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Conservation agriculture practices in a peanut cropping system: Effects on pod yield and soil penetration resistance

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ABSTRACT: Conservation agriculture principles applied to peanut can reduce soil erosion and production costs when cultivated in rotation with sugarcane. Still, the problem with soil compaction is the leading cause of skepticism about the efficacy of this practice. This research aimed to study the effect of three soil management strategies compared with conventional for peanut cv. IAC-OL3, cultivated in rotation with sugarcane using the MEIOSI (method of intercropping occurring simultaneously) system for agronomic practices with additional analysis on changes in soil physics properties. The trial was conducted in 2019-2020 in Planalto municipality (São Paulo, Brazil) under a green-harvested sugarcane field, using a randomized complete block experimental design. The trial consisted of four soil management treatments (conventional tillage, minimum tillage with chisel, strip-tillage, and no-tillage) with five replications. Although no differences were verified in soil bulk density and porosity among treatments, the highest values of soil penetration resistance were observed in no-tillage treatment for all evaluations (before planting, at the beginning of flowering, and before and after harvesting) in comparison with conventional tillage. The difference in soil penetration resistance among the treatments diminished from planting to the end of the cycle. Furthermore, low soil disturbance and maximum covering with straw significantly increased the available water capacity and reduced the incidence and severity of *groundnut ringspot virus* (GRSV) on peanut plants. Consequently, both minimum-tillage and no-tillage have increased the pod yield on average by 695 and 991 kg ha^{-1} more than strip-tillage and conventional tillage, respectively, without differences in terms of quality and pod losses.

Keywords: *Arachis hypogaea* L., no-tillage, strip-tillage, soil compaction, groundnut ringspot virus (GRSV).

INTRODUCTION

Peanut (*Arachis hypogaea*) is one of the most important leguminous cash crops with dual-purpose (oilseed and food). It is predominantly cultivated in semi-arid conditions, mainly in China (40 %), India (15 %), USA (7.2 %), and some African countries (Rachaputi et al., 2021). In this scenario, Brazilian peanut production, which represents less than 2 % of the world production, is concentrated in São Paulo State, where around 200 thousand hectares are cultivated yearly, mainly as a crop rotation with sugarcane and pasture. In the last ten years, this system has had new technologies implemented (cultivars, harvester machines, and fertilizers), which have contributed to an increase in the area cultivated, the production, and the yield by 53, 61, and 38 %, respectively (Conab, 2023).

Traditionally, conventional intensive tillage is adopted as the primary practice for achieving good peanut production. Butts and Valentine (2019) mentioned that, for many years, tillage with moldboard plow followed by disking was the best option to increase yield up to 336 kg ha^{-1} due to the reduced impact of diseases. On the other hand, peanut growers have spent a lot more fuel and labor with tillage operations to create a residue-free raised or flat seedbed. Consequently, soil erosion and an expressive cost increase are serious constraints for the peanut cropping system.

Soil loss remains a challenge for peanut cropping around the world because it is cultivated mainly in sandy soils. McCarty et al. (2016) explained that in the USA, from 1975 to 2014, the soil loss was estimated at 12 Mg ha^{-1} yr^{-1}. This study showed that for each 1.0 kg of pod harvested, 5.0 kg of soil is lost by erosion. In ranking 27 crops in terms of soil losses, peanuts are fourth in soil loss, with an average loss of 27 Mg ha^{-1} yr^{-1} (Anache et al., 2017). Research carried out in Brazilian soils for 12 years verified soil losses were more than 30 Mg ha^{-1} yr^{-1} (Marques et al., 1961). This major susceptibility to soil erosion comes from large space between rows (0.90 m), low vegetive growth at the beginning of development, and the great number of tillage operations used for peanut crop at least seven times prior to planting (Bolonhezi et al., 2019). Also, it is important to say that in a sugarcane field harvested without burning, normally, the distance between terraces is increased to save time in the harvesting operations, but during the spring/summer with the highest precipitation, the occurrence of soil erosion increased quickly and significantly (Bolonhezi et al., 2019). According to Kuhwald et al. (2022), peanut production is included on the list of crops with high soil loss due to harvesting, but there is little information about it.

Considerable research has investigated the use of full, reduced, and no-tillage on the agronomic performance of peanuts since the beginning of the 1980s decade (Grichar and Boswell, 1987; Wright and Porter, 1991; Sholar et al., 1995) and until the present-day conservation tillage continues to be an essential issue (Mulvaney et al., 2017; Balkcom et al., 2018; Tubbs, 2019). However, even with all advantages in terms of protection against soil erosion, there is still great skepticism about the efficacy of applying conservation agriculture principles. This skepticism happens because there are many challenges related to the difficulty of improving the seed-to-soil contact for proper moisture absorption (low plant stand), and due to the high soil compaction can cause much more difficult at the time of digger, and consequently, the pod loss is increased (Jackson et al., 2011).

As an alternative to alleviate soil compaction and improve the quality of plant stand, it was developed in the USA to use as a strip-tillage. This comprises a coulter ahead of a subsoil shank followed by baskets that create a residue-free, smooth seedbed to facilitate seed-soil contact (Aulakh et al., 2005). Siri-Prieto et al. (2009) have studied different combinations of strip-tillage in integration with grazing. They concluded that the effect of in-row subsoil plus disk resulted in 42 % more productivity and better plant stand than no-tillage, even with lower soil water content. Other studies have shown that strip tillage in comparison to conventional tillage has reduced the soil mechanical resistance (Zhao et al., 2009; Jackson et al., 2011), which has increased the profitability (Faircloth et al., 2012), along with diminished weed infestation (Aulakh et al., 2015). Strip-tillage has increased the size of nodules in the root system (Rowland et al., 2015) and has reduced soil moisture loss (Hawkins et al., 2016). But this depends on the conditions the strict no-tillage shows higher pod yield and economic return in comparison with strip-tillage (Godsey et al., 2011).

