SEASONAL CHANGE OF SOIL PRECOMPRESSION STRESS IN COFFEE PLANTATION UNDER SUB-HUMID TROPICAL CONDITION

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ABSTRACT: The objective of this study was to describe the seasonal change of precompression stress behavior in coffee plantations in the sub-humid tropic zone of Brazil as affected by agriculture traffic associated with the time since the establishment the coffee plantation, field slope, sampling position in and sampling depths. The coffee plantations on a uniform soil type; Red-Yellow Latosol were aged 2, 7, 18 and 33 years. Areas with side slope of 3, 9 and 15% were selected in these coffee plantations for this study. The soil was sampled at three positions on the coffee plantation row (bottom of traffic line, inter-row and top of traffic line) and at two depths (topsoil and sub-surface). Samples were collected over a one year period for each month of year. The study showed that the time since the establishment of a coffee farm and the slope steepness had significant effect on soil disturbance in mechanized operation. The coffee plantation with longer establishment time and on steeper terrain had higher precompression stress. The top traffic line presented higher load-bearing capacity than inter-row and bottom traffic line. The sites were more susceptible to compaction in the period from November to January of the year , because the Red-Yellow Latosol presented lower load-bearing capacity than the stress applied by tractor used in coffee management practices.

Index Terms: Agricultural traffic, *Coffea arabica L*., load-bearing capacity, soil degradation.

VARIAÇÃO SAZONAL DA PRESSÃO DE PRÉ-CONSOLIDAÇÃO DO SOLO EM PLANTAÇÃO DE CAFÉ DE CLIMA TROPICAL

RESUMO: *Objetivou-se, neste trabalho, avaliar o comportamento da pressão de pré-consolidação, no decorrer de um ano, em um Latossolo Vermelho-Amarelo cultivado com cafeeiros de diferentes tempos de implantação em diversas declividades do terreno. Este estudo foi conduzido em plantações cafeeiras localizadas em Três Pontas, sul de Minas Gerais. O solo da área de estudo foi classificado como Latossolo Vermelho-Amarelo. O trator utilizado na área de estudo foi um Massey Ferguson 265. Esse estudo foi conduzido em plantações cafeeiras com 2, 7, 18 e 33 anos de implantação. Nessas plantações foram selecionadas ruas de café, com 3, 9 e 15% de declividade. Foram coletadas amostras de solo indeformadas e deformadas na linha de tráfego de cima e de baixo e na entrelinha do cafeeiro, nas camadas de 0,0 a 0,03 m e 0,15 a 0,18 m. A avaliação da pressão de pré-consolidação, ao longo de um ano, indicou que o tempo de cultivo e a declividade do terreno tiveram um efeito significativo sobre a alteração estrutural do solo, sendo que as áreas com maior tempo de cultivo e as mais declivosas apresentaram os maiores valores de pressão de pré-consolidação. A linha de tráfego de cima apresentou maior capacidade de suporte de carga do que a entrelinha e a linha de tráfego de baixo. O período de novembro a janeiro foi a época mais crítica para o tráfego agrícola, pois o Latossolo Vermelho-Amarelo apresenta baixa capacidade de suporte de carga e esse é período crítico em termos de umidade no solo.*

Termos para indexação: *Capacidade de suporte de carga, Coffea arabica L., degradação do solo, tráfego agrícola.*

1 INTRODUCTION

Soil compaction has long been recognized as one of factors affecting crop production (GUIMARÃES; STONE; MOREIRA, 2002). The precompression stress, measured by uniaxial compression tests (ARAUJO-JUNIOR; DIAS JUNIOR; GUIMARÃES, 2008; DIAS JUNIOR, 1994; PAIS et al., 2011; SILVA et al., 2003a, 2010), is a useful physical-mechanical value that may be used as a reference to describe the maximum load-bearing capacity (DIAS JUNIOR; PIERCE, 1995; SEVERIANO et al., 2009; SILVA et al., 2003b). Besides, precompression stress has also been used as a measure of soil compaction susceptibility

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(AJAYI et al., 2010; ARAUJO-JUNIOR et al., 2011; IORI et al., 2012), thereby, loads that exceed the precompression stress value leads to additional soil compaction (DIAS JUNIOR, 1994).

