

Agronomic and Economic Evaluation of Sequential Spray of Silicon and Fungicides for a Sustainable Soybean Crop

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Abstract

This study was carried out to determine whether the yield of soybean cultivars and the severity of Asian Soybean Rust (ASR) are influenced by foliar spray of silicon exclusively or along with a fungicide mixture, as well as the economic viability of their use for a sustainable crop. The experiment was performed in randomized-block design, five replicates, two soybean cultivars and (2×6) + 2 factorial arrangements: S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4); S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); NC and PC (negative and positive control). The economic evaluation and sensitivity analysis were undertaken for Anta 82 RR. There was no interaction effect between the factors, and cultivar CD 2737 had a higher yield. ASR was less severe in CD 2737, and S3 and S5 provided the lowest disease severity. Exclusive spray of aluminum silicate was able to reduce the number of lesions with uredinia, open uredinia and uredinia per lesion. S3 increased grain yield, resulting in higher revenues and a 66.1% gross margin. Sensitivity analysis revealed that S3 was profitable in all scenarios.

Keywords: economy, *Glycine max*, *Phakopsora pachyrhizi*, plant nutrition

1. Introduction

The causal agent of Asian rust, *Phakopsora pachyrhizi*, is one of the most important pathogens of soybean crop, due to its high capacity to limit the grain yield. There are reports that income losses outweigh 80% under intense infection, depending on the susceptibility of the genotype (Inayati and Yusnawan, 2016). Nowadays the emergence of pathogen populations resistant to the fungicides active principles (Godoy *et al.*, 2016) has demanded the search for new technologies and integrated control measures for a sustainable soybean crop (Furlan *et al.*, 2018; Roehring *et al.*, 2018).

In economic terms, soybean (*Glycine max*) is considered one of the main agricultural products and one of the major human and animal food sources (Menezes *et al.*, 2019). In the 2017/18 crop, Brazil produced approximately 119 million tons of soybean grains in 35 thousand hectares of planted area (Companhia Nacional de Abastecimento, 2018). However, the sustainability of this crop may be threatened by the damage caused by Asian rust and the emergence of *Phakopsora pachyrhizi* populations resistant to the active ingredients of the

fungicides recommended for its control (Godoy *et al.*, 2016).

Studies about the mineral nutrition of soybean are of paramount importance to minimize factors that might reduce its yield, especially those related to losses caused by Asian rust (Sousa *et al.*, 2019). Among the useful elements, silicon stands out for providing benefits in soil chemical attributes (Fernandes *et al.*, 2020), the development of healthier plants (Rasoolizadeh *et al.*, 2018) and resistance to abiotic stress (Zargar *et al.*, 2019) and acting on important epidemiological components of diseases (Guerriero *et al.*, 2016). The disease resistance provided by silicon is related to the induction of physical and chemical barriers such as cell wall lignification and production of organic compounds and defense enzymes, which hinder the penetration and colonization of the pathogen on the host plant (Guerriero *et al.*, 2016).

There are reports of reduction in the severity of Asian soybean rust following silicon supply. Andrade Junior *et al.* (2015) observed decreases of 43 and 36% in the area under the disease progress curve for soybean rust when the plants were grown in soil containing calcium silicate or were sprayed with potassium silicate, respectively.

The association of several disease control methods in large crops is a recommended sustainable practice (Dias and Theodoro, 2017), and the integration between silicon fertilization and the fungicide use can be promising in that it allows for reducing expenses with chemical products and makes it possible to mitigate the risks of environmental contamination and the appearance of populations of resistant pathogens (Andrade Junior *et al.*, 2015).

The economic analysis of agricultural experiments, especially those evaluating the efficacy of agronomic inputs, adds value to the obtained results (Lacerda *et al.* 2015). This is especially true given the current economic situation of Brazil, in which costs cannot be transferred to consumers. Rather, production efficiency, quality, and profit must be increased (Bruni and Famá 2010).

It is of utmost importance that producers understand this business environment and play their part not only as producers but also as “rural administrators”, focusing on the management of the farm with a view to generating profit (Favato and Nogueira, 2017).

