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CROP PRODUCTION

Yield and profitability responses of cowpea to cropping systems and sowing seasons in Vitória da Conquista, Bahia State, Brazil

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ABSTRACT. Cowpea (*Vigna unguiculata*) crops produce a poor yield in northeastern Brazil compared to the other regions. The goal of this study was to assess the effects of irrigated cropping systems and sowing seasons on cowpea yield and profitability in Vitória da Conquista, Bahia, Brazil. Field studies were performed in four experiments during the rainy and dry seasons during 2016/2017 and 2017/2018, which denoted harvests 1, 2, 3, and 4, respectively. A randomized block design was used for each experiment with four replicates and the following treatments for cropping systems: (1) manual weeding; (2) liming and manual weeding; (3) liming and phosphorus (P) fertilization at sowing, nitrogen (N) and potassium (K) topdressing fertilization, and chemical weed control; (4) liming and P fertilization at sowing, K topdressing fertilization, rhizobia inoculation, and chemical weed control; (5) liming and P fertilization at sowing, N and K topdressing fertilization, rhizobia inoculation, and chemical weed control; and (6) seed pretreatment with cobalt (Co) and molybdenum (Mo), liming and P fertilization at sowing, N and K topdressing fertilization, rhizobia inoculation, and chemical weed control. The technology added to cropping systems increased the number of pods per plant, pod length, seeds per pod, and 100-seed weight, irrespective of the rainy or dry sowing season. Economic analysis, in turn, showed that the technology decreased the total operating cost despite increasing the cost of mechanical operations, inputs, and materials because of the replacement of manual weeding by chemical weed control. However, these costs were not influenced by the sowing seasons. We concluded that technologically enhanced cropping systems, especially systems 4 and 6, improved grain yield and provided greater profitability, which translated into improved economic benefits for farmers. Conversely, the sowing season influenced profitability, which was higher for dry season harvests, when there was less product offered and prices became higher.

Keywords: grain yield; mineral nutrition; inoculation; operating costs; economic analysis.

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Introduction

Cowpea is assumed to have been introduced in Brazil in the 16th century, likely in Bahia. Subsequently, its cultivation expanded to the Midwest region because of the development of cultivars with characteristics that favor mechanical cultivation (Saidi, Itulya, Aguyoh, & Ngouajio, 2010). In this region, cowpea cultivation has been successful because of more favorable weather conditions, but mainly because of the use of advanced technology, which leads to high yield (960 kg ha^{-1}, on average) and profitability (Freire Filho et al., 2011).

However, historically, cowpea production in Brazil has been mainly concentrated in the northeastern area with a cultivation area of 1.2 million hectares (Dias, Bertini, & Freire Filho, 2016), where the crop has always been considered a key protein food source and a major source of employment and income (Boukar et al., 2019). Despite successful cultivation in other regions, cowpea yield is still relatively low in northeastern Brazil, which ranges from 300 to 400 kg ha^{-1} because of the low cost of technologies employed (Freire Filho et al., 2011).

Compared to other leguminous crops, cowpea is considered adaptable to different soil conditions, climates, and cropping systems, although its yield is not always high. Higher grain yields are usually achieved with irrigation, which ensures adequate water supply even during drought periods (Benvindo et al., 2010; Sousa et al., 2010). Furthermore, it is believed that the use of innovative and conservation technologies, such as weed control, liming and fertilization, rhizobia inoculation, and seed treatment, when combined with irrigation, could lead to more economically satisfactory results, providing greater employment, income, and food production (Locatelli et al., 2014).