Although there are scientific results in Brazil showing many advantages of no-tillage, mainly in rotation with sugarcane (Bolonhezi et al., 2007; Leonel, 2010), recently it was started commercial experiences with equipment for strip-till, known as Rip Strip®. Preliminary studies have concluded that strip-tillage with Rip Strip® provides better quality of digging (Ormond et al., 2018) and an expressive reduction in the soil compaction, mainly for sugarcane rotation (Bolonhezi et al., 2019). But those results are not enough to recommend as a feasible practice. Furthermore, it should be considered that the digging operation before harvesting provides disturbance on the topsoil, then the concept of conservation agriculture is more suitable (Derpsch et al., 2014).

Soil bulk density and penetration resistance strongly correlate with the addition of water content. Variations in soil texture, water content, and bulk density are all influential properties that need to be modeled for to compare across an area in a field to compare penetration resistance (Vaz et al., 2013). The differences created by these parameters are important for comparing tillage types.

In addition, nowadays there is a trend towards increasing the adoption of MEIOSI (Method of Intercropping Occurring Simultaneously) system with pre-sprouted bud, in which the tillage is done just for the "mother row" and is maintained the space between them with residue on the soil surface (Figure 1). The MEIOSI system was created at the beginning of the 1980s and comprised the production of propagation material at the same time and site of the leguminous crop (Barcelos, 1984). This technique was kept on standby for many years, but nowadays represent almost 28 % of sugarcane new plantation according to the sugarcane survey from IAC (Revista Canavieiros, n.d.). Regarding the lack of information about peanut in MEIOSI system, our hypothesis was: peanut pod yield is not diminished by soil compaction when the conservation agriculture principles are adopted. The aim was to study the effect of three conservation tillage in comparison with conventional, for peanuts cultivated in rotation with sugarcane by MEIOSI system on agronomic characteristics and changes in soil physics properties.

MATERIALS AND METHODS

A field trial was initiated during the growing season 2019-20 at Planalto municipality (São Paulo State, Brazil). According to Santos et al. (2018), the soil was classified as *Latossolo Vermelho-Amarelo* álico, medium texture (18 % of clay), which is equivalent to a typic Oxisol (Landon and Booker, 2014). Soil physical and chemical properties were obtained after the seventh harvest of sugarcane (Table 1), with chemical properties determined by standard methods (van Raij, 2001). The studied site's geographic coordinates are 21° 02′ 06″ S and 49° 55′ 48″ W, and it is located at 423 m above sea level. The region's climate is classified as A.W., tropical with dry winters and rainy summers (Alvares et al., 2013), with a mean annual temperature of 23.4 °C and mean annual rainfall of 1,465 mm.

The experiment was implemented in a commercial field of sugarcane ratoon with cv. RB855156, which was harvested without burning for seven years. The experimental area was 27 ha planted to renew by the MEIOSI system and intercropped by splitting into 2.30 ha (8.3 %) of sugarcane and 24.7 ha (91.7 %) of peanuts. The last harvest was done on May 30, 2019, and the amount of straw on the soil surface was estimated at 20.7 Mg ha^{-1}. According to the chemical results, 3.0 Mg ha^{-1} of dolomitic limestone was applied (05/27/2019) on the soil surface to elevate the base saturation level (V%) up to 70 %. The limestone was incorporated at the conventional tillage.

Figure 1. Field planted in MEIOSI system with one row of sugarcane and 26 rows of peanuts planted before the next row of sugarcane.

By adopting the MEIOSI system (Barcelos, 1984), seedlings genotype RB966928 from pre-sprouted buds were transplanted into a single row spaced at 23.1 m apart from the next row on 7/10/2019 using conventional tillage. The strips between sugarcane rows were used as the peanut plots to install the trial using a completely randomized block with four treatments (conventional tillage, minimum tillage with chisel, strip-tillage, and no-tillage) and five replications. In June 2019, conventional tillage comprised five operations: twice harrow disk plus one deep subsoiler (up to 0.5 m), followed by two disk passes before planting. A 6-shank standard chisel (GTS®, model Terrus®) spaced by 0.60 m each other was used with a 0.45 m depth for the minimum tillage. The strip-tillage was done with an implement (Carderolli Company) similar to Rip Strip®. The version used had four lines with a coulter mounted in front of an in-row subsoiler regulated to 0.45 m depth, followed by fluted coulters and a rolling crumble basket to prepare a seedbed approximately 0.40 m width. Both the minimum tillage and strip-tillage were done on 8/17/2019. The tractor used for the operation was a John Deere 7200 model with 220 cv of power. A no-tillage planter was configured to sow directly under sugarcane straw with a vacuum planter (John Deere®, model 1113, adapted with a bigger coulter disk and a small shank to substitute the double disk) with six single rows, spaced by 0.90 m.

The peanut genotype IAC-OL3 (Godoy et al., 2014) was planted on 10/17/2020 using the same vacuum planter for all treatments and the same regulations in terms of seed density (17 seeds per meter), fertilizer in the furrow (8 and 27 kg ha^{-1} of N and P, respectively). At 30 days after planting, 59 kg ha^{-1} of K as KCl was applied by broadcasting. Using controlled traffic technology, a tractor was used to make all the chemical applications to control weeds, pests, and diseases.

Table 1. Soil chemical properties before planting peanut at Planalto, São Paulo, Brazil, 2019

Layer	OM	pH	P	K^+	Ca^{2+}	Mg^{2+}	H+Al	CEC	V%
m	g dm^{-3}	$CaCl_2$	mg dm^{-3}			mmol$_c$ dm^{-3}			%
0.00-0.25	14.9	4.9	21.0	0.7	16.3	4.1	23.1	44.2	46.9
0.25-0.50	11.0	5.1	7.3	0.4	12.3	3.0	20.3	36.0	43.3

OM: organic matter; CEC: cations exchangeable capacity; V%: base saturation.