This study was undertaken to determine if soybean yield is influenced by the control of Asian rust through sequential sprays of silicon and fungicides, as well as to investigate its economic impacts.

2. Material and Methods

The experiment was conducted at the Federal University of Mato Grosso do Sul, at Chapadão do Sul Campus (geographic coordinates: 18°4'33" S and 52°40'45" W; 810 m altitude), during the 2012/13 crop. According to the Köppen classification, the climate of the region is an Aw type, defined as tropical wet with rainy summers and dry winters (Kottek *et al.*, 2006).

The experiment was set up as a randomized-block design with five replicates in a (2×6) + 2 factorial arrangements. The first factor was represented by two cultivars of soybean (Anta 82

RR and CD 2737 RR) and the second factor consisted of aluminum silicate spraying (AlSi, $0.523 \text{ g SiO}_2 \text{ ha}^{-1}$) with or without association with a fungicide mixture [FM, (trifloxystrobin + prothioconazole), $60 + 70 \text{ g a.i. ha}^{-1}$]. Two additional treatments were tested: a negative control (without spray) and a positive control (spray of the fungicide mixture in R1+R4). The treatments consisted of sprays of aluminum silicate exclusively (S1: R1 + R4; S2: R1 + R5.1) or sequential sprays with the fungicide mixture, all at different phenological stages of the crop, namely: S3 (AlSi at R1 + FM at R4); S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); and S6 (FM at R1 + AlSi at R5.1). The silicate source used contained Al_2O_3 (20.53%), SiO_2 (17.43%), S (9.82%), CaO (1.31%), TiO_2 (0.34%), MgO (0.18%), Fe_2O_3 (0.16 %), and S_2O_5 (0.10 %).

The products were applied with a CO_2 -pressurized backpack sprayer calibrated to release a spray volume of 150 L ha^{-1} . The experimental plots had a total area of 9.0 m^2 ($1.8 \times 5.0 \text{ m}$), and the evaluations were undertaken in the usable area of 3.6 m^2 ($0.9 \times 4.0 \text{ m}$).

Severity was evaluated on three occasions after the disease was diagnosed (R5.2, R5.3, and R5.4), using a nine-grade diagrammatic scale (Godoy *et al.* 2006). In the evaluation, ten plants were chosen at random per plot, and in each plant, two leaves located in the lower and upper halves of the plant was separated. The individual scores assigned to each half were corrected mathematically, and different weights were assigned to them. A final score was then generated according to the following equation proposed by Madalosso *et al.* (2010):

$$\text{Severity} = (\text{severity in the lower half} \times 0.35) + (\text{severity in the upper half} \times 0.65).$$

After the severity data were obtained, the area under the disease progress curve (AUDPC) was determined (Campbell and Madden 1990).

The defoliation percentage in each plot was estimated at phenological stage R7, by employing a diagrammatic scale with six defoliation levels (Hirano *et al.* 2010). In that stage, ten plants were selected at random per plot and two leaves were collected from the middle third of each plant to determine the number of lesions with uredinia (NLU), number of uredinia per lesion (NUL), and number of open uredinia (NOU). A stereoscopic microscope with up to 80x magnification was used for these counts.

The soybean was harvested from the usable area of each plot at stage R9 and then the material was threshed and cleaned to determine the grain yield (kg ha^{-1}). Means were compared by the Scott-Knott test at the 5% probability level.

For the economic evaluations, the soybean sale price, inputs purchase price, and other expenses were determined based on the current market values (Turco *et al.* 2017, Gaspar *et al.* 2018). Among the cost system classifications, the following components that are part of the production process were surveyed: inputs [aluminum silicate, trifloxystrobin + prothioconazole (fungicide mixture), seeds of the cultivars used, seed treatment (mixture of pyraclostrobin $\{25 \text{ g L}^{-1}\}$ + thiophanate-methyl $\{225 \text{ g L}^{-1}\}$ + fipronil $\{250 \text{ g L}^{-1}\}$), biological inoculant, 00-20-20 fertilizer, potassium chloride, and glyphosate] and agricultural mechanization (harrowing, sowing, topdressing fertilization, spraying and harvesting).