Recent studies on cowpea in Ghana have challenged the need for nitrogen (N) and phosphorous (P) fertilization because researchers have found no significant effect of the application of these fertilizers on crop growth and yield (Daramy, Sarkodie-Addo, & Dumbuya, 2017). On the other hand, studies on cowpea in Brazil (Almeida et al., 2010; Costa, Nóbrega, Martins, Amaral, & Moreira, 2011; Ferreira et al., 2013), Kenya (Onduru, Jager, Muchena, Gachini, & Gachimbi, 2008), and Tanzania (Nyoki & Ndakidemi, 2013; 2014) showed that the application of bradirrizobium inoculants improved nodulation and increased shoot dry matter and grain yield. Additionally, inoculant application, together with P, increased dry matter and grain yield more than inoculant or P application alone, suggesting that cowpea growth and yield are limited by a phosphorus deficiency. The importance of P in cowpea nodulation and grain yield is well known (Singh et al., 2011; Ayodele & Oso, 2014; Abaidoo, Dare, Killani, & Opoku, 2016). The sowing season, in turn, also influences both agronomic components and bean yield because of the genotype × environment interaction and its correlation with cropping systems, resulting in higher or lower yield (Pereira et al., 2012). Therefore, the goals of the present study were to assess the effects of irrigated cropping systems and sowing seasons on cowpea morphological traits, yield, and profitability under the edaphoclimatic conditions of Vitória da Conquista municipality, Bahia State, Brazil.

Material and methods

Site description

The study site (14° 51′ S, 40° 50′ W; 923 m a.s.l.) was an experimental field located at the State University of Southwest Bahia, in Vitória da Conquista, Bahia State, Brazil. The soil was an Alic Yellow Latosol, with a moderate horizon A, and the local climate is a monsoon-influenced humid subtropical climate type (Cwa), according to the Köppen classification, with an average annual rainfall of 735 mm, which predominantly occurs from November to January.

Experiment description

Four experiments were performed during four periods, corresponding to two sowing seasons, November and March, generally known as the ‘rainy’ and ‘dry’ seasons, respectively, in two agricultural years, 2016/2017 and 2017/2018. Thus, the harvests corresponding to the sequence of the four sowing seasons are hereafter referred to harvests 1, 2, 3, and 4, respectively.

Meteorological data on the maximum and minimum temperatures, precipitation, and relative humidity were monitored during the experimental periods (Figure 1). The water supply for experiments was made available using a sprinkler irrigation system, and the water depth was determined by the cowpea crop cultivation coefficient (Kc), according to Murga-Orrillo et al. (2016).

The soil was chemically analyzed before the beginning of each sowing season (Table 1). Then, soil plowing (0.2 m deep) and harrowing were performed, followed by opening sowing furrows at 0.5 m. Liming and N-P-K fertilization were based on soil chemical analysis and recommendations for cowpeas (Freire Filho et al., 2011). Thus, during each experimental period, 20 kg N, 40 kg P_2O_5, and 30 kg K_2O were added per ha, using urea, single superphosphate, and potassium chloride as fertilizers, respectively.

A randomized block design was used for each experiment, with six treatments and four replications, totaling 24 plots. The treatments consisted of sowing and cultivation of cowpea in the following cropping systems:

(1) Manual weeding (control);

(2) Liming and manual weeding;

(3) Liming and phosphorus (P) fertilization at sowing + nitrogen (N) and potassium (K) topdressing fertilization + chemical weed control;

(4) Liming and P fertilization at sowing + K topdressing fertilization + rhizobia inoculation + chemical weed control;

(5) Liming and P fertilization at sowing + N and K topdressing fertilization + rhizobia inoculation + chemical weed control;

(6) Seed pretreatment with cobalt (Co) and molybdenum (Mo) + liming and P fertilization at sowing + N and K topdressing fertilization + rhizobia inoculation + chemical weed control.

