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Soil structure and its relationship with soybean yield[1]

Estrutura do solo e sua relação com a produtividade da soja

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HIGHLIGHTS:
Soils with average sand content between 100.00 and 800.10 g kg^{-1} had soybean productivity of 59 bags ha^{-1}.
Soils with aggregates of diameter above 1.50 mm had soybean productivity of 3,536.36 kg ha^{-1}.
The soil texture is a physical attribute that impacts soybean yield.

ABSTRACT: Soil structure conditions the interaction between the physical-hydraulic, chemical, and biological attributes and determines the potential of soil productivity. Therefore, the objective of this study was to evaluate the structure of soils of areas subjected to soybean production and the impacts of soil structure on crop yield. In total, 28 soybean production areas were selected in the State of Mato Grosso, Brazil, and analyzed for particle size, soil organic carbon and aggregates. Data of soil attributes were subjected to descriptive analysis, Pearson's correlation and Kruskal-Wallis test at $p \leq 0.05$. In general, considering the non-irrigated soybean production areas, it was found that soils with mean sand content between 100.00 and 800.10 g kg^{-1} and clay content between 120.00 and 627.80 g kg^{-1} showed average soybean yield of 3,536.36 kg ha^{-1}. Soils that had aggregates with mean weight diameter and mean geometric diameter above 1.50 mm showed soybean yield equal to or greater than 3,370.67 kg ha^{-1}. Soils of similar textural groups can define different levels of soybean yield, depending on characteristics such as the type of management adopted and production technology applied in the soybean production area.

Key words: *Glycine max*, physical indicator, agricultural areas

RESUMO: A estrutura do solo condiciona a interação entre os atributos físico-hídricos, químicos e biológicos e determina o potencial de produtividade do solo. Portanto, objetivou-se com este estudo avaliar a estrutura de solos de áreas submetidas a produção de soja e os impactos da estrutura na produtividade da cultura. Foram selecionadas 28 áreas de produção de soja localizadas no Estado de Mato Grosso, nas quais foram analisadas granulometria, carbono orgânico do solo e agregados. Os dados de atributos do solo foram submetidos à análise descritiva, correlação de Pearson e teste de média Kruskal Wallis a $p \leq 0.05$. De modo geral, considerando as áreas de produção de soja em sistema de sequeiro foi verificado que solos com teor médio de areia entre 100,00 e 800,10 g kg^{-1} e teor de argila entre 120,00 a 627,80 g kg^{-1} tiveram produtividade média de soja de 3.536,36 kg ha^{-1}. Os solos que apresentaram agregados com diâmetro médio ponderado e diâmetro médio geométrico acima de 1,50 mm tiveram produtividade de soja igual ou maior a 3.370,67 kg ha^{-1}. Solos de grupamentos texturais semelhantes podem definir níveis distintos de produtividade de soja, a depender de características como o tipo de manejo adotado e tecnologia de produção aplicada na área de produção de soja.

Palavras-chave: *Glycine max*, indicador físico, áreas agrícolas

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Introduction

Soil structure is defined by the arrangement of its particle-size fractions, including the porous spaces among them, besides the settlement of the aggregates with their different shapes and sizes (Marshall, 1962). Soil aggregates originate from the union of two or more primary soil particles (Lier, 2010). Soil structure and aggregation have distinct meanings, but both are physical attributes of the soil inherent to its structure.

Anthropic action causes relevant changes in soil structure, since the different management practices cause the breakdown of aggregates in different magnitudes. However, the adoption of more conservational practices, such as no-tillage system, favors the addition and accumulation of soil organic carbon, which benefits the increase in the diameter and stability of aggregates (Marasca et al., 2013; Almeida et al., 2018). In this context, structure is an attribute considered an indicator of soil quality, due to its sensitivity to the management practices adopted (Stefanoski et al., 2013).

Among the particle-size fractions of the soil, those defined as sand, silt and clay determine texture, which is one of the main indicators of quality and productivity, since they influence the dynamics of adhesion and cohesion between soil particles, management practices and, consequently, water dynamics, nutrient cycling, ion exchange and soil resistance (Centeno et al., 2017).