Based on these data, the gross revenue, effective operating cost, gross profit and gross margin were calculated. Together, these economic indices formed the statement of economic results (SER). Costs pertaining to infrastructure, labor, and other inputs were not included in any analysis, since they were the same in all treatments. Thus, some of the production process components were considered.

Sensitivity analyses were performed considering different situations, simulating variations in the economic scenario of the sale prices of the total production volume for all treatments (two control treatments and six spray sequences). The following values were adopted for each scenario: Maximum Price (US\$ 0.9/kg), Standard Deviation + (US\$ 0.8/kg), Average Price (US\$ 0.7/kg), Standard Deviation – (US\$ 0.6/kg), and Minimum Price (US\$ 0.5/kg).

3. Results and Discussion

There was a significant interaction effect ($P < 0.05$) between the evaluated factors only for AUDPC (Table 1), NUL, and NOU (Table 3). No interaction effect was detected between genotypes and sequences of aluminum silicate spray for NLU (Table 2), defoliation, or yield (Table 4).

Cultivar CD 2737 exhibited a lower degree of disease severity than Anta 82 RR when subjected to all treatments (Table 1). However, it is not classified as resistant to Asian soybean rust (Desenvolvimento Produção e Comercialização Agrícola, 2014). The difference in severity in relation to Anta 82 can be explained by morphological differences in the leaf blade, which influences the infectious process of pathogens. Lourenço *et al.* (2011) compared cultivars Monsoy 6101, Anta 82, Monsoy 7908, BRS Valiosa, and Pioneer P98Y11 and found that stomatal and trichome densities, in addition to leaf width, mesophyll, and parenchyma, influence the incidence and severity of leaf diseases in field conditions.

Table 1. Area under the disease progress curve (AUDPC) for the cultivating factors and application sequence (S) of aluminum silicate (AlSi) and fungicide mixture. Chapadão do Sul, MS, 2012/13 crop

Cultivars	Spray sequences							PC
	NC	S1	S2	S3	S4	S5	S6	
CD 2737	30.2 ^{eA}	25.3 ^{dA}	25.0 ^{dA}	11.4 ^{bA}	20.5 ^{cA}	14.4 ^{bA}	22.7 ^{cA}	6.1 ^{aA}
Anta 82	54.7 ^{eB}	44.7 ^{dB}	44.6 ^{dB}	21.0 ^{bB}	35.2 ^{cB}	23.1 ^{bB}	38.4 ^{cB}	10.3 ^{aB}

Means followed by the same lowercase letter in the row and upper case in the column do not differ by Scott-Knott's test at the 5% probability level. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4).

The AUDPC estimated in NC was higher than in all other treatments, whereas PC provided the lowest AUDPC. When the sprays began with aluminum silicate (R1) and then the mixture of fungicides at stages R4 (S3) or R5.1 (S5), lower disease progress was observed over time. Aluminum silicate spray in the beginning of flowering (R1) followed by spray of fungicide at pod formation (R4) or at the start of grain formation (R5.1) contributed to a lower AUDPC.

There were more lesions with uredinia (NLU) in the leaves of cultivar Anta 82 and S3 and S5 were the treatments that led to the lowest NLU, differing from positive and negative controls (Table 2). There was an interaction effect between the factors for NUL and NOU, with only the S3 sequence being similar to PC treatment for the two evaluated cultivars. Spray sequence S5 was only efficient in the plants of cv. Anta 82, which had a similar performance to those treated with PC. This result was likely due to its greater susceptibility to the disease (Table 1). The other spray sequences differed from NC, which led to the highest NUL and NOU means. These variables have been used to quantify differences between levels of resistance among soybean cultivars, since the use of these criteria allows the detection of both the presence of a higher resistance gene and the partial resistance (Inayati and Yusnawan, 2016).