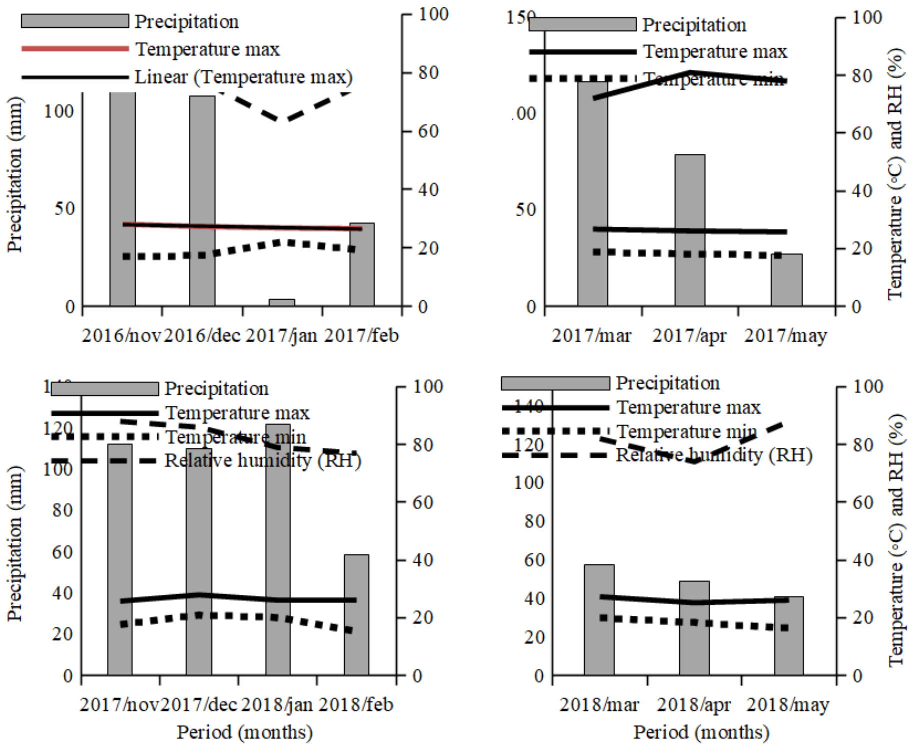

Figure 1. Precipitation, temperature (maximum and minimum), and relative humidity data for the four experiments with cowpea at different periods (harvests 1, 2, 3, and 4). Vitória da Conquista, state of Bahia, Brazil.

Table 1. Soil chemical characteristics at the beginning of each sowing season.

Sowing	OM	pH	P	K^+	Ca^{2+}	Mg^{2+}	H + Al	SB	CEC	V
Season	(g dm^{-3})	(H_2O)	(mg dm^{-3})			(cmol$_c$ dm^{-3})				(%)
1	10.9	5.1	7.0	0.15	1.7	0.8	3.4	2.7	6.1	44
2	11.0	5.7	6.0	0.15	1.9	0.9	3.2	3.0	6.2	48
3	9.7	4.5	5.0	0.14	1.7	0.6	3.7	2.4	6.1	39
4	10.5	5.2	5.0	0.14	1.8	0.7	3.1	2.6	5.7	46

OM = organic matter; SB = sum of bases; CEC = cation exchange capacity; V = base saturation.

The experimental plot dimensions were 3 × 5 m (15 m^2 total area), with six plant lines spaced 0.5 m apart. The plot useful area was 8.0 m^2, corresponding to the four central plant lines, excluding 0.5 m from each end. Ten seeds per linear meter were manually sown. After thinning, the number of plants per linear meter was reduced to eight, totaling 160,000 plants ha^{-1}.

Certified cowpea BRS Novaera seeds were used. This variety produces semi-erect plants with a cycle from 65 to 70 d, well-formed grains that reach high market value, and can be harvested manually or mechanically. BRS Novaera has been recommended for northeastern Brazil and is suitable for both family and commercial agriculture, meeting the demands of a wide range of consumers from Brazil and other countries. *Bradyrhizobium yuanmingense* BR 3267 inoculant strain was used for seed inoculation (treatments 4, 5, and 6) and was provided by Embrapa Agrobiologia.

Data collection and analysis

Ten plants containing 70% dry pods were randomly selected from the useful area of each plot to measure mean values for the following traits: number of pods per plant, pod length, seeds per pod, and 100-seed weight. The yield estimate was based on grain production (g plot^{-1}), and the data were expressed in kg ha^{-1}, considering 13% humidity. Data related to yield components were previously submitted to homogeneity (Cochran and Bartlett) and normality (Lilliefors) tests, followed by an analysis of variance and F test. Means were compared by Tukey's test ($p \leq 0.05$), using the SAEG statistical program, version 9.1.

The analysis of the economic performance of cropping systems was based on an integrated system of agricultural costs, which was analyzed using 'software 'developed by the Institute of Agricultural Economics (IEA) and the National Center for Technological Research in Informatics for Agriculture (Embrapa Informática Agropecuária; Martin, Serra, Oliveira, Ângelo, & Okawa, 1998). In this system, the effective operating cost

(EOC) consists of the costs of mechanized operations, manual operations, and materials consumed. Additionally, other costs are incorporated into the EOC, resulting in the total operating cost (TOC).