Agronomic characteristics were evaluated from the planting to the harvesting of peanut. The number of seedlings that emerged was counted 20 days after planting (11/1/2019) for a 1.0 m section at 10 points in each replication. Samples of aboveground biomass (shoot) were 1.0 m sections taken from at two points in all replications at five different development stages according to Boote (1982); V1/R1 (11/1/2019), R3 (12/18/2019), R4 (1/14/2020), R5 (1/30/2020), and R6 (2/12/2020). After recording fresh weight and the roots, pods and leaves were separated, the pods were counted and placed in a forced-air dryer at 60 °C for 72 h. A percentage of mature kernels was done by hull scrape method (Williams and Drexler, 1981), and samples were taken in 0.50 m per row at 117 (2/12/2020), 122 (2/19/2020), and 131 (2/27/2020) days after emergence. When peanuts reached optimum pod maturity (3/2/2020, at 135 DAE), all 24 rows were mechanically dug and inverted using a digger/inverter (KBM®, model AIA KBM2-L) and harvested three days later (3/5/2020) with a harvester of four rows (MIAC®, Twin Master model). Both harvest operations were done with a John Deere, model 6190J, with a 190 cv tractor (10.650 kg). For each plot (approximately 1.0 ha), all the production was collected and then transferred by truck to the cleaner. At the cleaner impurities were separated out, then the peanuts were weighed out to determine pod yield regarding 8 % of kernel moisture for storage. A sample of 15 kg of pods was taken to unshelled mechanically to determine the percentage of sound mature kernels (%). After harvesting, the pod loss was evaluated using Segnini et al. (2013) methods, taking all the pods on the soil surface and below ground, regarding a grid of 1.11 × 1.80 m. The pods lost were dried to determine the yield left in the field. Although this research was not a goal, it was included in the evaluation for the incidence and severity of *groundnut ringspot virus* (GRSV), according to Culbreath et al. (1997), because there was an expressive occurrence.

Soil resistance penetration (RP) was measured in all plots on October 3 (before planting), December 18 (initial flowering), January 30 (peak of pegging and pod filling), and March 10 (after harvesting). The measurements were done at each 1.0 cm depth using a digital penetrometer (DLG brand, PNT2000® model) in two randomly selected points per plot (in row and interrow) from 0.0 to 0.54 m soil depths. The data was transferred to a computer, and the results were expressed in MPa. On the same day of evaluation, soil samples were taken at five layers (0.00-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, and 0.40-0.50 m), according to the method by Camargo et al. (1986), to measure the soil gravimetric water content (GWC). At the peak of flowering and filling pods (1/14/2020), soil samples were taken using volumetric cylinders (0.05 m of height × 0.05 m of diameter) in two positions, in row and interrow of peanut crop. The samples were transferred to a private laboratory to determine the following physical properties: total porosity (TP), macroporosity (Ma), microporosity (Mi), bulk density (BD) and available water capacity (AHC) according to (Claessen, 1997).

Statistical analysis was performed using AGROESTAT software (Barbosa and Maldonado, 2009) to perform ANOVA and Tukey test (5 % probability) to determine the separation among the mean values. Mechanical penetration resistance in the soil was considered by an average of 0.10 m layer increments to allow for a comparison of treatments.

RESULTS

There were significant ($p<0.001$) differences among treatments on soil penetration resistance when the measurement was done before planting (Figure 2a). As it is shown, methods of tillage greatly affected soil mechanical resistance for layers below 0.10 m depth, but just for the MT (minimum tillage with a chisel), no statistical difference was observed in comparison with CT (conventional tillage). Minimum tillage with a chisel (MT) demonstrated good efficiency because it could reduce penetration resistance (PR) and keep the soil covered with sugarcane straw. At that moment, NT has already shown the highest values of PR below 0.20 m depth (from 4.8 MPa up to 5.8 MPa), significantly higher than other treatments. The same trend is observed for measurement done approximately 75 days later (Figure 2b), 117 days later (Figure 2c), and for an evaluation done after harvesting (Figure 2d), but for all treatments, there was an expressive increase in the magnitude of values across time from the beginning.

When evaluating in-row and interrow separately (Figures 3a, 3b, 3c and 3d) during the peanut growing cycle, it is possible to identify the difference between them, especially in the interrow measurements. For measurements done in-row, no statistical difference was observed among treatments at 62 DAP (Figure 3a), except in the layer 0.10-0.20 m at 113 DAP (Figure 3b). All measurements were higher than 2.9 MPa below the soil layer of 0.10-0.20 m at 113 days after planting (Figure 3b). However, the highest value was observed for MT and NT, with 10.2 and 12.3 MPa, respectively (Figure 3b). In comparison for measurement done in the interrow, no difference was verified from topsoil to deeper layers between CT and MT and between MT, NT, and ST (strip-tillage) at 62 DAP (Figure 3c). But for all of them, the highest PR was measured at the soil layer 0.40-0.50 m, with the following results: 8.54, 10.10, 12.10, and 12.20 MPa (Figure 3d), respectively for CT, MT, NT, and ST Comparing the PR between in-row and interrow for ST evaluated 113 days