Thus, soil structure conditions the interaction between physical-hydraulic, chemical and biological attributes and determines the productivity potential of the soil. Therefore, when the goal is to obtain high yields in crops such as soybean, in addition to adequate climatic conditions, it is necessary to have soils with favorable edaphic qualities, during all growth stages of the crop (Pereira et al., 2011).

Thus, the objective of this study was to evaluate the structure of soils of areas subjected to soybean production and the impacts of soil structure on crop yield.

Material and Methods

In this study, 28 soybean production areas (Table 1), cultivated in a minimum tillage system, were selected in the State of Mato Grosso, Brazil. The selection was made based on the socioeconomic and ecological diagnosis map of the Mato Grosso State Secretariat of Planning and General Coordination (Secretaria de Estado de Planejamento e Coordenação Geral de Mato Grosso - SEPLAN-MT), considering also the suggestion proposed by Maia et al. (2009), who separate the state into nine regions, considering climate variation, geology, geomorphology, soils and vegetation. In each of the areas, a plot was selected for the collection of soil samples and information about the soybean yield of the plot in the crop season of 2016, the year of the last soil turning operation, and the potential of the genetic material used in this crop season.

Soybean yield deficit was calculated by the difference between the potential of the genetic material and the soybean yield of the plot. Data of soybean yield deficit of the areas were subjected to cluster analyses, using the hierarchical method in dendrogram, considering the minimum distance between the values. From the data of the areas contained in each grouping, levels and sublevels of soybean yield were defined (Table 2).

Table 1. Location of the collection areas and additional information

Area	Ecoregion	STL(5)	SYD(6) (kg ha^{-1})
1	Paraná Basin - Climate: Am(1) and Cwa(2). Precipitation: 1250 to 1750 mm year^{-1}	2014	2400
2**		2016	900
3		2013	1620
4		2016	1500
5	Guaporé Depression - Climate: Ami(3). Precipitation: 1750 to 2250 mm year^{-1}	2013	720
6		2016	1320
7		2016	960
8	Cuiabá Depression - Climate: Am(1). Precipitation: 1500 to 1750 mm year^{-1}	2013	960
9		2013	1380
10		1997	2880
11		2014	1500
12		2016	1500
13*	Parecis Plateau - Climate: Ami(3). Precipitation: 1500 to 2250 mm year^{-1}	2013	1920
14		2015	900
15		2012	1200
16		2013	1440
17	North - Climate: Awi(4). Precipitation: 2000 to 2700 mm year^{-1}	2013	1400
18		2015	1440
19		2013	900
20	Xingú - Climate: Ami. Precipitation: 1750 to 2250 mm year^{-1}	2013	1020
21		2013	2160
22		2013	2820
23		2013	2040
24	Araguaia Depression - Climate: Ami. Precipitation: 1250 to 2000 mm year^{-1}	2015	1500
25		2014	1320
26		2013	1500
27	Northeast - Climate: Ami. Precipitation: 2000 to 2500 mm year^{-1}	2016	1320
28		2013	1500

**Irrigated with center pivot and supplemented with organic fertilization; *Brachiaria grass desiccation before soybean sowing; (1) Am - Tropical monsoon climate; (2) Cwa - Humid subtropical climate; (3) Ami - Very hot tropical monsoon climate; (4) Awi - Tropical savannah climate; (5) Year of last soil turning operation and liming; (6) Soybean yield deficit - 2016/2017 Season

To collect soil samples, the plot was subdivided into lower, middle and upper parts. In the central region of each part, a 3 m^2 area was delimited for collection of samples, where undisturbed, semi-disturbed and disturbed soil samples were taken in the layers from 0 to 0.10 and from 0.10 to 0.20 m.

In each plot, 18 undisturbed samples, 12 semi-disturbed samples (soil clod) and 0.5 kg of disturbed soil were collected for laboratory analyses of soil physical attributes.

Particle-size analysis was performed using the pipette method, with nine replicates for each study area and soil depth. Soil organic carbon was determined by the Walkley-Black method, in three replicates per area and soil layer from 0 to 0.20 m. All the above-mentioned analyses were performed according to the manual of soil analysis methods (Teixeira et al., 2017).