Soil water content has a fundamental role in precompression stress. Dias Junior (1994) highlights that for the same condition; soil water content is the factor that governs the amount of deformation that may occur in the soil. Similarly Hillel (1980) submits that soil moisture is the most important soil physical properties that influence soil - machine interactions. Thus, load applied by agricultural machine and equipment and the soil water content is the most important factors to be considered to avoid critical soil compaction.

In spite of its importance to sustainable mechanized agricultural production there are only few studies in Brazil that quantify the pressure levels that can be applied to avoid critical soil compaction (OLIVEIRA et al., 2003; SEVERIANO et al., 2011). Araujo-Junior et al. (2011) studying the impact of different agricultural management practices on soil structural sustainability found a critical water content for the traffic of machines and equipment on a Latossol. These authors considered only those stress that can cause additional soil compaction or change the initial state of the soil structure, and these are considered as stress that do not exceed internal strength of the soil as expressed by precompression stress.

Therefore, studies that identify and establish the adequate soil moisture conditions for the traffic of agricultural machinery and the pressure applied to the soil that would exceed their load-bearing capacity are important to avoid soil compaction. In order to minimize or avoid further compaction caused to soil during agricultural operations, it is desirable also to find seasons or periods of the year during which the soil is more vulnerable to the soil compaction. Silva et al. (2006) found out that changes in precompression stress due to mechanized operations in the rainy season are greater than those observed in the dry season, indicating a lowering of the load-bearing capacity of the soil with increasing soil water content. In many part of Brazil, there are well-defined rainy season and dry season, with 88% of the rain occurring mostly between the months of November to March.

Due to the reduction of precompression stress in the rainy season compared to the dry season, it is very important to control the traffic of agricultural machine at these periods.

Previous studies have shown that repeated traffic of agricultural equipment increases the degradation of soil structure (DIAS JUNIOR et al., 2008; SILVA; DIAS JUNIOR; LEITE, 2007, 2011). Martins et al. (2012) studying soil degradation in coffee plantations with 2, 7, 18 and 33 years of establishment, observed that the percentage of compacted soil samples increases with the establishment time, indicating that older plantation had accumulated relatively more traffic. Najafi, Solgi and Sadeghi (2009, 2010) also found increase soil disturbance with increases of traffic intensity. Besides traffic intensity, these authors observed that the slope steepness had a significant effect on soil disturbance, with the soil disturbance higher in the steepy terrain conditions.

Studies on the seasonal change of the soil precompression stress in coffee growing areas of Brazil are limited and information on the seasonal trend of precompression stress of agricultural soils is scarce in the literature. Thus, to establish the impact of mechanized operation in coffee culture, it is essential to identify the factors which affect and alter the soil structure. The development and implementation of practical guidelines in order to manage soil compaction for a wide range of conditions depend upon an understanding of the relative importance of applied pressure and water content during the compaction process (SMITH; JOHNSTON; LORENTZ, 1997). The aim of this study was to describe the seasonal change of soil precompression stress behavior in coffee plantations in the sub-humid tropic zone of Brazil as affected by agriculture traffic associated to the time since the establishment the coffee plantation, the field slope and in three sampling position in inter-row of the coffee plantation.

2 MATERIAL AND METHODS

The study was conducted in coffee plantations located in Três Pontas County, South of Minas Gerais State, Brazil (24°26’ S; 47°49’ W’ and altitude of 905m). This region presents predominant relief of undulating topography. The climate according to Koppen is Cwa, that is, altitude tropical, with an average annual temperature of about 18° C. The annual rainfall measured during the study was 1330 mm (Figure 1). In South of Minas Gerais State a year is characterized with some distinct climatic conditions, with two major seasons per year; the rainy season from November to April, and the dry season from May to October. The soil of the study area was classified as a clayey textured Red-Yellow Latosol (Oxisol)

(EMPRESA BRASILEIRA DE PESQUISAS AGROPECUÁRIA - EMBRAPA, 2006) with 510 g kg^{-1} of clay, 200 g kg^{-1} of sand and 290 g kg^{-1} of silt, and particle density of 2.62 g cm^{-3}. Soil samples were collected over one year (October 2010 to September 2011) once every month on the date, indicated in Figure 1.