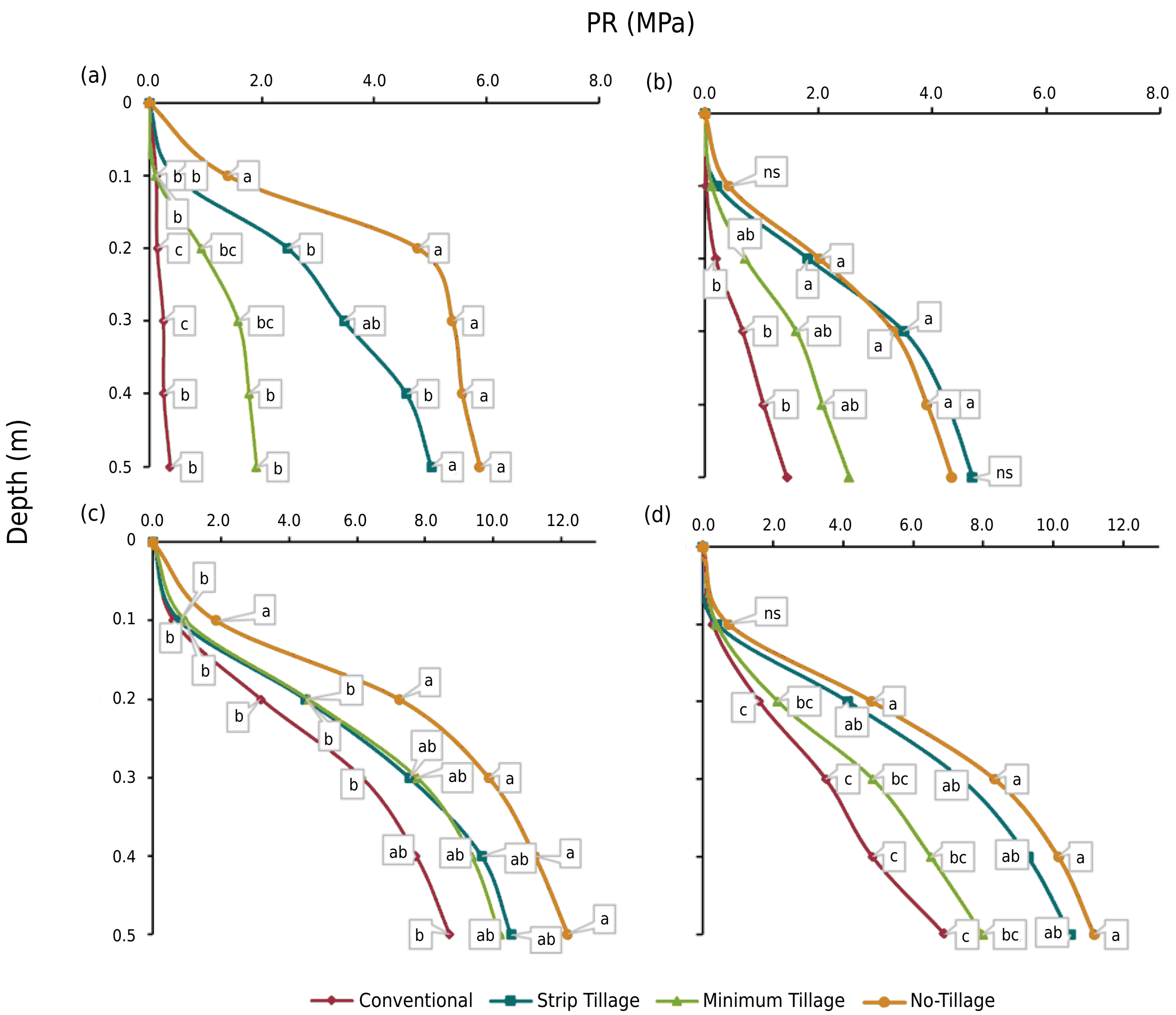

Figure 2. Soil penetration resistance (PR) for the following measurement dates: (a) 10/3/19, (b) 12/18/19, (c) 1/30/20, (d) 3/10/20, with the average comparing the soil management in each layer (depth). ns: not significant by the Tukey (5 %).

after planting (Figures 3b and 3d) proved a strong effect from in-row subsoiling. The effect of subsoiling in-row could diminish the soil penetration resistance in 54, 43, 23, and 23 %, respectively, for the layers of 0.10-0.20, 0.20-0.30, 0.30-0.40, and 0.40-0.50 m.

In this research, it was just observed significant differences for Mi (Microporosity) and AWC (Available Water Capacity) among treatments (Tables 2 and 3) for samples collected at interrow and at the first layer. Table 3 shows that the highest AWC was determined for NT (0.110 $m^3 m^{-3}$) and the lowest for MT (0.088 $m^3 m^{-3}$) at 0.00-0.30 m soil layer. The soil gravimetric water content (GWC) was measured simultaneously with penetration resistance evaluation and is presented in table 4. It is important to mention that the samples were taken regarding an average of plots, so no statistical analysis was done. Evaluations were done twice during the peanut growing season, with MT presenting 16 (62 DAP) and 24 % (113 DAP) more soil water content than CT. For all treatments, there was a reduction in the soil water content from 62 DAP up to the harvest. In addition, it is important to emphasize that all measured GWC presented values below the field capacity (0.220 g of water per g^{-1} of soil).

