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Productive and economic analyses of lowland soybean crops

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Abstract – The objective of this work was to estimate the relative yield that maximizes the profitability of the soybean crop in rotation with flood-irrigated rice. For this, 13 high-yield areas (from 2.6 to 5.2 ha) in lowland soybean-rice systems in Southern Brazil were selected before sowing. The calculation of production costs included seeds, seed treatment, fertilizers, lime, pesticides, irrigation, land, operational outsourcing, labor, and fuel consumption. The observed yield was transformed into relative yield by multiplying the quotient of the observed yield by the yield potential estimated by the CSM-CROPGRO-Soybean model. Water productivity was calculated as the ratio between the observed yield and available water during the crop cycle. Yield potential ranged from 6.1 to 7.4 Mg ha^{-1}, whereas relative yield ranged from 45.3 to 101.2%. In addition, costs ranged from US$564.86 to US$1,122.86 per hectare, and profitability from US$767.18 to US$3,149.75 per hectare. The highest profitability of the soybean crop in rotation with flood-irrigated rice occurs with a relative yield between 67 and 84%.

Index terms: *Glycine max*, cost, economic, profitability, yield gap, yield potential.

Análises produtiva e econômica de lavouras de soja em terras baixas

Resumo – O objetivo deste trabalho foi estimar a produtividade relativa que maximiza a rentabilidade da lavoura de soja rotacionada com arroz irrigado por inundação. Para tanto, 13 áreas (de 2,6 a 5,2 ha) de alta produção em sistemas soja-arroz, em terras baixas, na região Sul do Brasil foram selecionadas antes da semeadura. O cálculo dos custos de produção incluiu sementes, tratamento de sementes, fertilizantes, calcário, defensivos agrícolas, irrigação, terra, operações terceirizadas, mão de obra e consumo de combustível. A produtividade observada foi transformada em produtividade relativa, ao se multiplicar o quociente da produtividade observada pelo potencial produtivo estimado pelo modelo CSM-CROPGRO-Soybean. A produtividade hídrica foi calculada como a razão entre a produtividade observada e a água disponível durante o ciclo da cultura. O potencial de produtividade variou de 6,1 a 7,4 Mg ha^{-1}, enquanto a produtividade relativa variou de 45,3 a 101,2%. Além disso, os custos variaram de US$564,86 a US$1.122,86 por hectare, e a rentabilidade de US$767,18 ha^{-1} a US$3.149,75 por hectare. A maior rentabilidade da lavoura de soja em rotação com arroz irrigado por inundação ocorre com produtividade relativa entre 67 e 84%.

Termos para indexação: *Glycine max*, custo, econômico, lucro, lacuna de produtividade, potencial de produtividade.

Introduction

In the beginning of the 21st century, lowland soybean [*Glycine max* (L.) Merr.] was introduced to flood irrigated rice (*Oryza sativa* L.) fields due to the observed increase in resistant weeds in the latter crop, coupled with its high production costs and low profitability (Theisen et al., 2017; Lozano & Londoño, 2019; Puig et al., 2020; Silva et al., 2022). In Southern Brazil, the areas cultivated using the rice-soybean system grew 452% in the last 14 years, covering close to 505.000 ha, which is equivalent to approximately 60% of the flood irrigated rice area in the state of Rio Grande do Sul (IRGA, 2021). Compared with rice monoculture, the rice-soybean rotation brings benefits to the production system, including an improved rice yield and economic return, a higher benefit-cost, and return to labor (Cox & Gerard, 2010; Theisen et al., 2017; Ribas et al., 2021). Therefore, the diversification of the production system is suggested as one of the main strategies to increase crop productivity and farmer profit, as well as to reduce environmental impacts (Theisen et al., 2017; Lozano & Londoño, 2019; Puig et al., 2020; Ribas et al., 2021). However, there is still the need to identify the relative yield that maximizes the profitability of soybean in rotation with irrigated rice.

The first step to maximize profitability, while maintaining sustainability, is determining yield potential, which is defined as the productivity of a crop grown without any water or nutrient limitation and without biotic stresses related to weeds, pests, and diseases (Lobell et al., 2009). Within this framework, crop growth rate is determined by the solar radiation intercepted by the plant canopy, atmospheric CO_2 concentration, air and soil temperature, and the genetic characteristics of the used cultivar (Van Ittersum & Rabbinge, 1997; Evans & Fischer, 1999).