Table 2. Number of lesions with uredinia (NLU), per leaf for the cultivating factors and application sequence of aluminum silicate (AlSi) and fungicide mixture (FM), Chapadão do Sul, MS, 2012/13 crop

	Treatments	NLU
Cultivars	CD 2737	120 ^a
	Anta 82	130 ^b
	NC	151 ^d
	S1	132 ^c
	S2	135 ^c
Spray sequences	S3	107 ^b
	S4	134 ^c
	S5	111 ^b
	S6	134 ^c
	PC	93 ^a

Means followed by the same lowercase letter in the row and upper case in the column do not differ by Scott-Knott's test at the 5% probability level. FM: trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4).

Table 3. Number of open uredinia (NOU) per leaf for the cultivating factors and application sequence of aluminum silicate (AlSi) and fungicide mixture (FM), Chapadão do Sul, MS, 2012/13 crop

Cultivars	Spray sequences							
	NC	S1	S2	S3	S4	S5	S6	CP
NUL								
CD 2737	2.8 ^{cA}	2.4 ^{bA}	2.5 ^{bA}	1.7 ^{aA}	2.4 ^{bA}	2.1 ^{bA}	2.5 ^{bA}	1.7 ^{aA}
Anta 82	3.2 ^{cB}	2.6 ^{bB}	2.6 ^{bB}	1.9 ^{aB}	2.6 ^{bB}	2.4 ^{aB}	2.6 ^{bB}	2.0 ^{aB}
NOU								
CD 2737	199.3 ^{bA}	170.0 ^{bA}	169.6 ^{bA}	114.0 ^{aA}	167.0 ^{bA}	130.6 ^{bA}	171.6 ^{bA}	93.0 ^{aA}
Anta 82	234.3 ^{cA}	177.6 ^{bA}	171.0 ^{bA}	114.0 ^{aA}	179.3 ^{bA}	149.9 ^{aA}	185.6 ^{bA}	141.3 ^{aA}

Means followed by the same lowercase letter in the row and upper case in the column do not differ by Scott-Knott's test at the 5% probability level. FM: trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4).

The spray of aluminum silicate in R1 and fungicide in R4 (Anta 82 and CD 2737) or R5.1 (Anta 82) was able to reduce the components of resistance of the soybean cultivar to Asian rust, consequently inhibiting the progress of Asian rust over time. These findings corroborate those obtained by Lima *et al.* (2010), who evaluated the effect of silicon on the control of Asian rust and observed a reduction in the number of lesions per square centimeter in soybean plants and a lower disease progress rate. Similar results were also obtained by Cruz *et al.* (2012), who observed reductions of 27, 23, and 60%, in number of lesions, number of closed uredinia, and number of fully open uredinia, respectively in the leaflets of plants supplied with silicon in comparison with the leaflets of plants without silicon. Pereira *et al.* (2009) concluded that spray of potassium silicate in soybean cv. MG/BR-46 Conquista

reduced the severity of Asian soybean rust. However, the activity of resistance-related enzymes was not potentiated, suggesting that the product possibly acted upon the pathogen.

We hypothesize that, in the present study, aluminum silicate also had a direct influence on *Phakopsora pachyrhizi* to some extent due to the presence of aluminum, titanium, and iron in aluminum silicate, which might have exerted a direct action, at a certain degree, on the development of the pathogen (Guazina and Theodoro, 2017). We do not discard the possibility that other forms of action of potassium silicate might have occurred. In hydroponic growth conditions, Arsenault-Labrecque *et al.* (2012) reported that the ability of soybean cultivars to absorb potassium silicate triggered hypersensitivity reactions that led to a lesser severity of Asian rust.

