015/16, good soybean yields in 2016/17, and of high corn and edible bean prices during the 2015/16 crop year, the production system finished the three-year period under study with the highest net return. In this case, the market prices positively influenced the net return. The price of agricultural

Table III. Revenue, variable cost, and net return (US\$ ha⁻¹) of production systems, for the crop years 2014/15, 2015/16, and 2016/17.

	2014/15		2015/16		2016/17		Average		Cumulative
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
	C-C								
	C	S	C	S	C	S			
Revenues	603.78	994.10	685.66	1,225.57	457.47	1,375.42	582.21	1,198.27	5,341.72
Variable cost	852.44	783.11	816.13	709.20	748.44	788.84	805.76	787.47	4,779.43
Inputs	526.26	359.75	508.79	348.02	487.22	401.24	507.42	369.58	2,631.01
Agricultural operations	220.82	307.36	201.17	316.35	171.69	254.12	197.89	292.61	1,471.50
Other costs	105.63	116.28	106.18	125.83	89.53	133.47	100.45	125.29	676.93
Net return	-248.66	210.72	-130.47	435.09	-290.97	586.58	-223.28	410.80	562.56
	WO-R-W								
	WO	S	R	C	W	S			
Revenues	395.51	1,179.44	-	1,757.28	715.41	1,424.55	370.40	1,453.76	5,472.47
Variable cost	560.10	766.18	464.30	967.90	945.79	781.74	656.73	838.79	4,486.28
Inputs	323.18	359.75	310.90	469.21	559.28	401.24	397.69	409.98	2,423.56
Agricultural operations	167.32	283.33	110.55	333.55	267.22	245.39	181.79	287.42	1,407.35
Other costs	69.88	123.10	42.85	165.14	119.28	135.11	77.25	141.12	655.36
Net return	-164.59	413.25	-464.30	789.38	-230.37	642.81	-286.33	615.24	985.91
	O-BO-BR								
	O+R	S	BO+FT	C	BR	S			
Revenues	-	1,150.23	-	1,834.25	-	1,396.16	-	1,460.31	4,380.65
Variable cost	235.01	779.29	192.43	976.09	204.72	791.02	210.72	848.89	3,178.28
Inputs	101.27	338.19	77.52	469.21	76.15	401.24	84.89	402.88	1,463.58
Agricultural operations	111.37	317.99	96.35	337.64	108.64	255.21	105.36	303.53	1,227.20
Other costs	22.38	123.10	18.56	169.23	19.65	134.57	20.20	142.21	487.77
Net return	-235.01	371.22	-192.43	858.17	-204.72	605.14	-210.72	611.42	1,202.36
	CL-CR-SF								
	CL	C	CR	C	SF	S			
Revenues	577.30	1,371.60	252.76	1,647.83	292.06	1,463.58	373.95	1,494.43	5,604.85
Variable cost	421.17	907.30	594.77	862.26	506.33	798.12	507.42	855.99	4,089.95
Inputs	209.36	498.14	326.45	443.82	296.97	401.24	277.59	447.65	2,175.99
Agricultural operations	146.30	264.77	201.99	267.50	149.03	258.49	165.68	263.67	1,288.07
Other costs	65.78	144.39	66.33	150.94	60.32	138.39	64.14	144.67	626.16
Net return	155.86	464.30	-341.74	785.29	-214.27	665.46	-133.47	638.44	1,514.90
	BW-EB-BW								
	BW+FT	C	EB	S	BW+O	S			
Revenues	208.81	1,301.72	1,086.91	1,136.58	151.22	1,483.24	482.31	1,307.18	5,368.47
Variable cost	584.12	942.79	925.59	716.78	557.37	800.30	688.94	819.96	4,526.68
Inputs	322.09	501.96	504.69	330.82	383.50	401.24	403.43	411.34	2,444.04
Agricultural operations	198.98	296.16	286.60	270.50	115.73	259.58	200.35	275.41	1,427.55
Other costs	63.33	144.39	134.57	115.46	58.14	139.48	85.43	133.20	655.36
Net return	-375.31	358.66	161.32	419.80	-405.88	682.93	-206.63	487.22	841.79
	W-CL-EB								
	W	C+BR	CL	C	EB	S			
Revenues	316.63	1,289.71	369.31	1,708.15	1,322.46	1,460.31	334.10	1,429.19	6,466.29
Variable cost	564.20	910.03	472.48	877.00	1,240.58	797.85	759.09	861.72	4,862.14
Inputs	341.19	510.15	218.36	451.47	857.90	401.24	472.48	454.20	2,780.32
Agricultural operations	156.40	258.76	193.52	270.77	209.63	258.49	186.43	262.58	1,347.03
Other costs	66.60	141.12	60.60	154.77	173.33	138.12	100.17	144.67	734.79
Net return	-247.57	379.68	-103.45	831.15	81.89	662.46	-89.80	624.52	1,604.15