The investment in irrigation equipment was R$ 450.00 ha^{-1}, which resulted from an initial investment of R$ 9,000.00 ha^{-1}, considering the useful life of the equipment over 10 years and its use in two harvests per year. Thus, the investment in irrigation equipment per hectare corresponded to the initial investment across 20 harvests. The operational cost of irrigation was based on the ratio between the estimated cost of pumping and the cost of electricity.

The economic performance analysis was based on the following profitability indicators (Martin et al., 1998), expressed in Brazilian currency (R$):

a) Gross Revenue (GR), which results from the product between the number of grain bags (60 kg) produced and the mean value paid per grain bag.

b) Operating Profit (OP), which is calculated by the GR minus total operating costs (OP = GR – TOC);

c) Profitability Index (PI), which results from the percentage of the OP relative to GR [PI = (OP/GR) × 100], and indicates the available revenue rate of the activity after the payment of all operating costs and other charges, including depreciation;

d) Equilibrium Price (EP), which is defined at a given level of TOC as the minimum price required to pay the TOC, considering the mean crop productivity (EP = TOC/mean crop productivity);

e) Leveling point (LP), which is defined as a given level of TOC as the minimum productivity required to pay the TOC, considering the mean price paid to the farmer (LP = TOC/mean price paid to the farmer).

Results and discussion

Yield components

In general, an improving trend in yield components was observed in cropping systems where technological resources were more numerous and diverse, depending on the harvest. The extent of the positive effects of technology, in turn, varied in intensity depending on the characteristics of each resource used in the systems.

Cropping systems influenced pod-related traits, such as the number per plant and length, both during the rainy and dry seasons. The effects were not dependent on the rainfall regime during each season and were probably caused by the continuous water supply through irrigation.

There was significant variation in the number of pods per plant, depending on the cropping system, at harvests 1 and 4. At harvest 1, this trait showed better performance in systems 5 and 6, compared to systems 1 and 2 (Table 2). At this harvest, higher temperature and relative humidity may have enhanced the positive effects of technological resources of cropping systems, such as fertilization and rhizobium inoculation, providing greater vegetative development and increasing the number of branches and flowers, which resulted in a higher number of pods. Kyei-Boahen, Savala, Chikoye, and Abaidoo (2017) also observed an improvement in the performance of yield components in cowpeas based on the response to fertilization and rhizobium inoculation. However, at the 4th harvest, the increasing effect of technology on the number of pods was not clear, probably because of the decreased temperature and relative humidity. For example, this trait was higher in system 4 than in systems 1 and 5.

Table 2. Mean values for the number of pods per plant under different irrigated cowpea cropping systems at four harvests. Vitória da Conquista, state of Bahia, Brazil.

Harvests	Number of pods per plant*					
	System 1	System 2	System 3	System 4	System 5	System 6
1	76.25 c	88.50 c	96.50 bc	103.00 abc	120.00 ab	130.00 a
2	80.50 a	83.25 a	90.25 a	87.25 a	97.50 a	98.50 a
3	94.75 a	95.75 a	99.25 a	94.75 a	93.50 a	97.00 a
4	75.75 c	93.25 abc	96.00 abc	124.25 a	83.25 bc	115.25 ab

*Mean values followed by the same letter on each row do not differ according to Tukey's test ($p \leq 0.05$).

Pod length was influenced by cropping systems at harvests 1, 3, and 4 (Table 3). At harvests 1 and 4, the data showed a trend for a longer pod length in response to systems with increasing technology. At harvest 1, this trait was greater in system 6 than in systems 1, 2, and 3, whereas at harvest 4, systems 5 and 6 showed better performance than did systems 1 and 2. At harvest 3, despite the lower positive effect at harvests 1 and 4, system 5 exhibited better performance than did system 2.

Pod-related traits usually improved in response to N-P-K fertilization, especially N (Cunha et al., 2011; Kyei-Boahen et al., 2017). However, a higher number of pods and longer pods are desirable traits only for manual harvest. Conversely, smaller pods with fewer grains are preferred for semi-mechanized and mechanized harvests because they are lighter, which provides better support and thereby reduces possible bending and breaking of the stalk (Silva, Magalhães, Sobreira, Schmitz, & Silva, 2016). The increase in the number of pods as well as in pod length, in systems 3, 4, 5, and 6, at harvests 1 and 4, could be attributable to the N, P, and K supply, especially N fertilization (Cunha et al., 2011; Kyei-Boahen et al., 2017).