The second step is to identify relative yield, considered as the yield of the producer's field expressed as a percentage of yield potential (Tenorio et al., 2020). Based on the obtained results, it is possible to determine the needed expenses, such as inputs and energy, to maximize the profitability of the business. Previous theoretical studies have indicated that a relative yield between 70 and 85% is the optimal range for economic and resource use efficiency (Cassman et al., 2003; Lobell et al., 2009; Fischer, 2015). For the soybean-rice system, these factors have been analyzed by Theisen et al. (2017), Ribas et al. (2021), and Xavier et al. (2021).

The objective of this work was to estimate the relative yield that maximizes the profitability of the soybean crop in rotation with flood-irrigated rice.

Materials and Methods

The study used secondary data from the dataset of Ribas et al. (2021) and Tagliapietra et al. (2022), from which 13 high-yield fields of the soybean-rice system in the states of Rio Grande do Sul and Santa Catarina, Brazil, were selected before sowing (Figure 1). In the selected fields, which ranged from 2.6 to 5.2 ha, management and economic data were collected in the 2020/2021 crop season.

During the crop season, surveys were carried out in the fields (namely field 1 up to field 13), and data were collected on soil, planting date, final density, cultivar (maturity group), rainfall and irrigation during the development cycle of the crop, yield, and costs.

Crop yield potential was estimated by the CSM-CROPGRO-Soybean model, validated for the subtropical environment in Brazil (Silva et al., 2021; Tagliapietra et al., 2021; Marin et al., 2022). Meteorological data were obtained from NASA-POWER (NASA, 2024), considering its acceptable agreement with data measured in the field according to several authors (Tagliapietra et al., 2021; Marin et al., 2022; Rizzo et al., 2022). Rainfall and irrigation were measured using pluviometers.

Data of production and the study area were also collected. Production was calculated based on grain production, discounted the found impurities and corrected for 13% moisture. The observed yield was transformed into relative yield (%), which was calculated by dividing the observed yield by yield potential, multiplied by 100. Yield data were subjected to the Kruskal-Wallis test (α=0.05).

Water productivity was calculated as the ratio between the observed yield (kg ha^{-1}) and the available water (mm) during the crop cycle (Pereira et al., 2012; Zanon et al., 2016). In addition, available water was considered as the sum of measured rain and the amount of irrigation.

Data of production cost were collected between pre-planting and harvest and included costs with seeds, seed treatment, fertilizers, lime, pesticides, irrigation,