W: wheat. S: soybeans. O: oats. BO: black oats. C: corn. WO: white oats. EB: edible beans. FT: forage turnip. R: rye. CR: crambe. SF: safflower. CL: canola. BW: buckwheat. BR: brachiaria grass. Monetary values corrected with the IPCA to December 2019 values, converted to US\$ dollar.

products, mainly commodities, suffers from uncertainties regarding the levels of production, local and global demand, issues related to the weather and even with policies such as protection strategies and customs barriers in markets (Godfray et al. 2010). All these factors contribute to the volatility of the market prices. Even though this agricultural system group included *Carioca* edible beans in the winter of 2016/17 that had the highest variable cost of the entire study (US\$ 1,240.58), this production system managed to present a net return that was 5.89% above the next-highest net return. Meanwhile, under CL-CR-SF, the primary factors responsible for high profitability were high market prices for corn during the 2015/16 crop year and high soybean yields in the summer of 2016/17.

O-BO-BR, which presented low revenues and low variable costs, had the third-highest net return (US\$ 1,202.36). As this agricultural system did not aim to market its winter crops, it required fewer inputs to produce the crops within this system, therefore decreasing expenditures for agricultural chemicals and fertilizers. It is important to note that the net revenue was negative in all winters crops. In addition, this system produced only crops for straw cover in winter, aiming to increase yield gains, since straw cover volumes improve soil quality over the long term, reflecting higher summer crop yields and greater operating profit (Leal et al. 2005). Another agronomic benefit related to the adoption of cover crops in crop rotation systems includes the weed population control and suppression of the weed seed bank (Koocheki et al. 2009, Li et al. 2019), reduction in surface soil compaction and an increase in subsequent summer corn and soybean crop yields when adopting cover crops in crop rotation systems (Debiasi et al. 2010).

WO-R-W and BW-EB-BW presented revenues and variable costs that fell in the middle of the

results from all agricultural systems. However, despite marketing nearly their entire winter crops, the two systems did not demonstrate the highest profits. Among all the crops adopted within these two systems, white oats, rye, wheat, and buckwheat had variable costs that exceeded their revenues, particularly due to high associated input costs. In the case of WO-R-W, the low yield and high variable cost of white oats in 2014/15, of rye in 2015/16, and of wheat in 2016/17 caused this system to assume fourth place in terms of profitability. The low profitability of BW-EB-BW was attributed to the adoption of buckwheat, which at no time demonstrated satisfactory revenues as a result of its low market value at harvest.

With respect to the less diversified crop rotation systems, C-C demonstrated the second-lowest accumulated revenue and the second-highest variable costs. The net return of this system was 2.8 times less than the highly diversified crop rotation system with the highest net return (W-CL-EB). The variable costs of winter corn in C-C were on average 2.32% higher than those of soybeans, and the costs for both crops were very close to those found in other studies (Ferreira et al. 2015, Silva et al. 2015). These costs may negatively affect the profitability of the system, since winter crops normally present lower revenues compared to summer crops (Bonjorno et al. 2010). Therefore, the low diversification crop rotation of C-C presented the lowest net return. As market uncertainties such as commodity price fluctuations, phytosanitary problems, or adverse weather exist in the agricultural sector, planting crop rotations with little diversification may represent risks for the producer (Ottonelli et al. 2016). In other studies, it was also found that the revenues from more diversified crop rotation systems were higher than those of crop rotations with less diversification (Santos et al. 1999, Goplen et al. 2018). One of the benefits

of high diversification in crop rotation is the capacity to reduce risk related to agricultural commodity price volatility and the price risk of other cultivars, or to counterbalance low prices through greater crop diversification (Santos et al. 2004, Lehmann et al. 2013, Castro & Silva Neto 2018).

Table IV presents annual values for the opportunity costs results of the different agricultural systems. While the results related to net return are important, when we consider opportunity costs such as working capital and land remuneration, our analysis provides an even greater coherent view of the agricultural market.