Phosphorus, although not required in large quantities, is critical to cowpea yield because of its multiple effects on nutrition and N fixation (Singh et al., 2011; Muoneke, Ndukwe, Okocha, & Akpan, 2015). For example, P supply is essential to establishing cowpea reproductive parts and inducing flowering and subsequent pod production (Ayodele & Oso, 2014). Potassium, in turn, is an inducer for increased pod yield in cowpea (Muoneke et al., 2015).

There was significant variation in the number of seeds per pod, depending on the cropping system, at harvests 1, 3, and 4 (Table 4). At harvest 1, this trait was higher in system 6 compared to system 1; therefore, corroborating the positive effect of increasing technology on the number of seeds per pod. At harvests 3 and 4, the effect was not as clear as at harvest 1. Nonetheless, at harvest 3, system 5 performed better than did system 2, whereas at harvest 4, systems 5 and 6 performed better than did systems 1 and 2.

The influence of cropping systems on the number of seeds per pod in this study was not congruent with the supposition that this trait is influenced by genetic heritability rather than by environmental factors (Lopes, Oliveira, Souto Filho, Goes, & Silva, 2011). Nevertheless, our data corroborated other studies with cowpea, which confirmed the positive effects of mineral fertilization on the number of seeds per pod (Oliveira, Silva, Santos, Cancellier, & Fidelis, 2014; Pereira Junior et al., 2015).

Regarding the 100-seed weight, there was an influence of cropping systems at harvests 2 and 4 (Table 5). At both harvests, 100-seed weight exhibited a gradual increase in response to increasing technology in cropping systems. At harvest 2, although this effect was not as clear, 100-seed weight was higher in system 5 than in system 1. At harvest 4, the influence of increasing technology was more noticeable because systems 4, 5, and 6 performed better than systems 1 and 2. The 100-seed weight was greater than 20 g in all cropping systems.

For systems under fertilization and weed chemical control, 100-seed weight was higher than that of the other systems. According to some authors, 100-seed weight can be slightly influenced by cultivation systems (Freitas, Dombroski, Freitas, Nogueira, & Procópio, 2013), but it could be more influenced by the environment, including dry periods (Silva, Morais, Santos, d'Arede, & Silva, 2014).

Table 3. Mean values of pods length in cowpea under different irrigated cropping systems at four harvests: Vitória da Conquista, state of Bahia, Brazil.

Harvests	Pods length (cm)*					
	System 1	System 2	System 1	System 4	System 1	System 6
1	14.60 d	1	14.60 d	1	14.60 d	1
2	15.93 a	2	15.93 a	2	15.93 a	2
3	14.74 ab	3	14.74 ab	3	14.74 ab	3
4	15.73 c	4	15.73 c	4	15.73 c	4

*Mean values followed by the same letter on each row do not differ according to Tukey's test ($p \leq 0.05$).

Table 4. Mean values of seeds per pod in cowpea under different irrigated cropping systems at four harvests: Vitória da Conquista, state of Bahia, Brazil.

Harvests	Seeds per pod*					
	System 1	System 2	System 1	System 4	System 1	System 6
1	7.30 c	1	7.30 c	1	7.30 c	1
2	7.50 a	2	7.50 a	2	7.50 a	2
3	7.00 ab	3	7.00 ab	3	7.00 ab	3
4	8.10 b	4	8.10 b	4	8.10 b	4

*Mean values followed by the same letter on each row do not differ according to Tukey's test ($p \leq 0.05$).

Table 5. Mean values for 100-seed weight in cowpea under different irrigated cropping systems at four harvests: Vitória da Conquista, state of Bahia, Brazil.

Harvests	100-seed weight (g)*					
	System 1	System 2	System 1	System 4	System 1	System 6
1	24.95 a	1	24.95 a	1	24.95 a	1
2	27.33 b	2	27.33 b	2	27.33 b	2
3	26.16 a	3	26.16 a	3	26.16 a	3
4	25.31 c	4	25.31 c	4	25.31 c	4

*Mean values followed by the same letter on each row do not differ according to Tukey's test ($p \leq 0.05$).