There was no interaction between the cultivar and spray sequence factors for defoliation and yield (Table 5). Cultivar CD 2737 defoliated less than Anta 82, and the plants that received no spray (NC) behaved similarly to those that were treated with sequences S1, S2, S4, and S6; i.e., the plants lost fewer leaves early when sprayed with aluminum silicate (R1) and, subsequently, the mixture of fungicides at stages R4 (S3) or R5.1 (S5). Similar results from alternate spray of aluminum silicate and fungicide were obtained by Carvalho *et al.* (2012), who observed a decrease of more than 40% in defoliation in coffee plants. Defoliation may be directly related to disease severity and yield, and higher disease intensity degrees mean greater defoliation and decreased yield (Zuntini *et al.*, 2019). In the current study, this relationship was also verified, since the plant yield was higher in S3 (2,523 kg ha⁻¹) and S5 (2,454 kg ha⁻¹).

The grain yields found when only aluminum silicate was applied (S1 and S2) or when it was applied after the use of fungicide mixture (S4 and S6) were similar to that obtained with NC treatment. Overall, the present results indicate that when the plants had high NUL, NLU, and NOU values, the lowest yields were obtained. This observation is in line with the damage quantification work developed by Danelli *et al.* (2015), who found that, in terms of foliar incidence, the damage coefficients ranged from 3.41 to 9.02 kg ha⁻¹ for every 1% of foliar incidence; for density of lesions, they ranged from 13.34 to 127.4 kg ha⁻¹ for 1 lesion/cm² and, lastly, for uredinium density, they ranged from 5.53 to 110.0 kg ha⁻¹ for 1 uredinium/cm².

Table 4. Defoliation and yield mean values for the cultivating factors and application sequence (S) of aluminum silicate (AlSi) and fungicide mixture, Chapadão do Sul, MS, 2012/13 crop

	Treatments	Defoliation (%)	Yield (kg ha ⁻¹)
Cultivars	CD 2737	54 ^a	2.448 ^a
	Anta 82	64 ^b	2.088 ^b
	NC	67 ^c	2.016 ^c
	S1	73 ^c	1.950 ^c
	S2	69 ^c	1.872 ^c
Spray sequences	S3	51 ^b	2.526 ^b
	S4	61 ^c	2.202 ^c
	S5	51 ^b	2.454 ^b
	S6	65 ^c	2.112 ^c
	PC	33 ^a	2.850 ^a

Means followed by the same lowercase letter in the row and upper case in the column do not differ by Scott-Knott's test at the 5% probability level. FM: trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4).

The effect of silicate fertilization on the yield of several agricultural crops has been investigated even in crops that are not considered silicon accumulators (Lotfi *et al.*, 2018). However, this effect is not always observed in the genotype, since the source, mode, dose and time of silicated products sprays may influence the response in the crop. According to Shwethakumari and Prakash, (2018) the soybean genotype KBS-23 had a better response in grain yield by foliar application of silicon acid in relation to the BAD-2 genotype. Moreira *et al.* (2010) reported that only from the third application the silicon accumulated sufficient levels in the plant, with higher dry mass accumulation and yield.

In spite of the lower yield and high defoliation resulting from aluminum silicate spray at the two phenological stages of the crop, its potential should be better assessed in future

experiments using a larger number of foliar spraying cycles or even via soil supply. This is because, in the current experiment, treatments S1 and S2 led to lower severity and NUL in both cultivars and a reduction of NOU from the exclusive use of aluminum silicate only in cultivar Anta 82 RR (Tables 1 and 2).

In terms of integrated plant disease control, the association between silicon and fungicides shows to be promising, given the systematic loss of agronomic efficiency of fungicides caused by the appearance of *Phakopsora pachyrhizi* populations resistant to several fungicide groups (Godoy, 2012; Dalla Lana *et al.* 2018).

The highest revenue among the disease control criteria was achieved with the S3 treatment, in which aluminum silicate was used in R1 combined with the spray of the fungicide mixture in R4. This result is similar to that obtained with PC treatment, in which two fungicide sprays were performed (Table 5). The highest revenues obtained with S3 and PC treatments were possible because of the increase in grain yield (510 and 834 kg ha⁻¹, respectively) compared with NC. The treatments S3 (2.526 kg ha⁻¹) and CP (2.850 kg ha⁻¹) showed a soybean grain yield near to the Mato Grosso do Sul State average, especially in relation to the most recent crop season 2018/19, which was 2.980 kg ha⁻¹ (Companhia Nacional de Abastecimento, 2019).

