academicJournals

Vol. Vol. 10(33), pp. 3342-3347, 13 August, 2015
DOI: 10.5897/AJAR2015.9952
Article Number: 0F2FAD154958
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Sample scaling in soil compaction assessment experiments with motorized penetrometer

Lindolfo Storck[1]*, Betânia Brum[1], André Brugnara Soares[1], Tangriani Simioni Assmann[1], Alcir José Modolo[1], Sarha Giovana Kazue Kobata[2] and Wilson Henrique Tatto[2]

[1]Programa de Pós-graduação em Agronomia (PPGAG), Universidade Tecnológica Federal do Paraná (UTFPR), Via do Conhecimento, km 01, Pato Branco – PR, 85503-390, Brazil.
[2]Curso de Agronomia, UTFPR, Via do Conhecimento, km 01, Pato Branco – PR, 85503-390, Brazil.

Received 30 May, 2015; Accepted 21 July, 2015

The objective was to estimate the sample size (number of points by experimental plot) to estimate soil resistance to penetration in different depth ranges and for different animal stocking density rates. The data was obtained from a factorial experiment in a randomized block design, three replicates, consisting of two grazing intensity levels (canopy heights: 10 and 20 cm) and two levels of nitrogen fertilization applied on the coverage (0 and 200 kg N ha^{-1}) in the form of urea. The penetration resistance (PR) of the soil was achieved in 20 points randomly determined inside each experimental unit (paddock). A "Motorized soil penetrometer" was used (DLG, Model PNT-2000-M). The PR average values were determined for the depth range of the soil (characters): 00-40, 00-10, 10-20, 20-30 and 30-40 cm. For the same estimation error of the soil's penetration resistance, the sample size (number of points) depends on the depth range of soil and animal stocking density. In experiments with varying animal stocking density rate on pasture in winter, 15 points per experimental unit are sufficient to estimate the average with an estimation error of 15% of the average soil penetration resistance.

Key words: Sample size, grazing pressure, crop-livestock integration, soil depth.

INTRODUCTION

The feasibility of the integrated crop-livestock system depends on the management adopted in the grassland and grazing pressure during the winter, as this affects the performance of cash crop plants in summer, whether for the production of grain or forage. However, the use of different grazing pressures can result in different levels of soil compaction, due to animal treading, even more that the grazing pressure changes animal movement patterns (Baggio et al., 2009), leading to different soil compaction patterns. Differences in the degree of compaction may determine mechanical difficulties at sowing and change the density and regularity of plant density, with consequences for the crop yield.

The correct measure of soil compaction in experiments, by using the equipment known as "Penetrometer", is essential for improving experimental accuracy and labor efficiency. The penetrometer allows the measurement of one of the most important physical properties of the soil, the penetration resistance (PR). This property is related to various soil properties, which are indicators of the

*Corresponding author. E-mail: lindolfostorck@gmail.com, Tel: 55 46 32202548.

degree of compaction (Tavares Filho and Ribon, 2008).

The importance of the representativeness of measurements (sample size) is also known in the experimental units to reduce experimental error and, consequently, increase the accuracy of the research results (Cargnelutti Filho et al., 2011; Storck et al., 2012; Benin et al., 2013). The diagnosis of soil compaction in large areas requires time and it is labor-intensive, especially when working with precision agriculture, in which there is the need to sample many points (Molin et al., 2012). Tavares Filho and Ribon (2008) point out that studies on the number of sample points are scarce, since, in general, they are set out aimed at better value for money, which do not necessarily present statistically reliable results. PR measurements are being conducted with various sampling plans, with no differences in the number of points, when the distribution is systematic (mesh) or when it is at random points (Tavares Filho and Ribon, 2008). Also, the sample size can vary with the management system of the pasture and the sampling depth range.

In the absence of information about the size of the experiments, the number of sampled points per experimental unit has been variable. There are cases with less than 10 points (Lima et al., 2013; Freitas et al., 2012; Silveira et al., 2010; Moraes et al., 2012) and cases with 10 to 20 (Ralisch et al., 2008; Tavares Filho and Ribon, 2008) per study unit, size not specified. Other studies used sample sizes equal to 16 (Coelho et al., 2012), 570-1333 (Mome Filho et al., 2014), 1,111 (Roque et al., 2008), 7,100 (Iaia et al., 2006) and 11,100 (Molin et al., 2012) points ha^{-1}.