Economic indicators

Regarding cowpea cultivation as an inexpensive protein food source (Osipitan, Yahaya, & Adigun, 2018), the choice of more efficient and low-cost management is crucial to achieving greater economic profitability. Manual weeding was performed only in cropping systems 1 and 2. In these systems, weeding had the highest specific cost of the TOC, ranging from 49.7 to 55.5%, depending on the harvest. In cropping systems 3, 4, 5, and 6, where manual weeding was replaced by chemical weed control, a predictable increase in the costs of mechanical operations, inputs, and materials occurred. However, TOC was significantly lower in systems where herbicides were used, rather than manual weeding. System 4 had the lowest TOC at all harvests. According to Muoni, Rusinamhodzi, and Thierfelder (2013), the use of chemical control by herbicides is recommended instead of manual weeding for weed control, either because it reduces the handling time or saves on labor costs. A substantial difference in TOC was not found among the harvests (Table 6).

Table 6. Details for operating costs (R$) of planting cowpea under six irrigated cropping systems at four harvests: Vitória da Conquista, state of Bahia, Brazil.

Specific costs	System 1	System 2	System 3	System 4	System 5	System 6
			Harvest 1			
Manual weeding	1,935.00	1,855.00	0.00	0.00	0.00	0.00
Mechanical operations	530.00	710.00	908.00	908.00	908.00	908.00
Inputs and materials	403.50	427.76	1,061.63	963.97	1,066.10	1,083.10
Irrigation	553.02	553.02	553.02	553.02	553.02	553.02
Variable costs	180.08	186.62	132.77	127.63	133.00	133.90
Total operating cost	3,601.60	3,732.40	2,655.42	2,552.62	2,660.12	2,678.02
			Harvest 2			
Manual weeding	2,010.00	1,930.00	0.00	0.00	0.00	0.00
Mechanical operations	540.00	715.00	965.00	965.00	965.00	965.00
Inputs and materials	355.67	391.39	1,019.37	903.95	1,006.07	1,031.15
Irrigation	545.10	545.10	545.10	545.10	545.10	545.10
Variable costs	181.61	188.49	133.13	127.05	132.43	133.75
Total operating cost	3,632.38	3,769.98	2,662.60	2,541.10	2,648.60	2,675.00
			Harvest 3			
Manual weeding	2,015.00	1,930.00	0.00	0.00	0.00	0.00
Mechanical operations	530.00	710.00	950.00	950.00	950.00	950.00
Inputs and materials	391.32	409.75	1,129.25	1,038.05	1,130.48	1,149.10
Irrigation	513.40	513.40	513.40	513.40	513.40	513.40
Variable costs	181.56	187.53	136.45	131.65	136.52	137.5
Total operating cost	3,631.28	3,750.68	2,729.10	2,633.10	2,730.40	2,750.00
			Harvest 4			
Manual weeding	2,015.00	1,935.00	0.00	0.00	0.00	0.00
Mechanical operations	530.00	710.00	950.00	950.00	950.00	950.00
Inputs and materials	361.47	379.26	951.10	861.51	1,162.76	975.80
Irrigation	564.12	564.12	564.12	564.12	564.12	564.12
Variable costs	182.66	188.86	129.74	125.03	129.98	131.04
Total operating cost	3,653.25	3,777.25	2,594.97	2,500.67	2,599.67	2,620.97

Throughout the cowpea crop cycle, weeding was usually performed three to four times, which contributed to increased cropping costs. The option for manual weeding was used because the herbicides recommended for the control of weeds typical to cowpea plantations are still scarce. Nevertheless, given the shortage of rural labor to meet the growing demand from cowpea planting areas, manual weeding has been gradually associated or even replaced by herbicides, which perform more efficient weed control at a lower cost (Mancuso, Aires, Negrisoli, Corrêa, & Soratto, 2016; Mesquita et al., 2017).