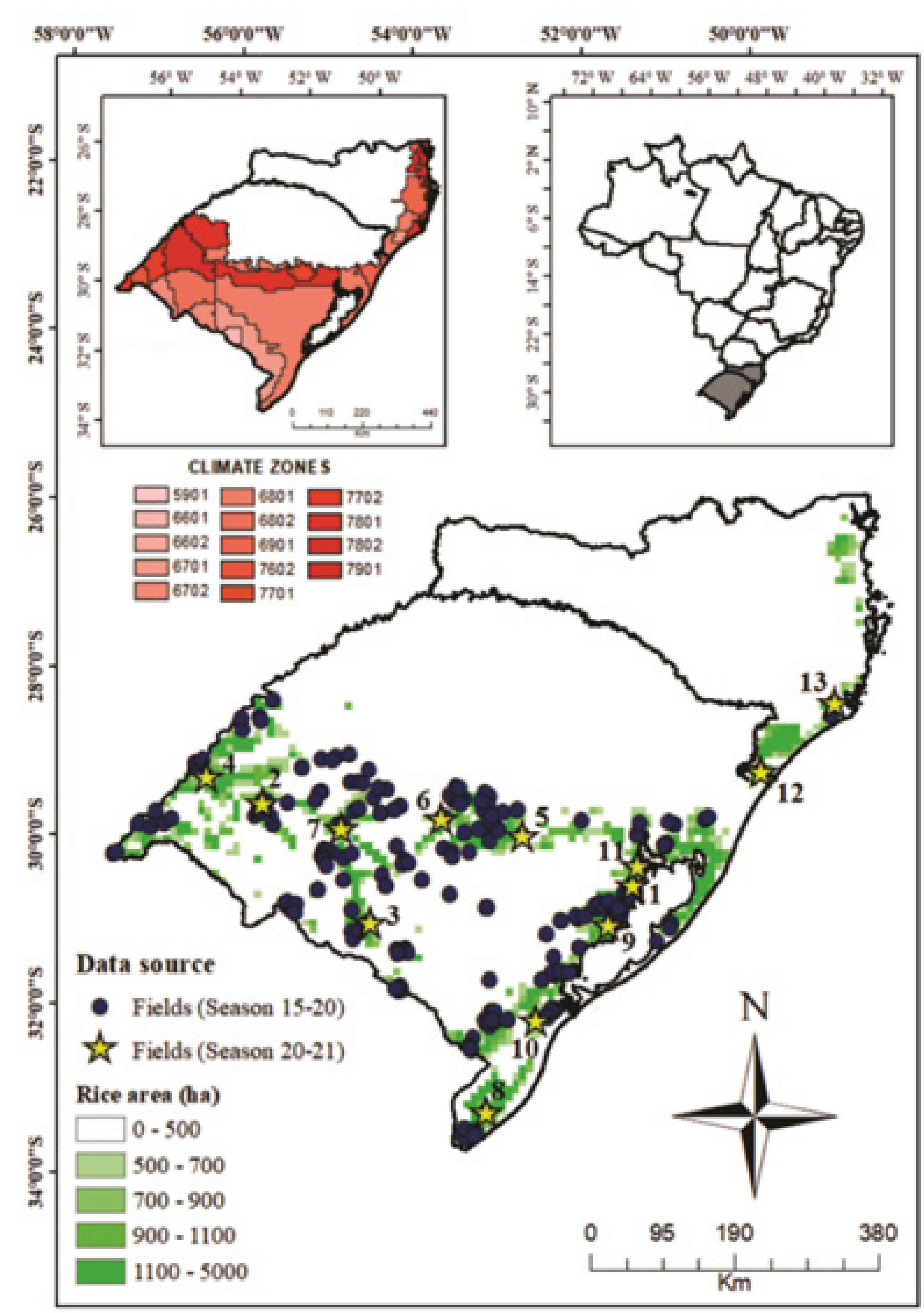

Figure 1. Location of the 225 fields observed (solid blue circles) in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil, from which the following 13 lowland soybean (*Glycine max*) fields (stars) were selected for analysis in the 2020/2021 growing season: 1, Tapes; 2, Alegrete; 3, Dom Pedrito; 4, Itaqui; 5, Cachoeira do Sul; 6, Santa Maria; 7, Cacequi; 8, Santa Vitória do Palmar; 9, Camaquã; 10, Rio Grande; 11, Barra do Ribeiro; 12, Torres; and 13, Tubarão. The rice (*Oryza sativa*) production area is shown in green (Mapspam, 2024). The climate zones in the upper left panel follow the global yield gap atlas methodology and are based on development degree days, the annual aridity index, and temperature seasonality (Global Yield Gap Atlas, 2024).

land, outsourced operations, labor, and fuel. The cost of labor was assumed as US$2.23 per hour, which is the predominant value paid per hour of labor in the studied region, multiplied by the number of hours estimated for each operation. The cost of fuel was calculated by multiplying US$0.71 per liter of diesel by the consumption of each operation. Expenses with taxes, insurance, storage, freight, depreciation, and maintenance were not determined, mainly because these data are associated with other services that will bias the analysis. Another reason for this is that the present study was carried out in part of the farm area and, therefore, the farmer informed the selling price of the grain for each field.

Profitability was calculated as the gross revenue minus production cost, representing the financial gain of the farmer under two scenarios: with and without land rental. Gross revenue was obtained by multiplying yield by the selling price of US$14.84 per bag of 60 kg of soybean, which corresponds to the average price reported by the producers in the 2020/2021 crop season. The obtained results were analyzed as relative values using the highest observed result as a reference. The financial indicator of benefit-cost was used, being calculated by dividing the gross revenue by the production cost.

The evaluated fields were classified into the four following groups, based on their relative yield and profitability: group 1, high relative yield and high profitability; group 2, high relative yield and low profitability; group 3, low relative yield and high profitability; and group 4, low relative yield and low profitability.

A spider chart was used to present the data obtained for yield, profitability, gross revenue, and costs. The R statistical software, version 4.1.1 (R Core Team, 2021), and the fmsb (version 0.7.5) and ggplot2 (version 3.4.4) packages were used to generate the chart.