Possibly, the number of sampling points is related to the operation of the equipment, gathering of data from other variables at the same points and the availability of human resources. In order to determine the number of evaluation points (sample size) from PR data of 40 points sampled in three crops (Molin et al., 2012), they observed that from 15 points (replicates) the trend is for the standard error to present very similar values in all three fields, between 5 and 15% of the average, though without significant decrease in their values by increasing the number of points. Tavares Filho and Ribon (2008) concluded that there is a variation in the sample size in relation to the management system and sampling depth. Also, the effect of grazing management on the sample size to estimate the PR is not known. The objective was to estimate the sample size (number of points by experimental plot) to estimate soil resistance to penetration in different depth ranges and for different animal stocking densities.

MATERIALS AND METHODS

The "crop-livestock integration" experiment was conducted in a property located in the city of Abelardo Luz, Santa Catarina State, Brazil (26º 31' 34" S; 52 º 15' 36" W; altitude 851 m). According to the Brazilian system of soil classification (Santos et al., 2013), the soil of the area is classified as "Latossolo Bruno distrófico" (Dusky latosol, dystrophic, typical), very clayey texture (69.5% clay, 26.8% silt and 3.7% sand) with prominent horizon A (between 0 and 39 cm).

The factorial experiment in a randomized block design, three replicates, consists of two grazing intensity levels (grazing pressure) through the grazing method with continuous stocking varying stocking density (Mott and Lucas, 1952), seeking to maintain two sward canopy heights of black oat (*Avena strigosa*, cv. BRS 139.) + annual ryegrass (*Lolium multiflorum* cv. Barjumbo), 20 and 30 cm, and two levels of nitrogen fertilization applied once, on the top: 0 and 200 kg N ha^{-1}, in the form of urea. These four managements result in various numbers of animals per area unit, which depends on the forage availability. The total area of the 12 experimental units of the experiment is equal to 16 ha, approximately 1.2 ha per working experimental unit. The forage (oat + ryegrass) was sowed on 04/03/2014, and the grazing started on 20 May, 2014. On the 10 October, 2014, the cattle were removed from the experimental area aiming at preparing for soybean cultivation. On 13 November 2014 the data were collected for penetration resistance of the soil and soil moisture. Soil moisture was determined, at one point per experimental unit at depths of 0-5, 5-10, 10-20 and 20-40 cm. The results were submitted to analysis of variance per depth.

The penetration resistance of the soil (PR) was performed in 20 randomized points in each paddock. For this operation we used a "digital motorized soil penetrometer" (DLG, Model PNT-2000-M), recording the values of PR every 10 mm deep (between the surface and 400 mm), using the cone type 2 (129 mm^2). The measurement unit was the soil resistance to the penetration of the cone, expressed in MPa (Mega Pascal). The PR average values were determined for the depth range of the soil: 00-40, 00-10, 10-20, 20-30 and 30-40 cm, thus representing five evaluated layers.

For each layer, variance analysis was conducted according to a randomized block design with sampling in the experimental unit. Assumptions were tested regarding the management effect and experimental error (variance among experimental units) according to Barbin (1998). Were also tested the assumptions of error normality and homogeneity of variances between managements (Barbetta et al., 2004). For this analysis, we used the Genes software (Cruz, 2013).

The PR mean (m) was estimated for each management and layer (20 points x three blocks), and the within experimental unit variance (s^2 = mean of the 20-point variances in three block). We calculated the sample size (η) for the confidence interval with half-width (HW) equal to 5, 10, 15 and 20% of the mean (m) estimate with a confidence level (1-α) of 95% through the expression $\eta = t_{\alpha/2}^2 s^2/(HW)^2$ (Barbetta et al., 2004), in which $t_{\alpha/2}$ is the critical value of the *Student's* t distribution such that $P(t>t_{\alpha/2}) = \alpha/2$ with (n-1) degrees of freedom with α = 5% error probability, and s^2 is the variance estimate. Later, η as fixed as the total points (N = 20) used to calculate the half-width of the confidence interval (HW20, 1-α = 0.95) as a percentage of the mean (m) estimate for each management and depth range through the expression $HW20 = 100\, t_{\alpha/2} s / m\sqrt{\eta}$ (Barbetta et al., 2004), where *s* is the sample standard deviation estimate. For the calculations, we used the resources of Excel® spreadsheet.

RESULTS AND DISCUSSION

Soil compaction, estimated by the penetration resistance of the soil (PR) was significantly ($p < 0.05$) affected by management only in the 10-20 cm layer (Table 1).

Table 1. Analysis of variance with degrees of freedom (DF), sources of variation (SV) for the resistance of the soil to penetration (MPa), by depth range; average, selective accuracy (SA), p-value of the Kolmogorov-Smirnov test (α-KS) and p-value of the Bartllet test (α-Bartllet) between managements.