According to the farms records, prior to the installation of the coffee plantations, the soil was plowed and disked once to a depth of 40 cm and then harrowed. All the equipment used in the coffee crop management were pulled by a Massey Ferguson 265 tractor, with a mass of about 3,940 kg, front tyre type 6 - 16 (contact area of 381 cm^2) and rear tyre type 16.9 - 24 (contact area of 2145 cm^2). The equipment pulled by the tractor are: fertilizer miname with approximate mass of 210 kg (3 passes per year), spray jet Arbus 400 Jacto with 400 L capacity and mass of 230 kg (3 passes per year), mower Kamaq with a mass of 340 kg (3 passes per year) and the spray jet PH 400 with 400 L capacity and mass of 210 kg (2 passes per year). Thus the total number of passes per year of the tractor is 11 on the same traffic line for each plantation at different ages since establishment.

This study was conducted in coffee (*Coffea arabica*) plantations with 2 years (planted in 2008 with spacing 3.5 m x 0.7 m – Cultivar Mundo Novo), 7 years (planted in 2003 with spacing 3.5 m x 0.9 m – Cultivar Paraíso MG), 18 years (planted in 1992 with spacing 3.5 m x 1.0 m – Cultivar Mundo Novo) and 33 years (planted in 1977 with spacing 3.5 m x 2.0 m – Cultivar Catuaí Amarelo) of establishment. In these coffee plantations, areas (coffee row) with side slope of 3, 9 and 15% were selected. The soil were sampled at three positions on the coffee row (Figure 2): bottom of traffic line (B), inter-row (I) and top of traffic line (T) at two layers: 0.00 m – 0.03 m (topsoil) and 0.15 m – 0.18 m (sub-surface). Thus, samples were collected from these seventy two conditions (4 establishment times x 3 slopes x 3 sampling positions x 2 depths) with 12 replicates.

The evaluation of the soil precompression stress occurred in four distinct steps. Sampling the soil in the field, uniaxial compression test on the samples in the laboratory, determination of the precompression stress and estimation of the load-bearing capacity models, as detailed follows:

Soil sampling process – Soil samples were collected in sampling rings with dimensions 2.54 x 6.40 cm. The rings was pushed into the soil with Uhland soil sampler, after which the samples was properly waterproofed (wrapped in plastic and paraffin), to maintain the field moisture and preserve the soil structure during transport to the laboratory.

Uniaxial compression test – in the laboratory, the samples were submitted to uniaxial compression test in a fixed ring consolidometer according to the procedure of Bowles (1986) modified by Dias Junior (1994).

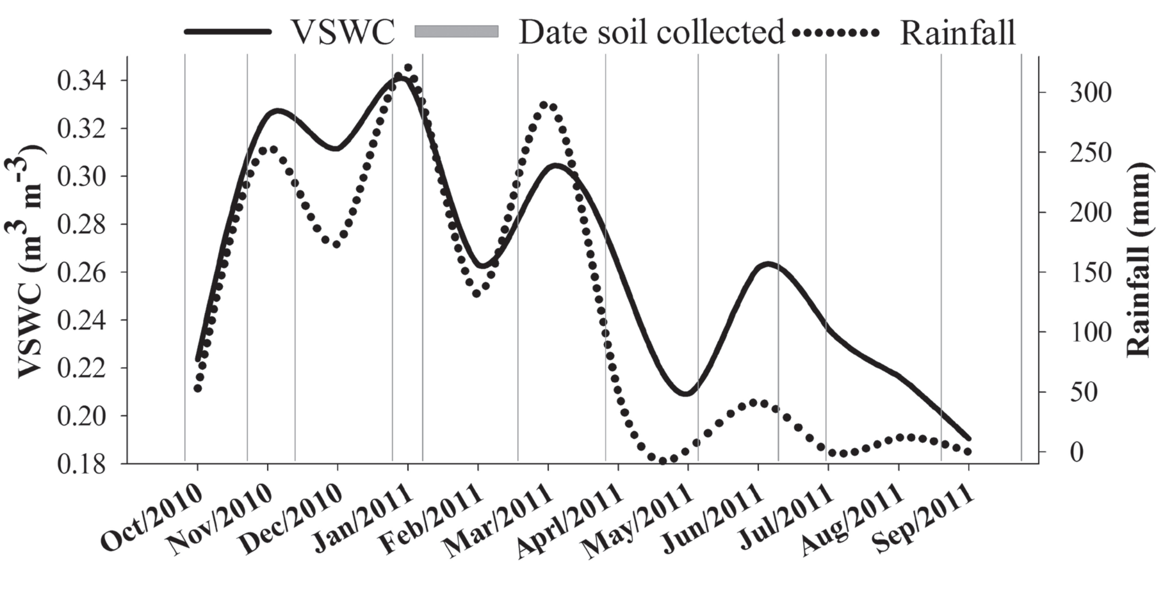

FIGURE 1 - Volumetric soil water content (VSWC) for different dates, rainfall data for study area and dates of each soil collect (represented by vertical lines) realized in 2010 and 2011.