Therefore, when we considering opportunity costs, the only economically feasible agricultural systems were CL-CR-SF and W-CL-EB. Despite demonstrating positive profits, other production systems – in particular, the least diversified crop rotation, C-C – were not economically feasible. For all agricultural systems, the largest fraction of opportunity cost was land remuneration, as found in Mello & Esperancini (2015).

As producers in the south of the country have the option of storing grain in silos (specifically at cooperatives), the system for marketing grain in this region has diverged from the marketing process in the rest of the country. This is because producers burden no administrative costs of storing grain in silos during the first year following the soybean or corn harvest. As a result, producers end up having a longer period to make decisions regarding the best moment to sell their product. Thus, while soybeans and corn can be sold at the peak prices of the 12 months directly following harvest, our results may present a different tendency (for better or worse) since the

selling price of grain in subsequent years may be higher or lower than the price at harvest. Figure 3 presents the prices per 60-kg bag (US\$) of soybeans and corn during the period of June 2014 to June 2018.

Even if the sale of soybeans and corn had taken place at the peak of prices during the year following harvest, the opportunity costs results of the production systems analyzed in this study would have remained unchanged. Table V presents what would have been the opportunity costs results in annual values if soybeans and corn had been sold at the peak prices of each quarter of the 12 months following the harvest date.

As shown in Table V, only the Treatments CL-CR-SF and W-CL-EB would have been economically feasible; however, they demonstrated cumulative values that were below those found when soybeans and corn were sold immediately after harvest.

This study found a higher profitability of more diversified crop rotation production systems – a similar finding to studies conducted in other regions such as the Midwest U.S. (Al-Kaisi et al. 2016), in northeastern China (Fan et al. 2012), in India (Jat et al. 2014), and in Chile (González et al. 2013). All of these results further reinforce the importance of highly diversified crop rotation systems both in terms of their production gains and from an economic perspective.

We note that Brazilian producers have been adopting a production system that is no longer sustainable, neither in terms of economic performance, nor in that, it does not conform environmentally to conservation agriculture.

Table IV. Opportunity cost and economic profit (US\$ ha⁻¹) of the production systems for the 2014/15, 2015/16, and 2016/17 crop years.

	2014/15	2015/16	2016/17	Average	Cumulative
	C-C				
Agricultural system	C-S	C-S	C-S		
Revenue	1,597.78	1,911.08	1,832.95	1,780.60	5,341.81
Variable cost	1,635.72	1,606.30	1,537.30	1,593.11	4,779.33
Remuneration of production factors	471.65	484.46	418.36	458.15	1,374.46
Economic profit	-509.59	-179.68	-122.71	-270.66	-811.98
	WO-R-W				
Agricultural system	WO-S	R-C	W-S		
Revenue	1,574.93	1,757.25	2,140.20	1,824.13	5,472.38
Variable cost	1,326.33	1,432.38	1,727.66	1,495.46	4,486.37
Remuneration of production factors	450.61	473.21	422.62	448.81	1,346.44
Economic profit	-202.01	-148.34	-10.08	-120.14	-360.43
	O-BO-BR				
Agricultural system	O+R-S	BO+FT-C	BR-S		
Revenue	1,150.30	1,834.37	1,396.04	1,460.24	4,380.71
Variable cost	1,014.09	1,168.56	995.73	1,059.46	3,178.37
Remuneration of production factors	430.76	454.93	382.89	422.86	1,268.59
Economic profit	-294.55	210.88	17.42	-22.08	-66.25
	CL-CR-SF				
Agricultural system	CL-C	CR-C	SF-S		
Revenue	1,948.80	1,900.50	1,755.59	1,868.29	5,604.89
Variable cost	1,328.65	1,456.95	1,304.40	1,363.33	4,090.00
Remuneration of production factors	449.49	474.37	402.73	442.19	1,326.58
Economic profit	170.66	-30.82	48.46	62.77	188.31
	BW-EB-BW				
Agricultural system	BW+FT-C	EB-S	BW+O-S		
Revenue	1,510.53	2,223.47	1,634.50	1,789.50	5,368.50
Variable cost	1,526.97	1,642.35	1,357.48	1,509.21	4,526.80
Remuneration of production factors	464.55	485.81	406.78	452.38	1,357.15
Economic profit	-481.00	95.30	-129.76	-171.82	-515.46
	W-CL-EB				
Agricultural system	W-C+BR	CL-C	EB-S		
Revenue	1,606.22	2,077.27	2,782.88	2,155.46	6,466.37
Variable cost	1,474.15	1,349.58	2,038.48	1,620.74	4,862.22
Remuneration of production factors	460.60	466.43	449.32	458.78	1,376.35
Economic profit	-328.54	261.26	295.09	75.94	227.81