Table 2. Soybean yield levels and sublevels

Yield level	Mean(1)	Upper limit(2)
	(kg ha^{-1})	
A	3,536.36	4,080.00
B	2,595.00	2,760.00
C	1,950.00	1,980.00
Yield sublevel		
A1	3,891.43	4,080.00
A2	3,370.67	3,600.00

(1) Mean yield of the areas comprising each level or sublevel of soybean yield; (2) Highest soybean yield among the areas comprising the level or sublevel

Soil aggregation and aggregate stability analyses were performed using semi-disturbed soil samples, through wet sieving. Calculations were carried out using the equations proposed by Bavel (1949), Castro Filho et al. (1998) and Schaller & Stockinger (1953). Each analysis was performed in nine replicates per study area and soil layer.

Data analysis consisted, initially, of exploratory evaluation of the data, through descriptive statistics. Analysis of Pearson's correlation between the variables was performed to evaluate the degree of association of soil physical attributes with the soybean yield deficit of the study areas. Mean values of soil physical attributes were also compared between areas with different levels of soybean yield, using the Kruskal-Wallis test at p ≤ 0.05.

Results and Discussion

Soils of the sandy, medium-textured and clayey textural groups showed soybean yield deficits of 2010.00, 1476.92 and 1343.64 kg ha^{-1} and median yield deficits of 2160.00, 1380.00 and 1440.00 kg ha^{-1}, respectively, which made it possible to infer that sandy soils, in general, were less favorable to the development of soybean crop, which contributed to the greatest difference between potential of the genetic material and average yield of the plots (Table 3).

However, the minimum value of soybean yield deficit of sandy soils was equivalent to that of clayey soils. From this perspective, sandy soils with clay content ranging from 1.88 to 11.08% and clayey texture with clay content ranging from 38.46 to 59.99% had the same soybean yield (Table 3). Thus, these results are in accordance with Centeno et al. (2017), who stated that the productivity of a soil is directly related to its texture, but that this relationship is also influenced by other characteristics, such as the type of management adopted in the agricultural area. Therefore, sandy soils can be used for soybean cultivation, provided that for this there is an adequate control use and management and an adequate technological level of production is employed.

Table 3. Descriptive analysis of soybean producing areas of different textural groups

	Mean	Median	Minimum	Maximum	CV (%)
Sandy textural group					
Soybean yield deficit (t ha^{-1})	2010.00	2160.00	900.00	2820.00	37.19
Sand (g kg^{-1})	891.60	885.19	827.30	947.24	4.59
Silt (g kg^{-1})	46.84	39.71	14.72	85.50	52.00
Clay (g kg^{-1})	61.55	71.61	18.80	110.85	53.21
Mean weight diameter (mm)	1.28	1.27	0.81	1.81	17.70
Mean geometric diameter (mm)	0.76	0.77	0.44	1.19	24.04
Aggregate stability index (%)	49.30	49.42	30.62	70.34	29.52
Medium-textured textural group					
Soybean yield deficit (t ha^{-1})	1476.92	1380.00	720.00	2880.00	39.33
Sand (g kg^{-1})	662.61	659.43	458.79	805.48	12.87
Silt (g kg^{-1})	95.91	75.93	24.41	311.36	79.71
Clay (g kg^{-1})	241.47	248.19	152,00	391.03	30.25
Mean weight diameter (mm)	1.30	1.29	0.79	2.00	24.50
Mean geometric diameter (mm)	0.83	0.81	0.37	1.43	31.44
Aggregate stability index (%)	55.50	55.51	15.76	80.11	29.75
Clayey textural group					
Soybean yield deficit (t ha^{-1})	1343.64	1440.00	900.00	1500.00	15.41
Sand (g kg^{-1})	381.72	395.73	100.03	581.34	35.84
Silt (g kg^{-1})	117.90	109.18	24.15	335.71	70.68
Clay (g kg^{-1})	500.38	509.97	384.58	599.86	14.89
Mean weight diameter (mm)	1.69	1.56	1.07	2.37	22.42
Mean geometric diameter (mm)	1.22	1.10	0.62	1.92	30.55
Aggregate stability index (%)	85.76	86.48	55.56	94.72	9.92

CV - Coefficient of variation

In soils with medium and sandy texture, coefficients of variation (CV) of 37.19 and 39.33%, respectively, were observed for soybean yield deficit, while in soils of clayey texture the CV was 15.41%. Thus, clayey soils proved to be more stable environments for soybean yield, which was explained by the higher values of mean, median, minimum and maximum clay content, aggregate stability index and lower CV of these attributes. Thus, under similar environmental conditions, clayey soils are less susceptible to loss of production capacity when compared to those with sandier texture (Donagemma et al., 2016).