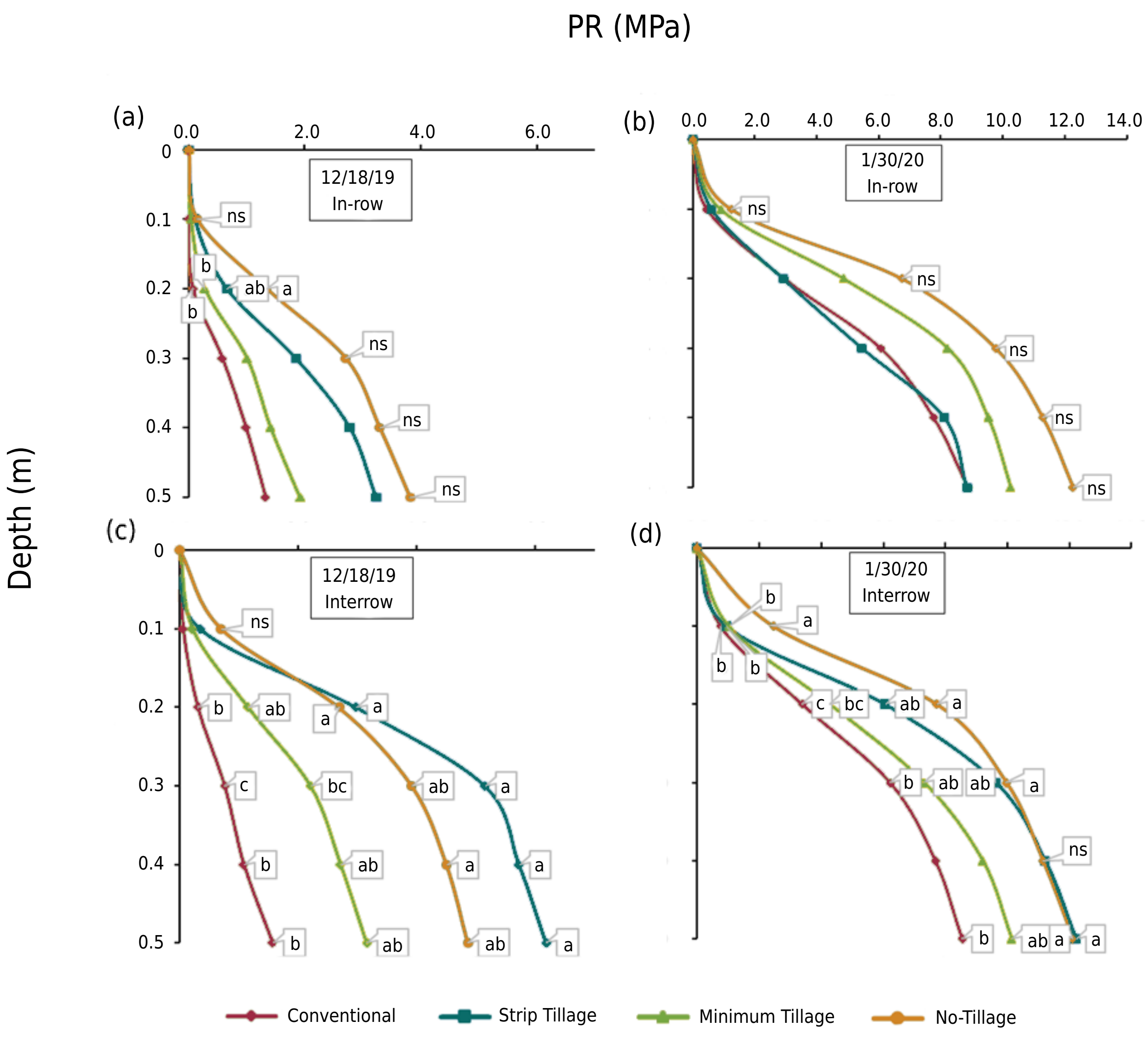

Figure 3. Soil penetration resistance (PR) at different dates and measurement positions (a) 12/18/19 in-row, (c) 12/18/19 interrow, (b) 1/30/20 in-row, (d) 1/30/20 interrow, means comparing the soil management in each soil layer (depth). ns: not significant by the Tukey (5 %).

Table 2. Soil physical properties in different conservation tillage in two positions (in-row and interrow) at the peanut crop. Planalto city, São Paulo State, Brazil, 2019

Soil layer[1]	Row[2]						Interrow[2]					
	CT	RS	MT	NT	Test F	CV	CT	RS	MT	NT	F Test	CV
m						Macroporosity						
	$m^3\ m^{-3}$					%	$m^3\ m^{-3}$					%
0.00-0.10	0.18	0.17	0.14	0.09	3.14^{ns}	36.56	0.10	0.12	0.15	0.09	1.16^{ns}	45.02
0.10-0.20	0.15	0.13	0.12	0.07	2.23^{ns}	38.46	0.06	0.09	0.11	0.07	1.52^{ns}	42.41
0.20-0.30	0.10	0.10	0.10	0.08	0.75^{ns}	34.02	0.07	0.07	0.09	0.06	1.52^{ns}	32.79
0.30-0.40	0.10	0.07	0.09	0.08	0.65^{ns}	33.31	0.08	0.08	0.07	0.08	0.29^{ns}	29.60
0.40-0.50	0.13	0.08	0.08	0.09	2.81^{ns}	31.79	0.09	0.10	0.10	0.08	0.73^{ns}	29.41
						Microporosity						
	$m^3\ m^{-3}$					%	$m^3\ m^{-3}$					%
0.00-0.10	0.24	0.23	0.22	0.25	1.89^{ns}	7.96	0.27ab	0.27a	0.23b	0.26ab	3.93*	7.16
0.10-0.20	0.24	0.23	0.23	0.25	2.29^{ns}	6.31	0.25	0.24	0.24	0.25	0.42^{ns}	9.16
0.20-0.30	0.24	0.24	0.25	0.25	0.97^{ns}	5.00	0.25	0.26	0.25	0.26	3.20^{ns}	3.06
0.30-0.40	0.25	0.26	0.26	0.26	0.52^{ns}	4.93	0.27	0.26ab	0.25b	0.26ab	6.48**	2.73
0.40-0.50	0.25	0.26	0.26	0.26	1.14^{ns}	4.57	0.26	0.26	0.25	0.24	0.63^{ns}	11.95
						Total Porosity						
	$m^3\ m^{-3}$					%	$m^3\ m^{-3}$					%
0.00-0.10	0.42a	0.40ab	0.36ab	0.34b	3.39^{ns}	11.83	0.37	0.39	0.39	0.36	0.48^{ns}	13.37
0.10-0.20	0.39	0.36	0.35	0.33	2.49^{ns}	10.79	0.32	0.34	0.35	0.32	0.61^{ns}	12.31
0.20-0.30	0.35	0.35	0.35	0.33	0.63^{ns}	7.74	0.33	0.33	0.34	0.32	0.46^{ns}	7.63
0.30-0.40	0.35	0.33	0.35	0.34	0.79^{ns}	7.16	0.35	0.35	0.32	0.34	1.25^{ns}	7.11
0.40-0.50	0.38	0.35	0.34	0.35	1.48^{ns}	8.94	0.35	0.36	0.36	0.32	3.42^{ns}	6.72
						Bulk Density						
	$Mg\ m^{-3}$					%	$Mg\ m^{-3}$					%
0.00-0.10	1.40	1.47	1.53	1.65	3.10^{ns}	8.84	1.61	1.63	1.54	1.64	0.44^{ns}	9.18
0.10-0.20	1.54	1.59	1.58	1.71	1.88^{ns}	7.76	1.71	1.70	1.65	1.72	0.64^{ns}	5.13
0.20-0.30	1.61	1.67	1.62	1.67	0.44^{ns}	6.39	1.70	1.74	1.65	1.75	1.48^{ns}	4.81
0.30-0.40	1.64	1.67	1.69	1.65	0.43^{ns}	3.85	1.65	1.65	1.71	1.66	1.31^{ns}	3.42
0.40-0.50	1.55	1.65	1.67	1.65	1.68^{ns}	5.69	1.58	1.56	1.58	1.62	0.71^{ns}	4.08

[1] Means in the lines compare soil management at the same soil layer; [2] measurement position; * significant by the Tukey test ($p<0.05$); ^{ns}: not significant at 5 % probability.