SV	DF	Mean square for the layers				
		00-40	00-10	10-20	20-30	30-40
Block	2	0.6603	0.7722	0.8070	3.1515	5.1815
Management	3	0.8457^{ns}	3.2678^{ns}	6.8169*	1.1553^{ns}	2.2729^{ns}
Among	6	1.9116*	1.6394*	0.6110^{ns}	3.0201*	8.9396*
Within	228	0.2158	0.5455	0.3497	0.2854	0.3218
Average	-	2.7264	3.4376	3.0593	2.2912	2.1178
SA	-	-	0.706	0.954	-	-
α-KS	-	0.699	0.773	0.813	0.668	0.711
α-Bartllet	-	0.045	0.065	0.003	0.008	0.004

* Significant effect by F test (α <0.05); ^{ns} = not significant.

Therefore, after 172 days of grazing, compaction in the 0-20 cm layer was affected by managements of animal stocking density and nitrogen. In this same layer (10-20 cm) the heterogeneity of variance among replicates was not significant, and, according to this result, the increase in the number of replications is less important than the increase of sample size to reduce the average estimated variance of the managements according to Barbin (1998). The reverse occurs with the remaining layers where the management effects were not significant.

The extent of the experimental precision, selective accuracy (SA = $(1-1/Fc)^{0.5}$), is classified as very high (Resende and Duarte, 2007; Benin et al., 2013) in the 10-20 cm layer; and high in the 0-10 cm, although with no management effect. In the cases where the F-value for management is smaller than one, there is no estimate of SA and a sampling plan that uses the same number of points of management should provide a larger sample size in detriment of the number of repetitions for the comparison of management with greater accuracy (Barbin, 1998).

For the other layers and in the average (00-40 cm) there is no effect of the management on the PR. The cause of no significance in the management of these bands may be due to the high value of the variation among the experimental plot (experimental error) that was significant. In this case, the experimental error is equivalent to the interaction "Management x Block" estimable for cases of sampling in the experimental units (Barbin 1998). If there is an interaction, differences in management practices within a block do not have the same order in relation to the other blocks, overcoming the main effect of management.

The overall average of PR varies between 2.12 and 3.44 MPa for the layers. Studies report that the value of 2.0 MPa has been accepted as the critical threshold of soil resistance to penetration (Taylor et al., 1966; Nesmith, 1987) to prevent crop yields. However, for Vepraskas and Miner (1986), values of 2.8 to 3.2 MPa slow elongation of roots and at 4.0 MPa there is no growth of roots. Another study concluded that PR values greater than 3.5 MPa did not restrict root development of corn, but influences its morphology (Tavares Filho et al., 2001). Thus, the degree of soil compaction observed in this study is close to the limit tolerated for a good plant growth.

Soil moisture (g g^{-1}) at the time of determination of the PR was 21.7% in the 0-5 cm layer; 24.5% in the 5-10 cm layer; 26.4% in the 10-20 cm layer; and 29.1% in the 20-40 cm layer. No significant effect of the managements on soil moisture was seen in the evaluated layers ranges. With this, the differences in PR values for the various managements are not related to soil moisture. However, in other studies, the magnitude of the PR is also related to soil management (Freitas et al., 2012; Ralisch et al., 2008; Girardello et al., 2014).

The assumptions of normality of the errors (Table 1) are not restricted to the hypothesis testing for the evaluated depth ranges. Thus, it is possible to use the t-distribution to estimate sample size. However, due to the heterogeneity of the variances among managements, it is not recommended to use a single sample size for the different managements. Heterogeneous (Cargnelutti Filho et al., 2010) and homogeneous (Krause et al., 2013) variances between treatments were also observed in other studies and were attributed to the effects of the treatments.

Considering that, to keep highest forage production in management M1 and M2 in relation to the managements M3 and M4 (Table 2), it was necessary to lower the animal stocking density rate (less grazing pressure) and when nitrogen is used in the pasture, management M1 and M3 the plants perform better. In these cases, there is the need to increase animal stocking density to maintain the same sward canopy height of the plant. Thus, there are two extremes of managements that influence soil PR, the M1 with lower rate of animal stocking density and M4 with the highest rate. Similarly, it should be noted that

Table 2. Sample size (number of points) for estimating the average soil resistance to penetration (PR, MPa) in portions under different managements, for estimation errors equal to half-width (HW = 5, 10, 15 and 20%) of the PR average estimation (α = 0.05) and half-width of confidence interval based on the number of measured points (HW20, n = 20) in percentage, average PR and average variance.