Table 4 shows the correlations between soil physical attributes and soybean yield deficit. Sand was positively and significantly correlated with soybean yield deficit, indicating that the increase in the sand fraction of the soil contributed to the increase in the yield deficit, that is, the difference between genetic material potential and the average yield of the plots increased, highlighting how challenging soybean cultivation is in sandy soils.

Sandy soils associated with the presence of hot climate limit soybean yield, because agricultural areas with high sand content, above 800 g kg^{-1}, have low water holding capacity, and when in hot regions, they show high evapotranspiration, which imposes a great challenge for soybean cultivation with satisfactory profitability (Franchini, 2016a,b).

Thus, the positive correlation between sand and soybean yield deficit is acceptable and justified by the fact that sandy soils, due to their structure, have low capacity to retain and provide water for plants. It must be pointed out that, in this study, 27 out of the 28 areas are exclusively dependent on water from rainfall.

The distribution of soybean production areas, as a function of sand and clay contents, is presented in Figure 1, which shows that soils with sand contents greater than 850.00 g kg^{-1} are allocated at the soybean yield levels A, B or C, which was explained by the different managements and production technology adopted in each cultivated area. Soybean cultivation in sandy soils has production potential equivalent to or even greater than that of clayey soils, provided that adequate management is adopted (Santos et al., 2008).

Table 5 shows that areas 2, 13 and 22 of the levels A, B and C had soybean yields of 3900.00, 2580.00 and 1980.00 kg ha^{-1}, respectively. Area 2, with approximately 94% sand, had no problems with water availability throughout the crop cycle, due to irrigation with center pivot. This area also received organic and chemical fertilization, which met the nutritional needs of soybean crop.

Table 4. Correlation coefficients between attributes related to soil structure, in the 0-0.20 m layer, and soybean yield deficit

Sand	0.451**
Silt	-0.326**
Clay	-0.390**
Mean weight diameter	-0.273*
Mean geometric diameter	-0.268*
Aggregate stability index	-0.236*

*, ** - Significant at p ≤ 0.01 and at p ≤ 0.05, respectively, by t-test

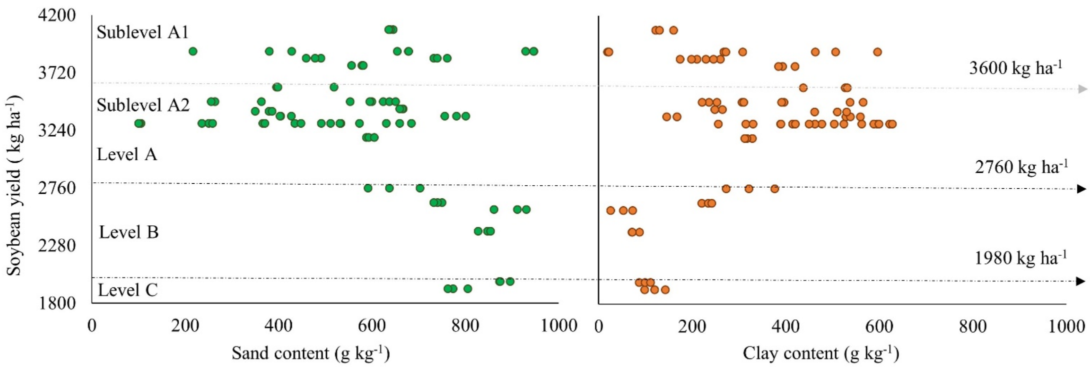

Figure 1. Distribution of soybean yield values as a function of sand and clay contents of the soils

Table 5. Yield and particle size of the areas with sandy soils

	Soybean yield ($kg\ ha^{-1}$)	Sand	Silt	Clay
			($g\ kg^{-1}$)	
Area		0-0.10 m layer		
2	3900	942.83	34.68	22.49
13	2580	900.90	46.89	52.21
22	1980	892.49	17.72	89.79
		0.10-0.20 m layer		
2	3900	938.86	42.21	18.93
13	2580	902.00	50.02	47.98
22	1980	869.75	22.83	107.42

Area 13, with 900.90 g kg^{-1} of sand, had lower soybean yield (1320.00 kg ha^{-1}) compared to area 2. It is worth pointing out that, in area 13, prior to soybean sowing, *Brachiaria* grass was desiccated for soil cover purposes (Table 2), but this practice did not equate to the joint use of irrigation and organic fertilization performed in area 2, which explains the difference in soybean yield.