A delay in the vegetative growth observed at the beginning certainly affected the percentage of mature pods close to the harvest. This effect is shown in figure 4, in which it can see that the percentage of mature pods at 131 days after planting was 67, 58, 52, and 48 %, respectively, for CT, ST, NT, and MT. The recommendation for all conservation tillage is to do the digging and harvesting when this index achieves more than 65 %; the percentage probably was below the day of digging. Even though there was less percentage of mature pods and more percentage of impurity in pod production, MT and NT produced an average of 695 and 991 kg ha^{-1} ($p<0.01$) more than ST and CT, respectively. But no difference was found among treatments for kernel yield (Figure 5).

The incidence (% of plants with symptoms) and severity (level of symptoms) of the virus (GRSV) were significantly higher ($p<0.001$) in conventional tillage (Figure 6). When the soil was covered with straw at any level, the percentage of plants with symptoms was 13.3 % lower than conventional tillage, and the level of injury was lower too. There was a significant negative correlation between pod yield with incidence ($r = -0.54^*$) and severity ($r = -0.48^*$) of the virus (GRSV).

Table 3. Available Water Capacity ($m^3\ m^{-3}$) in two measurement positions, in-row and interrow, evaluated at soil layer 0.00-0.30 m, the means compare the managements in each measurement position by Tukey test (p<0.05)

Treatment	Available Water Capacity	
	In-row	Interrow
	$m^3\ m^{-3}$	
Conventional	0.098	0.109a
Strip tillage	0.097	0.105ab
Minimum tillage	0.089	0.088b
No-tillage	0.105	0.110a

Means followed by different letter in the lines differ by 5 % probability.

DISCUSSION

Regarding the average of PR from the topsoil to the deeper layer, NT presented the highest value (4.6 MPa) and CT the lowest (0.2 MPa). The current research has shown the negative impact of mechanized harvest systems for sugarcane in terms of soil structure and indicates that there is alternative tillage to diminish soil penetration resistance. The high level of soil compaction in sugarcane fields after many years of green-mechanized harvest is common and is pointed out in several articles (Otto et al., 2011; Barbosa et al., 2018; Martíni et al., 2021). It is important to consider that the penetration resistance depends on the soil water content, and both are affected by the soil texture, structure, aggregation, and bulk density (Gliński and Lipiec, 1990; Vaz et al., 2013). In terms of the type of soil, our findings represent similar conditions for almost 25 % of sugarcane fields

Table 4. Soil gravimetric water content (GWC) in different conservation tillage for peanut crop in Planalto City, São Paulo State, Brazil, 2019

Treatments	Soil layer	Measurement dates							
		03/10/19	Mean[1]	18/12/19	Mean[1]	30/01/20	Mean[1]	10/03/20	Mean[1]
	m	$g^{-1}\ g^{-1}$							
	0.00-0.10	0.046		0.117		0.116		0.085	
	0.10-0.20	0.110		0.195		0.119		0.106	
Conventional	0.20-0.30	0.107	0.101	0.126	0.138	0.117	0.115	0.105	0.103
	0.30-0.40	0.114		0.127		0.104		0.106	
	0.40-0.50	0.127		0.124		0.117		0.113	
	0.00-0.10	—		0.187		0.099		0.073	
	0.10-0.20	—		0.174		0.066		0.071	
Strip Tillage	0.20-0.30	—	—	0.140	0.154	0.073	0.076	0.096	0.089
	0.30-0.40	—		0.133		0.034		0.096	
	0.40-0.50	—		0.138		0.106		0.109	
	0.00-0.10	—		0.220		0.102		0.065	
	0.10-0.20	—		0.150		0.115		0.083	
Minimum Tillage	0.20-0.30	—	—	0.151	0.171	0.124	0.121	0.090	0.090
	0.30-0.40	—		0.154		0.127		0.111	
	0.40-0.50	—		0.178		0.136		0.104	
	0.00-0.10	0.110		0.150		0.089		0.120	
	0.10-0.20	0.103		0.122		0.100		0.099	
No-Tillage	0.20-0.30	0.119	0.118	0.131	0.136	0.103	0.104	0.100	0.114
	0.30-0.40	0.130		0.139		0.113		0.120	
	0.40-0.50	0.129		0.139		0.117		0.130.	

[1] Average value of all layers.

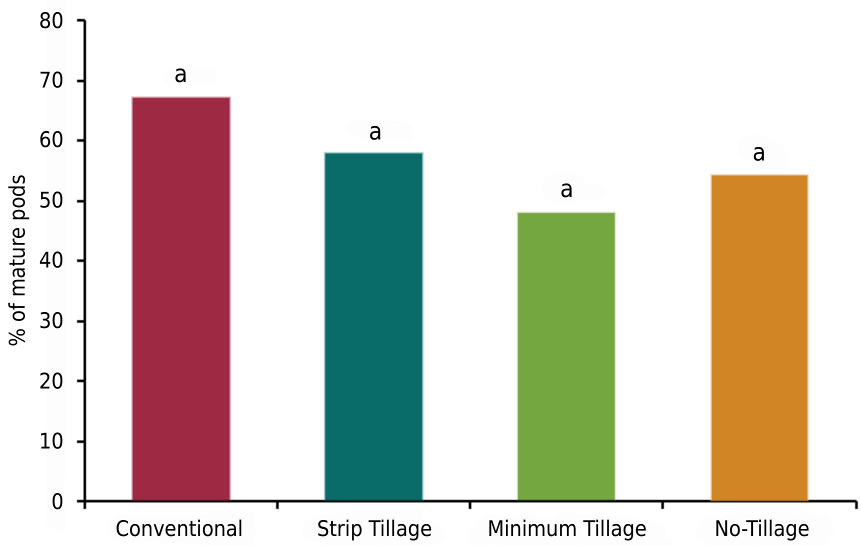

Figure 4. Percentage of pods ripe at 131 days after planting (%), the means compare the management with the percentage of maturation, means followed by the same letter do not differ by Tukey's test at 5 % probability.

in São Paulo State. Also, the evaluations of PR were done below the soil field capacity, which is expected to obtain much higher values. According to Moraes et al. (2013), the PR is more sensitive to soil compaction when the evaluation is done with dry soil conditions (GWC lower than the soil contraction limit).