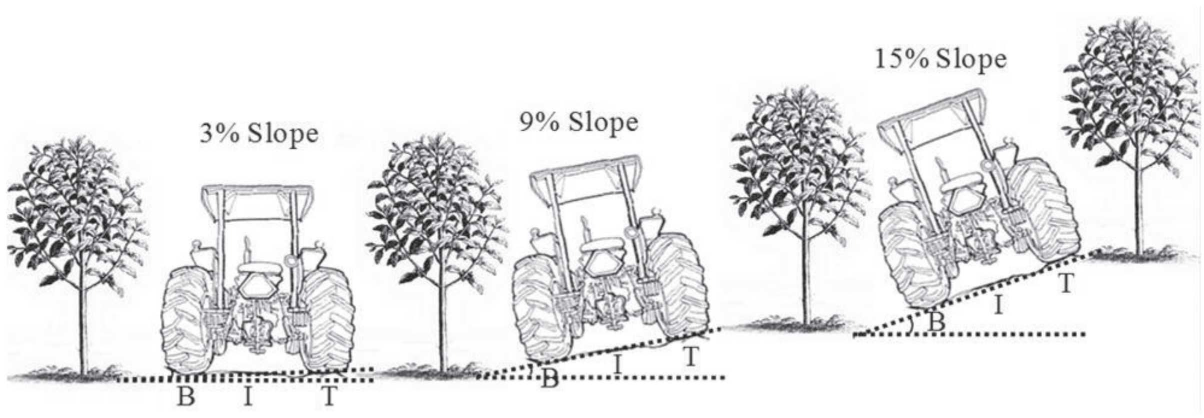

FIGURE 2 - Schematic representation of the sampling points in the coffee row with three side slope (3, 9 and 15% slope). B: bottom traffic line, I: inter-row and T: top traffic line.

The pneumatic S-450 Terra load floating ring consolidometer (Durham Geo Enterprises, USA) where pressures are applied from compressed air were used. The levels of pressure applied to the soil samples were 25; 50; 100; 200; 400; 800 and 1,600 kPa, following the assumption of Taylor (1948), which defines the maximum deflection up to 90% of the soil sample, for each pressure step. The applied pressures of 25, 50, 100, 200 and 400 kPa are associated with secondary compression curve, while the virgin compression line is determined from the points associated with applied pressure of 800 and 1600 kPa. The uniaxial compression tests were realized with soil samples at the field moisture content. Thus, the soil water content was determined by oven drying at 105-110°C for 48 hours after this test.

Determination of precompression stress – Using the values of sample deformation (bulk density) against the logarithm of the pressure applied, it was obtained the soil compression curve from which the precompression stress (σ_p) was estimated for each sample (DIAS JUNIOR; PIERCE, 1995).

3 RESULTS AND DISCUSSION

Figure 3 presents the changes in the precompression stress (σ_p) and volumetric soil water content for the coffee plantation with ages 2, 7, 18 and 33 years of establishment for the period October/2010 to September/2011. The 33 years old plantation consistently held lower moisture than other areas during the study period. Similarly, the difference in the soil water content, between the old plantation (33 years of establishment) and the younger plantations (2, 7 and 18 old) were higher during the wet periods. This lower moisture retention in the old plantation could cause higher precompression stress values relative to the younger plantation (2, 7 and 18 years old). Iori et al. (2012) simulating the behavior of precompression stress and load bearing capacity of soils at two moisture regimes (wet and dry seasons) found high values of precompression stress when the moisture content were low. These authors indicate that at lower soil moisture, the soil particle adhesion is minimal while the cohesion is higher resulting in higher load-bearing capacity.

The lower soil water content observed in the 33 years old plantation can result in moisture stress for coffee plants. The largest differences for soil water content in this plantation, compared to others, were observed mainly in December/2010, January/2011 and March/2011 and may be linked with infiltration and retention capacity of the soil, as well as, the root system. Lower precompression stress values in soils indicates lower load-bearing capacity and higher susceptibility to compaction (ARAUJO-JUNIOR et al., 2011; MARTINS et al., 2012; SANTOS et al., 2009). The 2 years plantation presented lower load-bearing capacity, consequently, higher susceptibility to compaction. Lower precompression stress values in younger coffee plantation were also found by Miranda et al. (2003). Assessing the effect of different management systems in coffee plantation on a Red Latosol, these authors found lower load-bearing capacity in younger plantation than older plantation from samples collected on the on the traffic lane.