Area 22, with 88% sand, had lower yield and was classified as level C, with yield of 1980.00 kg ha^{-1}. In this area, no management was performed to improve soil physical conditions; there was only chemical fertilization indicated for soybean crop. In this perspective, soybean crop planted in sandy soils are dependent on cultivation techniques that ensure, besides chemical correction, improvements in water retention and availability.

Clay was negatively correlated with soybean yield deficit (Table 4), i.e., increment of clay in the soil reduced soybean yield deficit in agricultural areas, reducing the difference between genetic material potential and mean yield of the plot. However, a trend of increase in the deficit was noted in areas with clay content from 500 to 599 g kg^{-1}. In this context, it can be affirmed that, among the soils with clay texture, the increment of clay caused a decrease in soybean yield (Figure 2), which is associated with the physical quality of these soils because, according to Klein (2014), soils with clay content above 350.00 g kg^{-1} are difficult to manage because they are heavier, hampering the penetration of plant roots and mechanized operations, besides being susceptible to compaction.

In general, considering the non-irrigated areas of soybean production, it was observed that soils with mean sand content between 100.00 and 800.10 g kg^{-1} and clay content between 120.00 and 627.80 g kg^{-1} had level A yield potential, that is, approximately 59 bags ha^{-1} (3,536.36 kg ha^{-1}). Considering the sublevel A1 of yield (~65 bags or 3,891.43 kg ha^{-1}), the mean sand content was between 341.33 and 744.54 g kg^{-1} and the

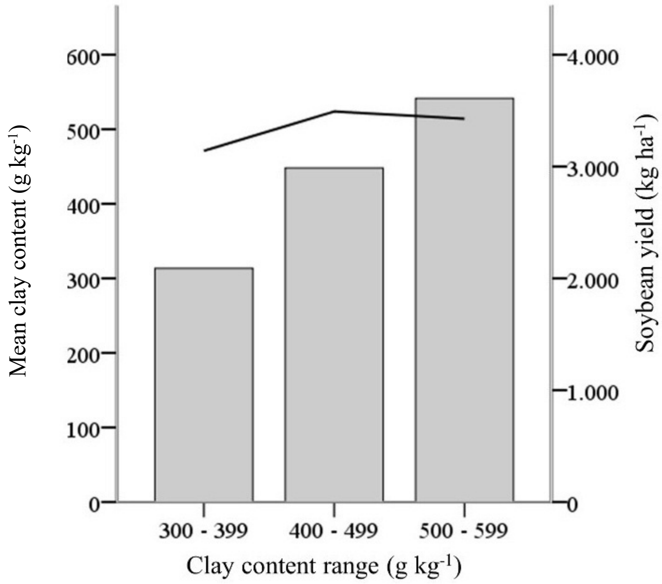

Figure 2. Soybean yield in soils grouped by clay content range

clay content was between 137.26 and 521.97 g kg^{-1}, that is, at that sublevel the average clay and sand contents contemplated only soils of the medium-textured and clayey textural groups.

It is worth mentioning that, by the Kruskal-Wallis test ($p \leq 0.05$), the average sand and clay contents of the group of soils with soybean yield level A differed from the contents found in those of the levels B and C, indicating that soil texture is a physical attribute that impacts soybean yield (Table 6).