Results and Discussion

Soybean yield potential ranged from 6.1 to 7.4 Mg ha^{-1} (Table 1 and Figure 2 A), whereas the average yield observed across the 13 evaluated fields was 4.8 Mg ha^{-1}, ranging from 2.9 to 7.5 Mg ha^{-1}. Tagliapietra et al. (2021) reported a similar yield potential range from 6.1 to 7.2 Mg ha^{-1}, but a lower average yield of 2.8 Mg ha^{-1}. Moreover, the observed average yield was 44% higher than the average yield reported for the states of Rio Grande do Sul and Santa Catarina (Conab, 2021). Winck et al. (2023) attributed the improvement in yield potential to the annual release of new cultivars.

Relative yield ranged from 45.3 to 101.2%. Field 1 reached the value of 101.2%, meaning that the estimated yield potential was lower than the observed yield, indicating the need for the frequent calibration of process-based models, such as CSM-CROPGRO-Soybean (Silva et al., 2021; Tagliapietra et al., 2021). In the North American Corn Belt, Tenorio et al. (2020) found field observations exceeded simulated yield potential in 4% due to inaccurate information on soil, climate, and yield.

Water productivity ranged from 3.9 to 21.3 kg ha^{-1} mm^{-1}, showing an average of 9.6 kg ha^{-1} mm^{-1} (Figure 2 B), similar to that of 9.1 kg ha^{-1} mm^{-1} reported by Zanon et al. (2016). In the present study, the highest values of 21.3 and 15.4 kg ha^{-1} mm^{-1} were obtained for fields 1 and 9, respectively, due to the presence of a water table at a depth of approximately 0.5 to 2.0 mm, whose influence on yield is known worldwide (Vitantonio-Mazzini et al., 2021).

In the 2020/2021 crop season, the price paid for a 60 kg bag of soybean increased substantially, jumping from US$14.80 to US$33.40. This high price and the low production costs resulted in high profits in that season (Conab, 2021). The calculated costs varied in U$557.80 ha^{-1} among the studied fields (Figure 3), whose average cost was US$778.90, close to that found by Puig et al. (2020) and Ribas et al. (2021). In the first scenario, a price of US$14.80 was necessary to pay the production costs of 52 bags of soybean per hectare. Under these conditions, field 11 showed a negative profitability (Figure 2 A and Figure 4 A) and a benefit-cost lower than 1 (Figure 4 B). In the second scenario (Figure 4 A), the exclusion of land rental had a significant and variable impact on production costs, with fields 3 and 13 presenting the highest benefit-cost. An average benefit-cost of 2.6 was obtained for the second scenario, which is a value similar to that of 2.2 found by Ribas et al. (2021).

Relative yield was considered a better way to compare the different fields (Lobell et al., 2009), allowing of the comparison of farms with different management practices, climate, and soil (Andrade et al., 2022). Based on their relative yield and profitability, the studied areas were organized into four groups

(Figure 5), as follows: group 1, fields 1, 2, 6, 9, and 12, characterized mostly by a high relative yield, with only fields 1 and 9 showing costs below average; group 2, fields 3 and 7, both with a relative yield and production costs below average, without expenses with irrigation and outsourced operations, and with costs with fertilizers, pesticides, and lime below average (Table 1 and Figure 3); group 3, only field 13, with a high cost of production; and group 4, fields 4, 5, 8, 10, and 11, characterized by a low relative yield and production costs above average.

When there is a high profit in the soybean-rice system, there is also a high relative yield and a low production cost, as observed by Xavier et al. (2021). The fields in the groups 1 and 2 presented profits above average, with a relative yield ranging from 67 to 100%. For these fields, the highest profit was obtained when relative yield was 100%; however, aiming a relative yield higher than 85% is risky (Lobell et al., 2009), especially since the financial return per unit of added expense is decrescent (Cassman et al., 2003; Grassini et al., 2011). Lobell et al. (2009) highlighted that new technologies may minimize uncertainties and allow to reach relative yields above 85%.

Except for field 1, none of the fields showed a relative yield above 84%, which is an indicative that a relative yield between 67 and 84% (Table 1 and Figure 5) and not between 67 and 100% should be aimed. Xavier et al. (2021) observed a similar range for irrigated rice in the state of Rio Grande do Sul, recommending a relative yield between 69 and 83%, which is in alignment with that from 70 to 85%

Table 1. Description of the locations and variables analyzed in 13 soybean (*Glycine max*) fields inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil(1).