In this research, the PR increased from the planting to the peanut harvest for all treatments, including CT, demonstrating a short effect in improving physical conditions. The PR generally increased during the season due to field traffic and natural soil settlement (e.g., precipitation, swelling, and shrinkage). The increase in PR with the decrease of water content in the soil profile and the impact of traffic on deeper soil compaction is reported by Moraes et al. (2013) in a study under NT conditions. This is why methodologies are recommended for standardized soil moisture (Vaz et al., 2013; Fernandes et al., 2020). Other methods available are very costly due to the need for field samplings and laboratory

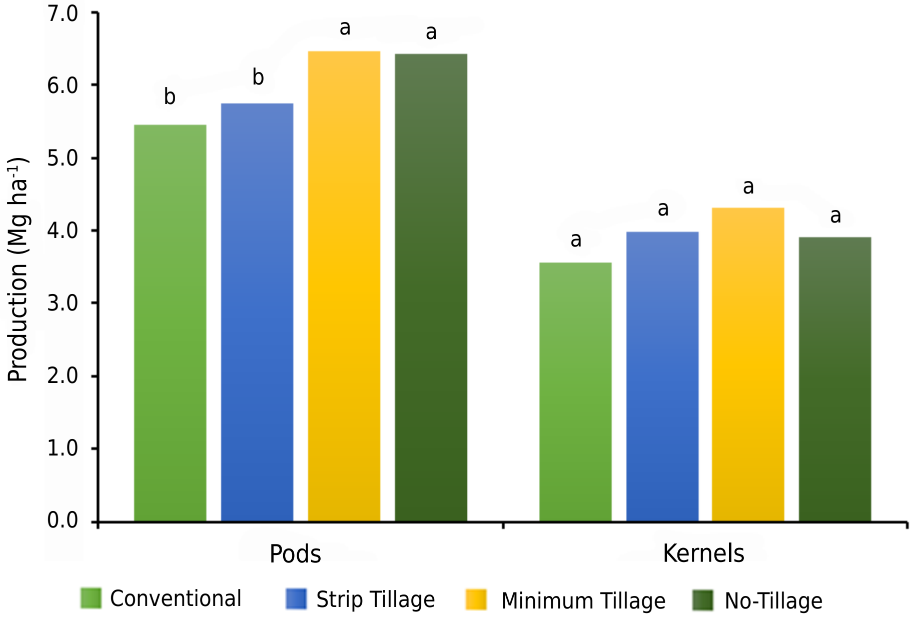

Figure 5. Production of pods and kernels, the means compare the soil management in each item by the Tukey test ($p<0.05$), means followed by the same letter do not differ by the Tukey test at 5 % probability.

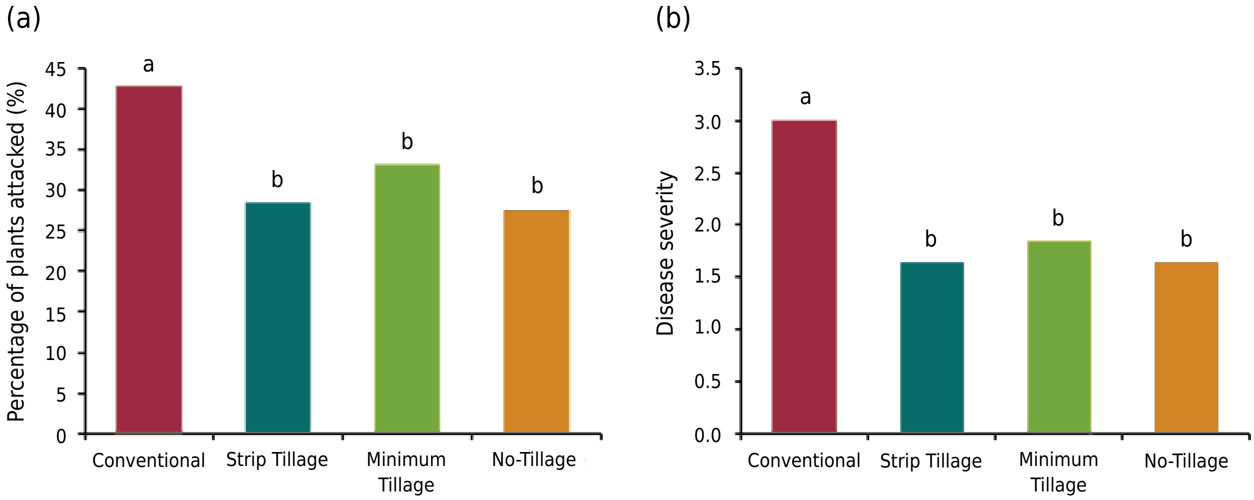

Figure 6. Percentage of plants infected by the virus (Groundnut Ringspot Virus, GRSV) (a) and disease severity for each soil management (b), the means compare the difference between the soil management by the Tukey test ($p<0.05$).

analysis (Fernandes et al., 2020), which was not our research's main goal. However, the reduction of the soil moisture verified during the peanut crop development could explain the PR increase when compared to before planting and 113 DAP.

Furthermore, the PR has a substantial variability spatiotemporal as reported by several authors (Guedes Filho et al., 2010; Vaz et al., 2013; Kuhwald et al., 2020), but sometimes the influence of water has not shown a high correlation with the PR (Bonnin et al., 2010). According to Kuhwald et al. (2020), the effect of complete conventional tillage in the field carried out for 18 years with minimum tillage was observed for just 18 months. The same temporal effect of conventional tillage in comparison with no-tillage for sugarcane was observed in other articles (Barbosa et al., 2018; Martíni et al., 2021). In general, more than 70 % of soil compaction in sugarcane fields occurs after the first harvest (Garside et al., 1997); thus, the benefits observed for conventional tillage in our findings will probably be lost after harvesting during the next sugarcane crop. This occurs from a great possibility of soil compaction happening again in the short term.