Table 4 shows that the mean weighted diameter, mean geometric diameter and aggregate stability index were negatively correlated with soybean yield deficit. Therefore, soils with larger, more frequent and more stable aggregates favored the reduction of soybean yield deficit in the agricultural areas. It must be pointed out that soils that had aggregates with a mean

Table 6. Comparison of the mean values of soil physical attributes

Attributes	Mean levels of soybean yield		
	A [(1)]	B [(2)]	C [(3)]
Sand (g kg^{-1})	507.03 b	782.34 a	830.83 a
Clay (g kg^{-1})	379.43 a	170.59 b	109.25 b
Organic carbon (g kg^{-1})	11.00 a	7.98 ab	5.11 b
Mean weighted diameter (mm)	1.53 a	1.17 b	1.20 ab
Mean geometric diameter (mm)	1.05 a	0.70 b	0.75 ab
Aggregate stability index (%)	70.38 a	52.30 b	52.14 b

Means followed by the same letters in the row do not differ by the Kruskal-Wallis test at $p \leq 0.05$; 1 - Mean soybean yield of 3,536.36 kg ha^{-1}; 2 - Mean soybean yield of 2,595.00 kg ha^{-1}; 3 - Mean soybean yield of 1,950.00 kg ha^{-1}

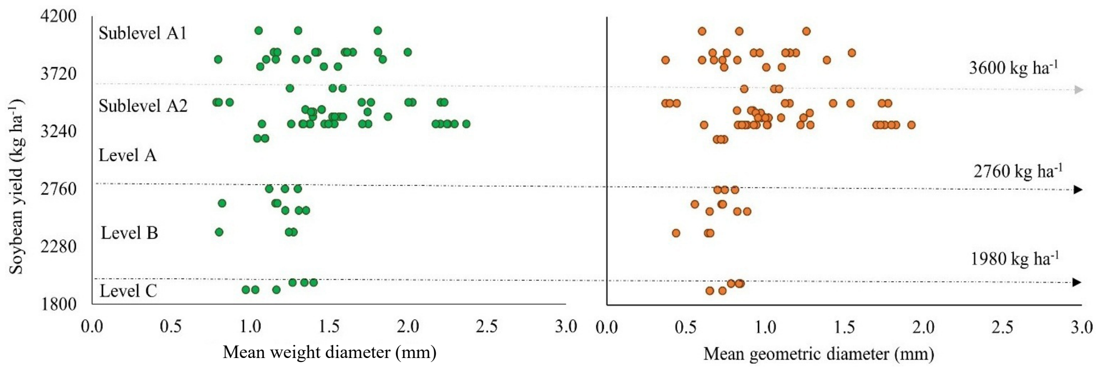

Figure 3. Diameter of soil aggregates at each soybean yield level

weighted diameter lower than 1.50 mm and mean geometric diameter lower than 1.00 mm had soybean yield levels A, B or C (Figure 3).

Conversely, the soils that had aggregates with mean weighted diameter (MWD) and mean geometric diameter (MGD) above 1.50 and 1.00 mm, respectively, were concentrated at the yield level A, giving indications that soils with higher occurrence of class 1.00 mm and high er percentage of aggregates with diameter above 1.50 mm had, on average, soybean yield potential of 3,536.36 kg ha^{-1}.

According to the Kruskal-Wallis test ($p \leq 0.05$), the soils of group A of yield had higher mean weighted diameter and mean geometric diameter of aggregates, when compared to those of group B. The aggregate stability index was higher in the soils of level A of yield (Table 6). These results were explained by the higher clay content in A, which contributed to a greater increase in organic carbon in these soils. Centeno et al. (2017) highlighted the increasing accumulation of organic matter in the soil as a function of the increase in clay content. Clayey soils have greater accumulation of organic carbon when compared to sandy soils, due to the greater physical protection promoted by clay (Dou et al., 2016).

Castro Filho et al. (1998), studying aggregate stability in an Oxisol under different planting systems, found that the conservation production systems had average values of MWD and MGD respectively ranging from 1.40 to 1.75 mm and from 0.77 to 0.98 mm in the 0-0.10 m layer, while for the 0.10-0.20 m layer they varied from 1.08 to 1.31 mm and from 0.66 to 0.77 mm, which indicates that the cultivation system adopted in the agricultural areas of this study have the potential to contribute to the conservation of soil physical quality.

Conclusions

1. Soybean cultivation is dependent on soil sand content, which defines the technological level of production to be adopted in the agricultural area, in order to obtain increments in crop yield and perform a sustainable soil management.

2. The structure of sandy and medium-textured soils contributes to show high coefficient of variation in soybean yield.

3. Soils of similar textural groups can define distinct levels of soybean yield, depending on characteristics such as the type of management adopted and production technology applied in the soybean production area.

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