HW (%)	Soil depth ranges (cm)				
	0-10	10-20	20-30	30-40	0-40
M1 = Managements without N application and high sward canopy height					
5	47	57	104	119	40
10	12	14	26	30	10
15	5	6	12	13	4
20	3	4	7	7	3
HW20	7.7	8.5	11.4	12.2	7.1
Average PR	2.664	3.700	2.849	2.177	1.931
Average variance	0.178	0.400	0.290	0.307	0.277
M2 = Management with N application and high sward canopy height					
5	89	45	98	109	51
10	22	11	25	27	13
15	10	5	11	12	6
20	6	3	6	7	3
HW20	10.6	7.5	11.1	11.7	8.0
Average PR	2.641	3.478	2.890	2.178	2.020
Average variance	0.222	0.674	0.234	0.291	0.277
M3 = Management without N application and low sward canopy height.					
5	58	45	65	99	35
10	14	11	16	25	9
15	6	5	7	11	4
20	4	3	4	6	2
HW20	8.5	7.5	9.0	11.1	6.6
Average PR	2.699	3.132	2.937	2.349	2.380
Average variance	0.159	0.355	0.244	0.225	0.349
M4 = Management with N application and low sward canopy height					
5	102	80	84	134	58
10	26	20	21	34	15
15	11	9	9	15	6
20	6	5	5	8	4
HW20	11.3	10.0	10.3	13.0	8.5
Average PR	2.901	3.440	3.562	2.460	2.141
Average variance	0.304	0.754	0.630	0.318	0.384

when the animal stocking density rate is higher, and therefore the forage mass is higher, ruminants grazing walk less, although the distance between feeding stations increases, the time spent per feeding station increases and the bites rate decreases (Baggio et al., 2009).

Considering the foregoing, it is fully understandable that in this study, the management with the most animal stocking density (M4 management) shows greater heterogeneity of the area. This is due, possibly to the routes of the animals journeys and choice (random) of the 20 points (129 mm^2 $point^{-1}$) of the PR's sampling, which may or may not match the area of the animals footprints (±100 cm^2). Other managements with fewer circulating animals are less likely to coincide a measurement point of the PR with the animal trod; this fact increases the heterogeneity among points.

A variation is observed in sample size between soil depth ranges and between the managements and for each estimation error (Table 2). Considering there was heterogeneity of variances among managements (Table

1), sample sizes should also be different. In this case, to maintain the level of significance of all managements of the experiment, one should adopt for the larger sample size between the management systems for the same magnitude of the estimation error. Considering also that the PR evaluation is unusual in one or other range of depth, one should also choose the sample size on the higher value range. In this study, for an estimation error equal 10% (HW, half-width of confidence interval = 10% from the average), the sample size would be equal to 34 points, corresponding to the management "With application of N and low sward canopy height"; in 30-40 cm layer. To match the availability of financial and human resources, It can be adjusted the magnitude of the estimation error for the feasible sample size (Table 2). Thus, for an estimation error of HW = 15%, the sample size is 15 points and eight points for an estimation error of HW = 20%. Considering, in this study, that we used 20 points per experimental unit, the estimation error (HW20) for this sample size has a maximum value among managements and depths equal to 13% of the average.

It was found, in another study, that significant decreases do not occur in the standard error values by increasing the number of points beyond 15, ranging between five and 15% among penetrometers, within each sampled area (Molin et al., 2012). A variation in sample size in relation to the management system and the soil layers was also reported. In addition, the sample size for a 10% estimation error of the mean is n = 15 points for no-till system and perennial crops soils; and n = 20 points for conventional till (Tavares Filho and Ribon, 2008). For chemical analyzes of soil samples, the collection of at least eight single soil samples would be enough to form a representative composite sample for evaluation of average soil fertility in a seemingly homogeneous sampling unit, but the reliability or accuracy of the estimate the medium fertility will be higher the larger the number of single samples collected to form a composite sample (Santos et al., 2009). In this study, this would be equivalent to increasing the number of PR measurement points per experimental unit.

Conclusions

For the same estimation error of the soil's penetration resistance, the sample size (number of points) depends on the depth range of soil and animal stocking density. In experiments with varying animal stocking density on cool-season grasses pasture, 15 points per experimental unit are sufficient to estimate the average with an estimation error of 15% of the average soil penetration resistance.

Conflict of Interest

The author(s) have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The National Council for Scientific and Technological Development (CNPq) for the resources of the Universal Notice, productivity grants and IC. The Higher Education Personnel Training Coordination (CAPES) for the scholarship granted.

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