Field	Maturity group	Planting date	Harvest date	Rain - irrigation (mm)	Harvested area (ha)	Observed yield(1) (Mg ha^{-1})	Yp (%)(2)	Costs (x1,000 US$ ha^{-1})		
								Seeds	Fertilizer	Pesticide
1	5.5	11/03	03/25	354-0	4.8	7.5a	100a	0.09	0.17	0.10
2	5.5	10/10	03/14	558-66	2.6	5.9a	80.5a	0.12	0.19	0.17
3	5.0	10/20	03/14	524-0	4.6	4.9ab	66.6ab	0.07	0.10	0.10
4	6.3	10/29	04/08	877-80	5.2	3.7b	50.7b	0.07	0.10	0.10
5	5.9	10/10	03/30	415-0	3.0	3.8b	55.8b	0.03	0.18	0.09
6	5.9	11/01	04/04	679-0	3.6	4.9a	71.6a	0.07	0.09	0.14
7	4.8	10/31	03/13	462-0	3.0	4.7ab	69.4ab	0.05	0.12	0.11
8	6.6	11/04	05/03	847-0	3.9	4.3b	63.8b	0.07	0.15	0.16
9	6.4	11/01	04/07	349-0	3.4	5.4a	82.9a	0.08	0.12	0.11
10	6.7	11/04	04/23	475-0	3.0	4.2b	65.9b	0.04	0.11	0.16
11	5.9	11/07	03/31	240-0	3.0	2.9b	45.3b	0.08	0.14	0.15
12	5.5	11/17	04/04	792-0	2.6	5.1a	83.8a	0.06	0.18	0.16
13	6.6	10/16	04/03	786-0	3.1	4.5ab	74.1ab	0.04	0.16	0.17

Field	Costs (x1,000 US$ ha^{-1})							Sale price (US$ kg^{-1})	Gross revenue (US$ ha^{-1})	Profitability (US$ ha^{-1})
	Lime	Fuel	Outsourced operations	Labor costs	Irrigation	Cost of land	Total			
1	0.06	0.05	0.00	0.01	0.00	0.21	0.69	0.51	3.84	3.15
2	0.01	0.04	0.02	0.01	0.05	0.51	1.12	0.47	2.82	1.69
3	0.01	0.04	0.00	0.01	0.00	0.39	0.71	0.52	2.45	1.72
4	0.04	0.04	0.02	0.01	0.01	0.19	0.56	0.52	1.91	1.35
5	0.02	0.06	0.00	0.01	0.00	0.35	0.73	0.50	1.93	1.21
6	0.01	0.07	0.00	0.01	0.00	0.40	0.80	0.50	2.48	1.69
7	0.03	0.05	0.00	0.01	0.00	0.24	0.62	0.51	2.39	1.78
8	0.03	0.00	0.24	0.00	0.00	0.21	0.87	0.51	2.21	1.34
9	0.03	0.04	0.03	0.01	0.00	0.29	0.70	0.53	2.86	2.17
10	0.01	0.04	0.02	0.01	0.00	0.28	0.66	0.51	2.15	1.50
11	0.04	0.06	0.00	0.01	0.00	0.25	0.73	0.52	1.50	0.76
12	0.11	0.08	0.00	0.03	0.00	0.21	0.84	0.50	2.56	1.71
13	0.03	0.06	0.00	0.01	0.00	0.62	1.09	0.55	2.48	1.39

(1)Means followed by equal letters, in the columns, do not differ from each other by the Kruskal-Wallis test, at 5% probability. (2)Yp, relative yield.

obtained in previous theoretical studies (Cassman et al., 2003; Lobell et al., 2009; Fischer, 2015). However, it is advisable to take into account environmental and social factors, such as the emission of pollutants and farmer ownership succession, in order to pursue a profitable but sustainable business.