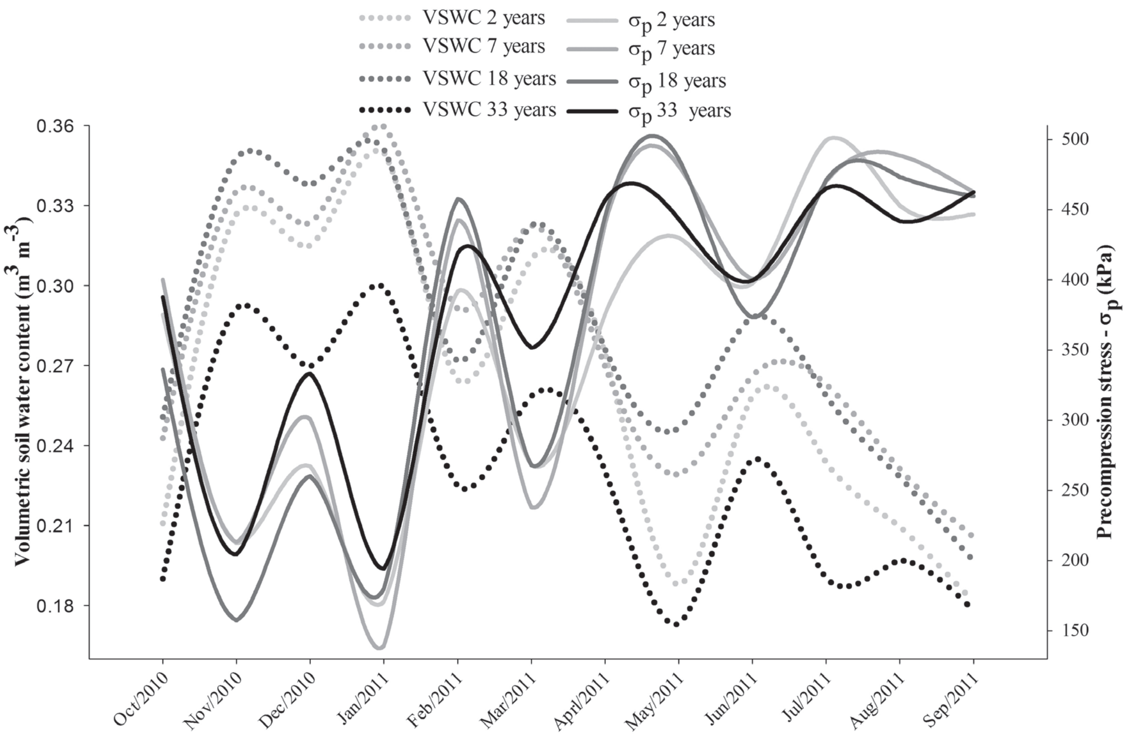

FIGURE 3 - Volumetric soil water content (VSWC) and precompression stress (σ_p) for total period studied for areas of 2, 7, 18 and 33 years of establishment.

Similarly, Martins et al. (2012) observed that the 0-3 cm layer of the coffee farms with 7, 18 and 33 years of establishment had higher load-bearing capacity than the 0-3 cm layer of a 2 years old Coffee farm, but this observation was for volumetric water content lower than 0.18 m^3 m^{-3}. For higher volumetric soil water content the 0-3 cm layer, these authors found higher load-bearing capacity in the younger plantation (2 years) relative to the older plantation (7, 18 and 33 years) In this study, we observed higher load-bearing capacity in the 2 years plantation when compared with the older plantation at a soil water content of 0.21 m^3 m^{-3} in June and July/2011.