The costs involved in the agricultural activity are usually very high, which is due not only to the employed technologies, but also the control of pests and diseases, making it an uncertain environment for producers who purchase inputs at high prices. Further, at the time of sale, these producers are at the mercy of the prices, which fluctuate constantly (Favato and Nogueira, 2017).

According to Colussi *et al.* (2016), expenses for the control Asian rust can account for up to 15% of the effective operating cost (EOC). In the present study, in PC, the fungicide cost was 11.3% of the EOC. The cost of spray sequences S3, S4, S5, and S6 (AlSi + FM) and S1 and S2 (AlSi) represented 6.3% and 15% of the EOC for the control of Asian rust, respectively.

In addition to causing environmental damage, fungicide use raises production costs (Kandel *et al.*, 2016), requiring the adoption of a product that lowers costs without affecting the environment. In spray sequences S3, S4, S5, and S6, the fungicide spray costs were 50% lower than in PC treatment, in which the second fungicide spray, which would cost US\$ 37.4, was replaced with the spray of aluminum silicate, whose cost per hectare was lower (US\$ 2.4/kg c.p. ha⁻¹).

The most significant expenses in soybean production are related to inputs, which, according to Companhia Nacional de Abastecimento, (2016), can amount to up to 68.8%. In sequential sprays S3, S4, S5, and S6 and in PC, the inputs costs accounted for 68.9% and 70.6% of the EOC, respectively. The use of aluminum silicate in S3 led to a 5.3% reduction in the production cost compared with PC treatment and generated a 20.2% higher revenue than the NC treatment.

Table 5. Statement of Economic Results of the sequential application of aluminum silicate (AlSi) and fungicide mixture (FM) in the cultivar Anta 82 RR, Chapadão do Sul, MS, 2012/13 crop

Treatments	NC	S1	S2	S3	S4	S5	S6	PC
Gross Revenue (US\$)	1391,4	1345,9	1292,0	1743,5	1519,8	1693,7	1457,7	1967,1
Costs (US\$)								
Inputs								
Aluminum silicate	-	4.7	4.7	2.4	2.4	2.4	2.4	0
FM	-	-	-	35.2	35.2	35.2	35.2	70.3
Seeds Anta 82 RR	117.2	117.2	117.2	117.2	117.2	117.2	117.2	117.2
Seed treatment *	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
Biological inoculant	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
00-20-20 fertilizer	164.8	164.8	164.8	164.8	164.8	164.8	164.8	164.8
Potassium chloride	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2
Glyphosate	0	29.7	29.7	29.7	29.7	29.7	29.7	29.7
<i>Sub-total Inputs</i>	340.6	375.0	375.0	407.8	407.8	407.8	407.8	440.6
Agricultural Mechanization								
Harrowing	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
Sowing	60.6	60.6	60.6	60.6	60.6	60.6	60.6	60.6
Topdressing fertilization	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Spraying	-	21.4	42.9	42.9	42.9	42.9	42.9	42.9
harvesting	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6
<i>Sub-total Mechanization</i>	140.8	162.3	183.7	183.7	183.7	183.7	183.7	183.7
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	910.0	808.6	733.4	1152.0	928.4	1102.3	866.2	1342.7
Gross margin (%)	65.4	60.1	56.8	66.1	61.1	65.1	59.4	68.3

Dollar quotation (annual average 2012/13): R\$ 1,82. FM: trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4). * Seed treatment: pyraclostrobin + thiophanate-methyl + fipronil, 25 + 225 + 250 g i.a., 200ml/100g of seeds. EOC Effective operating cost.

Sensitivity analysis allowed us to evaluate market trends where fluctuations in the sale price of soybean are constant, from the most favorable market conditions (US\$ 0.9/kg) to unfavorable times (US\$ 0.5/kg). These variations are influenced by several variables, the most noteworthy of which are economic, social, and environmental. These price fluctuations originate great uncertainty for soybean producers (Hirakuri and Lazzaroto, 2014).