But considering the benefits for peanut crop, the in-row subsoiling has shown benefits in terms of soil compaction reduction. The effect of ST in terms of reduction on PR in the present study is similar to earlier reports (Zhao et al., 2009; Jackson et al., 2011; Bolonhezi et al., 2017). Nevertheless, it is important to emphasize that values of PR higher than 2.5 MPa (Camargo and Alleoni, 1997) are considered restrictive to plant root development in most crops. It could be considered that the tillage in sugarcane renovation, independently of the crop rotation, is done to improve the physical and chemical conditions for the next sugarcane. Thus, it is considered the critical threshold for root sugarcane values of PR >2.0 MPa and BD >1.78 Mg m^{-3} (Otto et al., 2011) or PR >1.5 MPa and BD >1.7 Mg m^{-3} for sandy soils (Barbosa et al., 2018). The peanut values of PR and BD were higher than 2.55 MPa and 1.32 Mg m^{-3}, respectively, which can affect the biomass, surface, and density root (Leonel et al., 2007a, b).

Since peanut pods are developed below ground, and more than 60 % of root biomass is concentrated at 0.30 m depth (Inforzato and Tella, 1960; Bolonhezi et al., 2007), soil physical conditions in the topsoil are very important. Consistent with other studies (Siri-Prieto et al., 2009; Hawkins et al., 2016), the current results about soil physic properties revealed the importance of keeping the maximum residue to reduce soil water loss. Even though MT presented the lowest AWC, the average GWC for both evaluations was higher than CT treatment. Siri-Prieto et al. (2009) studied several conservation tillage practices for peanuts and pointed that when the soil water content is deficit by 33 % of the available water capacity, transpiration, and stomatal conductance can be reduced, resulting in less photosynthates for plant growth and yield. In this study, for all treatments, the GWC was higher than less than 33 % of AWC, showing the peanuts were not in a water-deficient growing condition. Otherwise, peanut plants would have a different root growth under drought stress, which can be an adaptative mechanism by the plants (Siri-Prieto et al., 2009).

Although our research showed negative results in terms of soil physical properties for NT, no significant difference was observed for the plant stand and number of pods per plant (Table 5). These results are an indicator of the improvement from this new planter which provides a good seedbed conditions even with the presence of residue, in contrast with previous studies carried out in other countries (Grichar and Boswell, 1987; Colvin and Brecke, 1988; Hartzog and Adams, 1989; Rahmianna et al., 2000; Jordan et al., 2001; Siri-Prieto et al., 2009) and in Brazil (Bolonhezi et al., 2007, 2017). In comparison, a lower vegetative dried biomass for NT, MT, and ST was observed from 13 to 103 days after planting, indicating slower growth at the beginning of development. This could be caused by the immobilization of nitrogen, the low water content in the germination process, or a negative effect of soil compaction on root growth, as presented by some authors (Na et al., 2018; Grichar, 1998).

A simple comparison of productivity with other studies is not possible due to many aspects, such as: type of soil, cultivar, cropping history, and characteristics of implements. There is little result for peanut in rotation with sugarcane, and the majority has shown lower or no significant difference in pod yield for MT and NT (Bolonhezi, 2007; Leonel, 2010). Previous studies with ST for Brazilian conditions have significantly reduced pod yield in clayey soil, but without a decrease in sandy soil (Bolonhezi et al., 2017).

Surprisingly, the pod yield can be explained by the occurrence of the virus. It is important to say that this virus is transmitted by thrips (*Frankliniella ocidentalis*). Marois and Wright reported similar results (2003), and the cause is related to the presence of straw as a physical effect or as an influence on the natural enemies, which can reduce the number of insects. When infected with the virus during its immature form, this insect can be a virus vector when feeding on plants. The presence of straw in conservation tillage can reduce the thrips densities and, consequently, the incidence of the virus (Johnson et al., 2001; Olson et al., 2006). According to Knight et al. (2015, 2017), in conservation tillage, the presence of residue influences the reflection of ultraviolet light, which can affect the behavior of thrips; then, there is a reduction in density, mainly in immature forms. Although the thrips population has not been evaluated in current research, it

Table 5. Agronomic characteristics for peanut in different soil managements. Planalto City, São Paulo State, Brazil, 2019

Treatments[(1)]	Days after planting								Plant Population
	13	60	103	131	87	104	117	131	
	Dry Matter (Shoot)				Pods				
	Mg ha^{-1}				No. plant^{-1}				1000 pl ha^{-1}
Conventional	0.13a	5.06a	8.38a	6.72	19	20	26	43	115
Strip Tillage	0.11ab	3.58b	6.65b	6.40	13	16	26	39	118
Minimum Tillage	0.09b	3.53b	6.58b	6.88	24	26	42	50	112
No-Tillage	0.11ab	3.53b	6.64b	8.28	22	23	39	50	109
F test	3.85*	5.94*	5.01*	1.24^{ns}	3.21^{ns}	1.54^{ns}	0.84^{ns}	0.41^{ns}	1.23^{ns}
CV (%)	13.55	17.71	12.39	23.58	18.06	14.80	22.45	23.09	6.54

[(1)] Means in the same column compare soil management on the evaluated date; ns: not significant at 5 % probability; *: significant by the Tukey test ($p<0.05$).

can be inferred that different amounts of sugarcane straw provided by treatment have influenced the occurrence of the virus.

Finally, we need to consider that all alternative tillage methods evaluated in this research are considered conservation management because of the maintenance of 30 % or greater residue cover on the soil surface (Balkcom et al., 2018). An important consideration needs to be taken regarding the benefits and challenges of both crops' peanut and sugarcane cropping systems. The main goal is the reduction of soil erosion and the maintenance of soil carbon stock. Still, there are a lot of other advantages in terms of soil health and reduction of inputs and costs, which are extremely important to society.

CONCLUSIONS

Soil penetration resistance in the peanut crop with no-tillage with the presence of sugarcane straw was higher than in conventional tillage. Still, conventional peanut production with tillage practices has a diminishing effect compared to no-tillage as the season goes on. However, the greatest penetration resistance values were consistently observed in no-tillage. While minimal tillage and no-tillage have less percent of mature pods and greater impurity during production, they have produced on average 695 and 991 kg ha^{-1} more than strip-tillage and conventional tillage, respectively. Minimum soil disturbance plus maximum residue on soil surface have significantly reduced the incidence and the severity of *groundnut ringspot virus* (GRSV) in peanut runner-type cultivar in rotation with sugarcane.

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Writing – review & editing: Chandler Edwin Gruener (lead), Denizart Bolonhezi (equal) and Olavo Betiol (equal).

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