Figure 4 presents the changes in the precompression stress (σ_p) and volumetric soil water content for areas inside the coffee plantation with 3, 9 and 15% of field slope. Areas with 3% slope presented higher volumetric soil water content in dry period (May to September). In wet period we observed similar soil water content in all the slopes except in November/2010 when the 15% slope had higher water content than other areas, probably because November is the begin of rain season and the moderate field slope (15%) presented lower soil water infiltration and consequently more soil water content, for other hand, the other side slopes (3 and 9%), presented largest soil water infiltration. It was also observed that the 15% side slope presented higher precompression stress values and load-bearing capacity than the two other side slopes (3 and 9%) only in the dry period (May to August). This higher load-bearing capacity in the moderate field slope (15%) indicate a greater resistance to compaction, however, this also imply a higher resistance to the coffee plant roots penetration (ARAUJO-JUNIOR et al., 2011; MARTINS et al., 2012; MIRANDA et al., 2003) and possibly indicative that traffic in steep areas had more impact on soil structure than in the other less steep areas (Figure 4).

Evaluating the operational performance of a tractor running perpendicular to the slope, Leite et al. (2011) found that the slippage of the tires increased with increasing the side slope of the track. These authors showed that there was a significant decrease in the tractive force as the inclinations increased, which can be attributed to a lateral weight transfer also increasing the slippage of the tires. Therefore, slippage of a tractor on steep slopes had higher impact on soil structure.

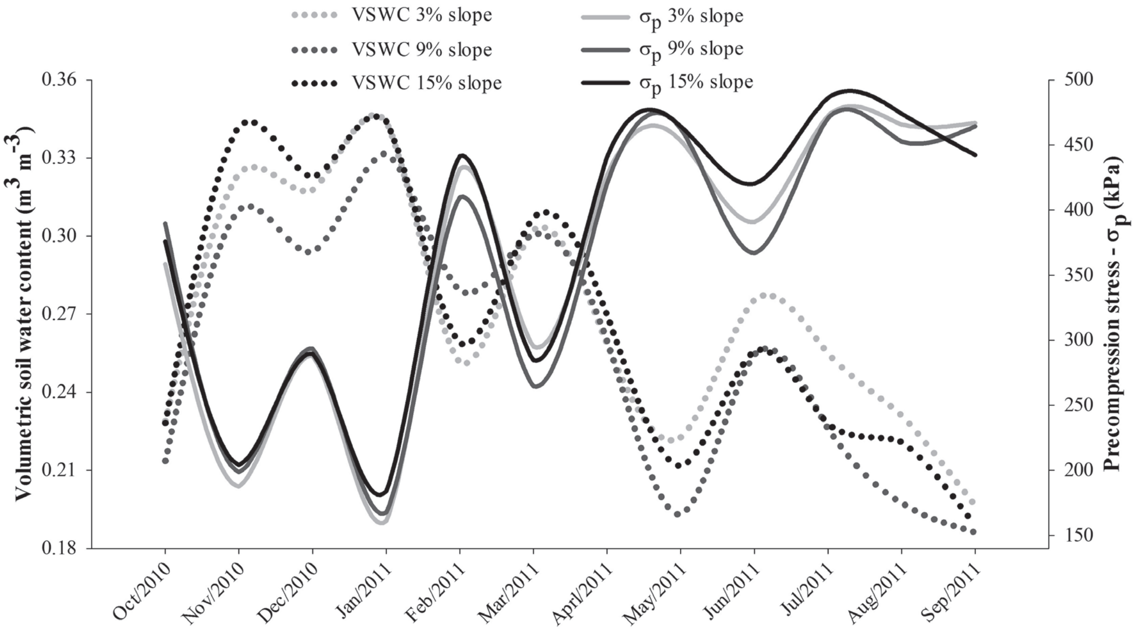

FIGURE 4 - Volumetric soil water content (VSWC) and precompression stress (σ_p) for total period studied for areas with 3, 9 and 15% of side slope.

Najafi, Solgi and Sadeghi (2009) explain that during skidding on steeply terrain, a given load gets uneven weight balance on the axles and increases soil disturbance. Jamshidi et al. (2008) also indicate that the uneven load distribution between tires in sloping land can result in higher dynamic peak loads being exerted on the soil. Similarly, Krag, Higgingbotham and Rothwell (1986) also found that slope steepness had a stronger effect on soil disturbance. They observed that during timber harvesting, the soil disturbance was more pronounced on slopes >20% than on slopes <20%. Najafi, Solgi and Sadeghi (2010), studying the effects of skid trail slope and ground skidding on soil disturbance, showed that the soil disturbance increased dramatically on the treatments with the slopes of >20%. Davies, Finey and Richardson (1973) also identified wheel slip on agricultural tractors as causing significant compaction.

The results in this study showed that traffic operations in areas with higher side slope caused impact on soil structure, increasing soil resistance to compaction, but besides soil disturbance, a steep terrain may cause instability of the tractor.