Regarding profitability indicators (Table 7), at harvest 1, GR was higher in cropping systems 4 and 6, with values of R$ 4,822.08 and R$ 4,308.54 ha^{-1}, respectively. At harvest 2, GR was even higher in systems 3, 5, and 6, with values ranging from R$ 5,293.96 to R$ 5,592.71 ha^{-1}. At harvest 3, a decrease in GR was observed, with the highest values ranging from R$ 2,511.20 to R$ 2,708.80 ha^{-1} in systems 3, 4, 5, and 6. At harvest 4, the highest GR (R$ 2,590.65) was found in system 6, which had the lowest maximum value among all harvests. The decrease in GR at harvests 1 and 2 may have been caused by fluctuations in cowpea supply and demand, which are usually related to meteorological variation among harvests, which determine the seasonality of prices (Pino, 2014).

Table 7. Profitability indicators of planting cowpea under six irrigated cropping systems at four harvests: Vitória da Conquista, state of Bahia, Brazil.

Profitability indicators	System 1	System 2	System 3	System 4	System 5	System 6
			Harvest 1			
Cowpea bags 60 kg	24.84	28.43	32.55	28.56	33.31	34.39
Gross Revenue	2,727.85	3,807.85	2,702.95	4,822.08	3,458.94	4,308.54
Leveling Point	26.90	27.92	18.82	19.72	19.61	19.81
Equilibrium Price	2.99	2.22	2.11	1.24	1.72	1.39
Operating Profit	-904.52	37.87	161.82	2,159.48	810.34	1,633.54
Profitability Index	-33.15	0.99	5.98	60.95	23.42	37.91
			Harvest 2			
Cowpea bags 60 kg	20.20	28.20	35.71	20.02	25.62	31.91
Gross Revenue	4,040.42	4,624.15	5,293.96	4,644.86	5,417.53	5,592.71
Leveling Point	22.20	23.01	16.39	15.76	16.42	16.54
Equilibrium Price	2.42	2.19	1.36	1.49	1.33	1.30
Operating Profit	430.31	881.54	2,628.33	2,082.03	2,747.21	2,902.78
Profitability Index	10.65	19.06	49.64	44.82	50.70	51.90
			Harvest 3			
Cowpea bags 60 kg	18.62	20.79	21.49	21.04	20.92	22.57
Gross Revenue	2,234.80	2,494.80	2,578.80	2,525.20	2,511.20	2,708.80
Leveling Point	30.26	31.25	22.74	21.94	22.75	22.91
Equilibrium Price	3.24	3.00	2.11	2.08	2.17	2.03
Operating Profit	-1.396.48	-1,255.88	-150.30	-107.90	-219.20	-41.20
Profitability Index	-62.48	-50.33	-5.82	-4.27	-8.27	-1.52
			Harvest 4			
Cowpea bags 60 kg	18.25	18.26	18.88	19.01	19.23	22.72
Gross Revenue	2,081.45	2,081.64	2,152.70	2,167.90	2,192.60	2,590.65
Leveling Point	32.04	33.13	22.76	21.93	22.80	22.99
Equilibrium Price	3.33	3.44	2.29	2.19	2.25	1.92
Operating Profit	-1,571.80	-1,695.61	-442.27	-332.77	-407.07	-30.32
Profitability Index	-75.51	-81.45	-20.54	-15.34	-18.56	-1.17

To endure fluctuations in market prices, farmers can either sell their entire crop immediately after harvest or sell it in the off-season when prices are usually higher (Silveira, Johann, Wander, & Campos, 2014). Given this, farmers need to understand the price fluctuations in the region to be able to monitor the best opportunities to sell their products and maximize profits. Carvalho, Ponciano, Souza, Souza, and Sousa (2014) also highlighted the importance of prior knowledge to price fluctuations and labor costs for the economic viability of tomato crops because these factors usually increase TOC and reduce GR. Therefore, knowledge of price fluctuations is essential for deciding the best planting season to obtain maximum benefits from price seasonality.

Although this study focused on dry grains that largely dominate the cowpea market, seasonal price fluctuations may eventually favor alternative marketing of the fresh grains. Thus, despite requiring additional labor (threshing grains), fresh grains can reach attractive prices, making it a good business option (Andrade, Rocha, Gomes, Freire Filho, & Ramos, 2010; Silveira et al., 2014).