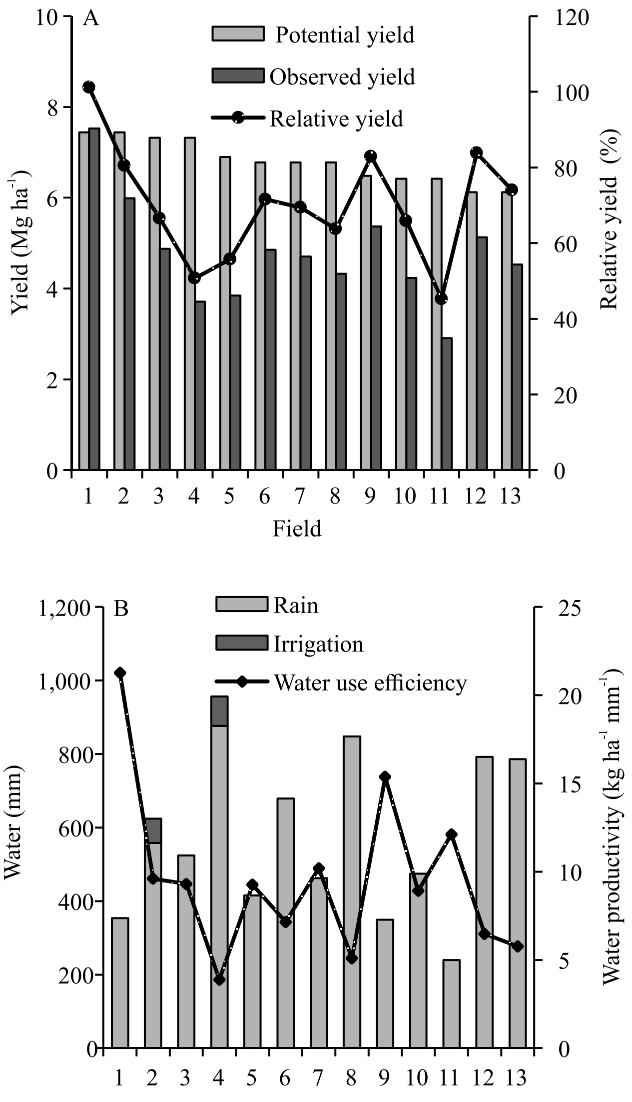

Figure 2. Yield potential, observed yield, and relative yield (A), as well as available soil water during the crop cycle (rainfall plus irrigation) and water productivity (B), obtained for 13 lowland soybean (*Glycine max*) fields (fields 1 to 13) inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil.

Field 2 presented the second highest observed yield of 6.0 Mg ha^{-1}, but also the highest cost of all, ranking as the sixth most profitable. This shows that a high yield is not enough to achieve a high profit, which depends on gross revenue and production costs (Arbage, 2012). Contrastingly, field 13 presented below average profits in spite of a high relative yield, which was attributed to a low yield potential and high costs. Both of these cases indicate that expenses should be proportional to yield potential (Mueller et al., 2012).

According to the obtained results, fields with similar production costs presented a great variation in yield and profit. For example, in the second scenario, fields 5 and 7 showed similar production costs. However, there was a difference of 859 kg ha^{-1} in yield and US$431.50 in profit between fields 5 and 7, indicating that the efficient allocation of resources is more important that spending more.

Field 1 was the most profitable since it presented the highest yield and gross revenue (Figure 6). Although the price paid for the soybean bag was only US$30.60,

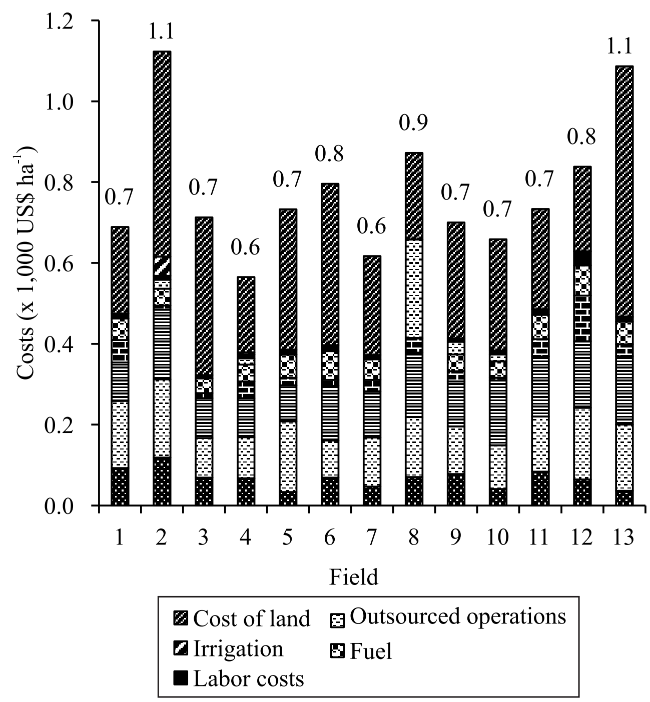

Figure 3. Decomposing the production costs of 13 lowland soybean (*Glycine max*) fields inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil.