The observed precompression stresses and volumetric soil water content for the bottom traffic line, inter-row and top traffic line are presented in figure 5. We observed higher soil water content at the bottom traffic line in the period from November/2010 to February/2011. The other sampling position (inter-row and top traffic line) had similar volumetric soil water content for this period (November/2010 to February/2011). The bottom traffic line (figure 2) accumulated more water than the other sampling position, being the lowest point. On the other hand, in the period from May/2011 to September/2011 (dry period), we observed low volumetric soil water content in the top traffic line. The inter-row presented similar volumetric soil water content with top traffic line in the period from October to February. In the period from May to September, similarity soil water content was observed in the inter-row and bottom traffic line. But between March to April, the inter-row presented lower water content than other samples points while the bottom traffic line had higher load support capacity. Generally, lower load-bearing capacity were observed in the inter-row and bottom traffic line (60% of period) while the top traffic line had higher load-bearing capacity. Leite et al. (2011) found that top traffic line had more slippage than bottom traffic line in side slope, being that this difference of slippage, between side tires, increased with increase the side slope. Khoury Junior et al. (2009) noted that this happens, because the shift of the lateral weight to the lower end of the slope, causing loss the tire ground contact. The loss tire ground contact causes slippage resulting in more soil disturbance.

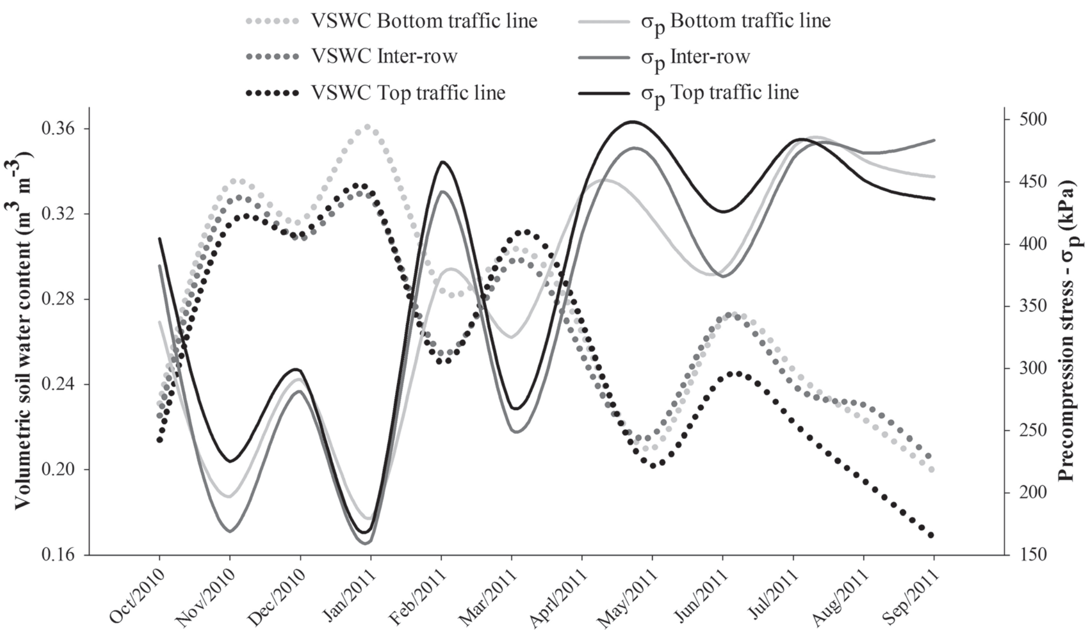

FIGURE 5 - Volumetric soil water content (VSWC) and precompression stress (σ_p) for total period studied for bottom traffic line, inter-row and top traffic line positions.

The lower precompression stress found at bottom traffic line indicates higher susceptibility of soil to compaction, being this traffic line the one with more possibility have problems with soil compaction. This problem with soil compaction was observed by Martins et al. (2012), who found the compaction that occurred on the traffic line located at the bottom of the ground was equal or greater than the compaction that occurred in the traffic line located at the top of the ground.