In this analysis (Table 6), S3 showed to be advantageous, providing a high revenue in all simulated scenarios. This was mainly a consequence of the increased yield achieved with the use of aluminum silicate combined with fungicide spray.

Table 6. Sensitivity analysis of the sequential application of aluminum silicate (AlSi) and fungicide mixture (FM) in the cultivar Anta 82 RR, Chapadão do Sul, MS, 2012/13 crop

Treatments	NC	S1	S2	S3	S4	S5	S6	PC
<i>Scenario Maximum Price</i>								
Gross Revenue (US\$)	1802.0	1743.0	1673.3	2257.9	1968.3	2193.5	1887.9	2547.5
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	1320.6	1205.8	1114.6	1666.4	1376.8	1602.0	1296.3	1923.2
Gross margin (%)	73.3	69.2	66.6	73.8	69.9	73	68.7	75.5
<i>Scenario Standard Deviation +</i>								
Gross Revenue (US\$)	1530.4	1480.3	1421.1	1917.6	1671.6	1862.9	1603.3	2163.5
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	1049.0	943.0	862.4	1326.0	1080.1	1271.4	1011.8	1539.2
Gross margin (%)	68.5	63.7	60.7	69.2	64.6	68.2	63.1	71.1
<i>Scenario Average Price</i>								
Gross Revenue (US\$)	1391.4	1345.9	1292.0	1743.5	1519.8	1693.7	1457.7	1967.1
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	910.0	808.6	733.4	1152.0	928.4	1102.3	866.2	1342.7
Gross margin (%)	65.4	60.1	56.8	66.1	61.1	65.1	59.4	68.3
<i>Scenario Standard Deviation -</i>								
Gross Revenue (US\$)	1252.5	1211.5	1163.0	1569.3	1368.0	1524.6	1312.1	1770.6
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	771.0	674.2	604.3	977.9	776.5	933.1	720.6	1146.3
Gross margin (%)	61.6	55.7	52	62.3	56.8	61.2	54.9	64.7
<i>Scenario Minimum Price</i>								
Gross Revenue (US\$)	1126.7	1089.8	1046.2	1411.8	1230.7	1371.5	1180.4	1592.8
EOC (US\$)	481.4	537.3	558.7	591.5	591.5	591.5	591.5	624.3
Gross profit (US\$)	645.3	552.6	487.5	820.2	639.2	780.0	588.8	968.5
Gross margin (%)	57.3	50.7	46.6	58.1	51.9	56.9	49.9	60.8

Dollar quotation (annual average 2012/13): R\$ 1,82. FM: trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹. NC: negative control; S1 (AlSi at R1 + R4); S2 (AlSi at R1 + R5.1); S3 (AlSi at R1 + FM at R4), S4 (FM at R1 + AlSi at R4); S5 (AlSi at R1 + FM at R5.1); S6 (FM at R1 + AlSi at R5.1); PC: positive control (trifloxystrobin + prothioconazole, 60 + 70 g a.i. ha⁻¹ at R1 + R4). * Seed treatment: pyraclostrobin + thiophanate-methyl + fipronil, 25 + 225 + 250 g i.a., 200ml/100g of seeds. EOC Effective operating cost.

The gross profit obtained in all analyzed scenarios indicates that soybean production with control of Asian rust using a treatment that combines aluminum silicate and fungicide is a viable economic alternative for the five evaluated market conditions. Among the tested treatments, S3 provided the best gross margins when compared with the other spray sequences.

4. Conclusion

Aluminum silicate spray at the R1 stage and fungicide spray at R4 or R5.1 provided the best control of Asian soybean rust in comparison with the other spray sequences, increasing grain yield. Aluminum silicate was able to reduce the number of lesions with uredinia, number of uredinia per lesion, and number of open uredinia. The severity of Asian soybean rust was lower in cultivar CD 2737 and Aluminum silicate spray at R1 and fungicide spray at R4 (S3) elevated grain yield, resulting in greater profit, with a gross margin of 66.1%.

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