W: wheat. S: soybeans. O: oats. BO: black oats. C: corn. WO: white oats. EB: edible beans. FT: forage turnip. R: rye. CR: crambe. SF: safflower. CL: canola. BW: buckwheat. BR: brachiaria grass. Monetary values corrected with the IPCA to December 2019 values, converted to US\$ dollar.

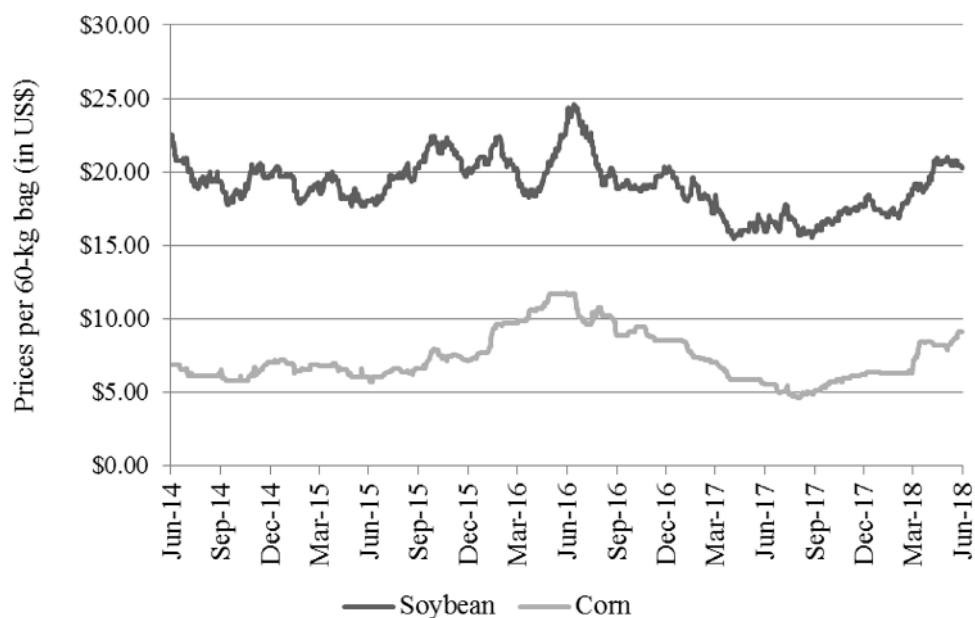


Figure 3. Prices per 60-kg bag (in US\$) of soybeans and corn, from June 2014 to June 2018. Data from Departamento de Economia Rural of the Secretaria da Agricultura e do Abastecimento do Estado do Paraná (DERAL-SEAB). Monetary values corrected with the IPCA to December 2019 values, converted to US\$ dollar.

Table V. Opportunity costs (US\$ ha⁻¹) of each production system for the 2014/15, 2015/16, and 2016/17 crop years, assuming peak quarterly prices.

Agricultural system	2014/15	2015/16	2016/17	Average	Cumulative
C-C	-368.97	230.59	-392.33	-176.90	-530.71
WO-R-W	-138.28	-192.93	-83.65	-138.29	-414.86
O-BO-BR	-232.44	164.33	3.61	-21.50	-64.50
CL-CR-SF	263.97	-72.65	-91.24	33.36	100.08
BW-EB-BW	-392.70	68.67	-297.66	-207.23	-621.68
W-CL-EB	-240.93	218.05	224.72	67.28	201.84

Monetary values corrected with the IPCA to December 2019 values, converted to US\$ dollar.

CONCLUSIONS

Diversified crop rotation systems perform economically better. Increasing diversity in crop rotation systems favors profitability and feasibility compared to less diversified systems, such as corn-soybean. Despite the higher cost, diversified systems with a higher number of commercial crops in winter presented higher profits. However, diversified systems with a high proportion of cover crops in winter are

economically infeasible because their net return is negative.

Thus, our results demonstrated the economic differences between highly and less diversified crop rotation systems. The benefits of more diversified crop rotation systems are significant for agriculture, affecting production, the cost-benefit of agricultural production, and opportunity costs.

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