It was compared the load-bearing capacity and volumetric soil water content for two soil layers in this study (Figure 6). Between October and December, the topsoil (0.00-0.03 m) presented higher soil water content than the sub-surface (0.15-0.18 m). In spite of the higher soil water, the topsoil had higher precompression stress values than the sub-surface, for this same period. Wet soil are more susceptible to compaction than dry soil, thus the topsoil was more susceptible to compaction than sub-surface, due to the higher soil water content. When machine traffic occurred in these coffee plantation areas, the soil structure from topsoil were more affected than soil structure in the sub-surface, increasing the precompression stress values. Besides, the pressure applied by coffee machine is higher in the topsoil, causing more soil disturbance thereby increasing the precompression stress values. On the other hand, during the dry periods (from April to September) the topsoil layer that was more susceptible to compaction because of the lower precompression stress values. This behavior could not be linked to the soil water content as both layers had similar volumetric soil water content values. Probably, the soil in the sub-surface had higher cohesion than those at the topsoil, resulting in higher load-bearing capacity for sub-surface. However, this behavior (sub-surface with higher load-bearing capacity than topsoil) wasn’t observed in wet periods, because in this period the soil cohesion was minimal, due to the high soil water content. Analyzing the period from January to April, it was observed that both layers presented similar precompression stress values. Similar results also were obtained by Martins et al. (2012) who found similarity between layers (0.00-0.03 m and 0.15-0.18 m) in older coffee plantation and explain that this occurs due to the natural structure recovery of the 0.15-0.18 m layer in relation to the 0.00-0.03 m layer.

In this study, it was observed the lower precompression stress values occurred in rainy seasons. Silva et al. (2006) also found lower precompression stress values in rainy seasons compared to the dry seasons, and explained that in rainy seasons there is a alleviating of the load-bearing capacity. Therefore, higher impacts on soil structure due coffee machine operations will occur during the rainy season.

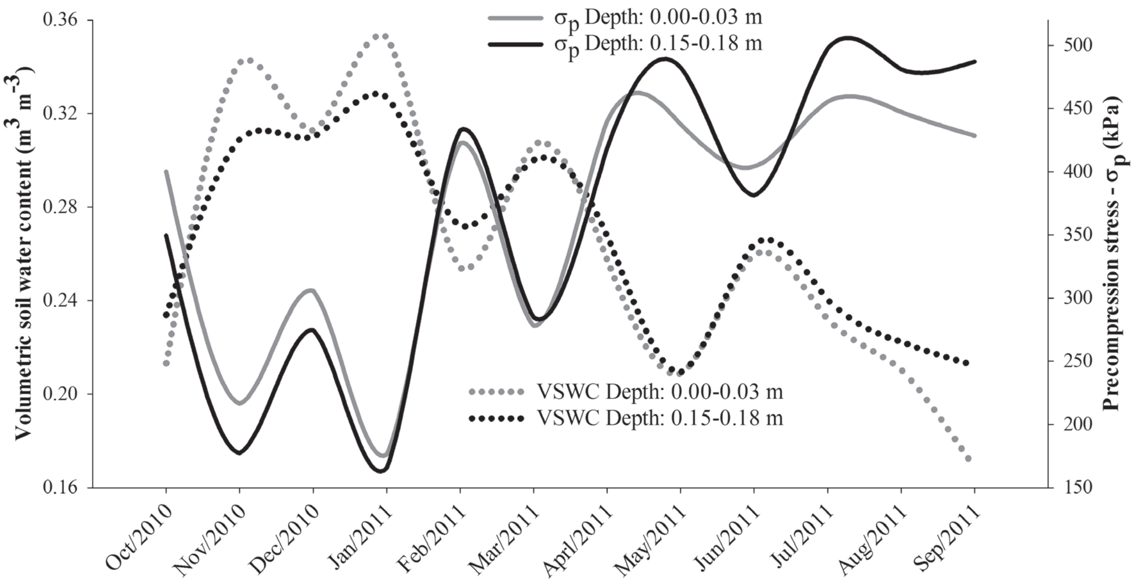

FIGURE 6 - Volumetric soil water content (VSWC) and precompression stress (σ_p) for total period studied for topsoil (0.00-0.03 m) and sub-surface (0.15-0.18 m).

4 CONCLUSIONS

The study showed that the time since the establishment of a coffee farm and the slope steepness had significant effect on soil disturbance in mechanized operation, with areas that the coffee plants with longer establishment time and with more terrain lateral inclination had higher precompression stress. Top traffic line presented higher load-bearing capacity than inter-row and bottom traffic line. The period from November to January is the period that the soil is more susceptible to compaction, because the Red-Yellow Latosol presented lower load-bearing capacity than the stress applied by tractor used in coffee management practices.

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