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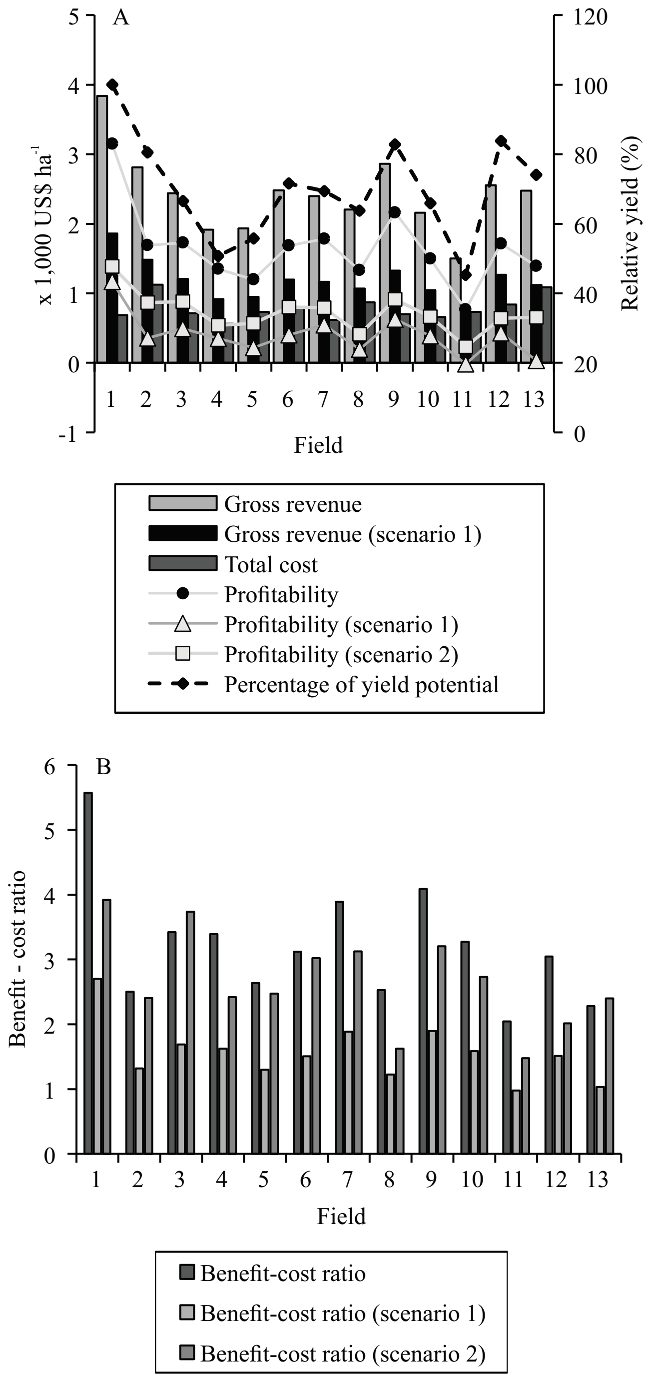

Figure 4. Gross revenue, gross revenue in the first scenario, total cost, profitability, profitability in the first scenario, profitability in the second scenario, and relative yield (A), as well as benefit-cost ratio, benefit-cost ratio in the first scenario, and benefit-cost ratio in the second scenario, obtained for 13 lowland soybean (*Glycine max*) fields (fields 1 to 13) inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil. Scenario 1 and scenario 2, with and without land rental costs.

yield was much higher than that of the other farms. The combination of low production costs and high yields led to this high profit (Bento & Restuccia, 2017).

In general, high production costs resulted in a lower profit, as observed for fields 2, 8, and 13. However, the opposite did not seem to be true, considering that fields 4 and 10 presented a low profit despite a relatively low production cost due to an income and gross yield at the same level. Ali et al. (2020) concluded that, in modern agricultural, production profits are associated to a low production cost and high yield, but also highlighted that market opportunities and environmental specificities can influence the financial result.