The LP at harvest 1 ranged from 18.82 to 27.92 bags ha^{-1} in cropping systems 3 and 2, respectively. At harvest 2, LP ranged from 15.76 to 23.01 bags ha^{-1} in systems 4 and 2, respectively. Based on mean yields of approximately 16 ha^{-1} bags, which usually occurs in the Midwest region of Brazil (Rodrigues, Damasceno-Silva, Rocha, & Bastos, 2016), where many technological resources are used with crops, the PL values at harvests 1 and 2 showed that some cropping systems could become high-risk, and the producer may not make a profit if production does not cover TOC.

At harvests 3 and 4, an increase in the LP range was observed, with the lowest in system 4 (21.93 bags ha^{-1}) and the highest in system 2 (33.13 bags ha^{-1}). The LP increased at harvests 3 and 4, resulting from a decrease in market prices and TOC maintenance. The LP is reached when GR and TOC are the same; that is, there is no profit or loss (Oliveira, Santana, & Homma, 2013). Therefore, market price determines the total production required to compensate for TOC.

Studies have shown that increasing technology in cropping systems leads to increased TOC. Conversely, as production increases, there is also an increase in LP (Gomes et al., 2013; Ozelame & Andreatta, 2013). Nevertheless, this trend was not observed in the present work because TOC was higher in cropping systems with fewer technological resources, mainly because of manual weeding.

At all harvests, the EP range was inversely proportional to the technological resources used in the cropping systems. Thus, at harvests 1, 2, and 3, the highest EP ranged from R$ 2.42 to R$ 3.24 (system 1), and at harvest 4 was R$ 3.44 (system 2). The lowest EP ranged from R$ 1.24 to R$ 2.03 in systems 4 (harvest 1) and 6 (harvests 2, 3, and 4). According to Gerlach, Arf, Corsini, Silva, and Coletti Júnior (2013), this variation in EP data results from the influence of TOC and productivity. It should be noted that in an agricultural year, if TOC is maintained and yield varies, EP will also vary, and profitability only occurs if the prices charged are higher than the EP.

Technological resources based on fertilization and irrigation can influence EP. In soybean planting, a decrease in PE was found in cropping systems with technological resources, such as increasing doses of molybdenum (Mo) and other nutrients, as well as inoculation and irrigation (Oliveira, Lazarini, Tarsitano, Pinto, & Sá, 2015).

OP at harvest 1 was negative in system 1 (R$ -904.52 ha^{-1}), but was positive in the other systems, ranging from R$ 37.87 (system 2) to R$ 2,159.48 (system 4). At harvest 2, when the sale price was R$ 0.46 more than that at harvest 1, all systems were profitable, with OP ranging from R$ 430.31 ha^{-1} (system 1) to R$ 2,902.78 ha^{-1} (system 6). At harvests 3 and 4, a decrease in OP was observed for all systems because of a decrease in productivity and prices. According to Pelegrini, Bezerra, and Hasparyk (2017), a drop in productivity may occur because of environmental ecological instability, whether in monocultures or successive planting of the same crop and regardless of the cropping system.

In general, the highest PI was at harvests 1 and 2, especially in systems with more technological resources (3, 4, 5, and 6). According to Mousinho, Andrade Júnior, and Frizzone (2008), a PI above 15% for cowpeas is considered to be quite attractive. Given the risks of agricultural activity, large revenues should not always be used as a reference because they are also susceptible to large risks. For this reason, the choice of cropping system is often based on the perspective of profitability with lower risks.

Conclusion

The increasing technology added to cropping systems, especially mineral nutrition and/or rhizobium, as well as chemical weed control, increased the number of pods per plant, pod length, seeds per pod, and 100-seed weight. These effects occurred at different harvests and suggested no influence of the rainy or dry sowing season, probably because of the irrigation in all cropping systems.

The economic analysis showed that increasing technology, despite increasing the costs of mechanical operations, inputs, and materials, decreased the TOC because of the replacement of manual weeding with chemical weed control. However, these costs do not influence the sowing seasons.

We concluded that technologically enhanced cropping systems, especially systems 4 and 6, and improved grain yield and provided greater profitability, which translates into improved economic benefits for farmers. Conversely, the sowing season influenced profitability, which was higher at dry season harvests, when there was less product in the market, and prices were higher.

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