The results of the present study show that the first step towards obtaining a high profit is yield increment. The increment of 1% in relative yield led to an increment of US$33.40 in profit (Figure 5). Therefore, yield potential resulting from yield increment and a low production cost is an example of an efficient use of resources, which is the key to a sustainable

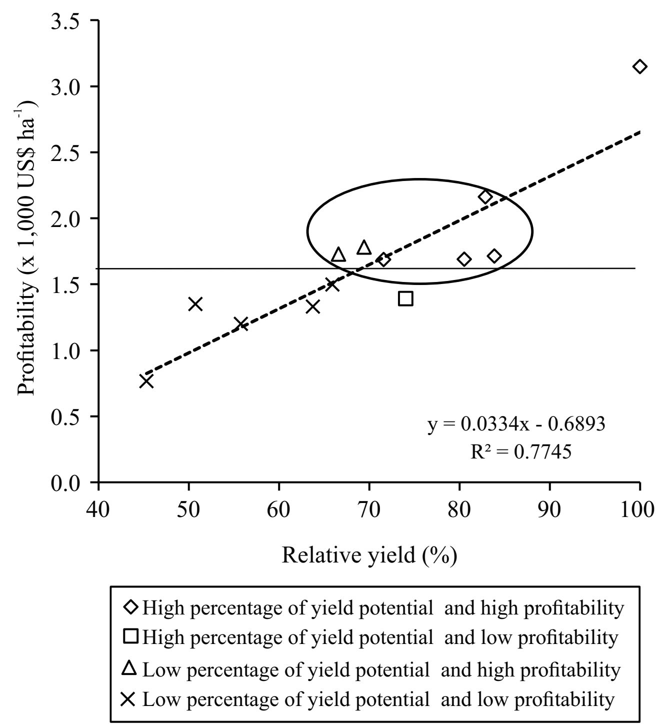

Figure 5. Groupings by relative yield and profitability of 13 lowland soybean (*Glycine max*) fields inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil. The continuous lines represent the average. Values within the ellipse represent the relative yield target.

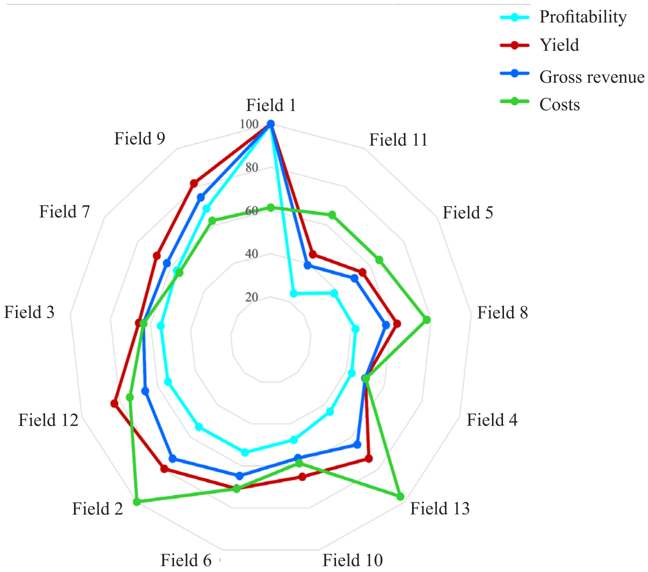

Figure 6. Economic parameters of profitability, yield, gross revenue, and production costs, all as a percentage of the highest observed value, obtained for 13 lowland soybean (*Glycine max*) fields (fields 1 to 13) inserted in a flood-irrigated rice (*Oryza sativa*) system in the states of Rio Grande do Sul and Santa Catarina, Southern Brazil.

and profitable production, as reported by Xavier et al. (2021). Among the management decisions that do not impact production costs, but increment yield are: the definition of sowing date, maturity group of the cultivar, and sowing density. This shows the importance of specific studies that improve decision making, combining technology, socioeconomic aspects, and the allocation of resources. In this line, Andrade et al. (2022) emphasize the importance of acquiring information from producers, searching for the best decisions in order to reduce the yield gap and to improve production efficiency.

Conclusions

1. The relative yield that maximizes profit in the soybean (*Glycine max*)-rice (*Oryza sativa*) system is between 67 and 84%.

2. In general, high production costs lead to a lower profit, but apparently not vice-versa.

3. An efficient use of resources is the key to a sustainable and profitable soybean production.

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