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Effects of different soil sampling instruments on assessing soil fertility in the caatinga area, Brazil

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Soil sampling is designed to ensure obtaining reliable information about the existence, concentration and distribution of the analyzed substances in the investigated area. The caatinga is usually characterized as tree and shrub formations, mostly with high fertility soils, but suffering major physical limitations. This study aimed at determining the minimum number of single samples that theoretically should be used to form a composite sample representative of the depths 0 to 10, 10 to 20, and 20 to 30 for the chemical characteristics: pH, P, K⁺, Ca²⁺ and Mg²⁺, as well as show that the average fertility estimated from the arithmetic mean of the results of single samples did not differ statistically from that estimated from the chemical analysis of the composite sample and statistically evaluate the effects of collection instruments (auger, cut-shovel and cup-auger) at a depth of 0 to 10 in the main indices of soil fertility. The study was conducted in a caatinga area near the city of Arcoverde, State of Pernambuco-PE. Samples were collected from 40 plots of 250 m². The minimum number of simple samples that should be used to form a representative composite sample for fertility indices increases with decreasing angular error. According to the results, there was less spatial variability to the pH at all depths analyzed. Below 0.2 m, the number samples to be at maximum for proper estimations of P and K⁺ levels in soils. A smaller number of samples can be taken for the variables, pH, Ca²⁺ and Mg²⁺. Significant differences in rates of fertility (pH, P and Mg²⁺) were observed among the instruments. The order of variability was different for all instruments. There were no differences in fertility rates for the average of single samples over the average of composite samples consisting of three simple subsamples.

Key words: Soil analysis, collection instrument, variability.

INTRODUCTION

The term "caatinga" is of Tupi origin and means "white forest"; it refers to the aspect of vegetation during the dry season, when most trees lose leaves and the whitish and

bright stems dominate the landscape (Prado, 2003). The semi-arid caatinga of northeastern PE (Pernambuco) occupies 735 km², being bounded on the east and west

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by the Atlantic and Amazonian forests, respectively and on the south by the Cerrado. It is composed of numerous botanical families of herbs, shrubs, trees and vines; this vegetation has been classified as steppes-savanna, ranked in several typologies (Ibge, 1992). This vegetation presents adaptive morphological and physiological mechanisms to persist in a dry environment, where water available for plants is derived solely from the short rainy season (Fernandes, 1998).

Droughts and dry spells occur in large extensions and high evapo-transpiration rates because high temperatures favor the occurrence of water deficits (Paupitz, 2009). Average annual temperatures are relatively high, 26 to 29°C, and the average insolation is 2800 h/year (Alves, 2007).

The caatinga soils, although mostly of high fertility, they suffer from major physical limitations with respect to depth, stoniness and topography (Almeida, 2008). Chemical analysis of soil samples is the most widespread technique among the existing methods for the assessment of soil fertility and aims at quantifying the nutrient content in the soil (Santos et al., 2009).

The soil sampling techniques differ from environment to environment; thus a single sample represents a soil area in a universe of high spatial variability. The soil variability is the result of complex interactions of factors and processes of its formation. In addition to the factors and processes, soil and crop management practices are additional causes of variability (Coráje, 1997; Santos et al., 2009).

The greater the variability of a soil characteristic, the appropriate representation of a composite sample is directly related to the quantity and quality of single samples (Guarçoni et al., 2006). Thus, the chemical characteristics of a sample will be more representative when its distribution across a sampled universe is greater.

There is not a single pre-established instrument for collecting samples for soil fertility analysis. Soil samplers commonly used in Brazil include the screw-auger, auger, dutch auger and cut-shovel (Alvarez and Guarçoni, 2003; Guarçoni et al., 2007; Oliveira et al., 2007).

Using an auger in the place of the cut-shovel has the advantage of greater speed in the sampling of simple samples and handling and transport of a smaller soil volume in the field prior to homogenization (Salet et al., 2005). But, the lower soil volume collected with auger causes increased variability of soil fertility rates, making it necessary to collect more simple samples to form a representative composite sample (Oliveira et al., 2007). Schlindwein and Anghinon (2002) evaluated the influence of the data collection instrument (screw-auger and cut-shovel) of the soil sample on measures of average and variability of chemical characteristics of a clayey Oxisol. For all chemical characteristics analyzed (pH, P, and K⁺), regardless of fertilization type, the variability was higher when the screw-auger was used than when using the cut-

shovel, especially for phosphorus. Alvarez and Guarçoni (2003) also studying both instruments, ascertained that the P showed greater variability for Mg²⁺, K⁺, MO, and pH, with higher values for the auger. The influence of different sampling methods in the results of soil analysis were also reported by other researchers (Bacchi et al., 1995; Alvarez and Guarçoni, 2003; Lin et al., 2005; Guarçoni et al., 2007; Oliveira et al., 2007; Wang et al., 2008).

Thus, this study attempts to determine the minimum number of simple samples that theoretically should be used to form a representative composite sample of the depths 0-10, 10-20, 20-30 for the chemical parameters: pH, P, K⁺, Ca²⁺ and Mg²⁺, and attempt to show that the estimated average fertility from the arithmetic mean of the results of simple samples does not differ statistically from that estimated from the chemical analysis of the composite sample, in addition to evaluate the effects of data collection instruments (auger, cut-shovel and cup-auger) at a depth of 0-10 in the main indices of soil fertility.

MATERIALS AND METHODS

The study was conducted near the city of Arcoverde, State of Pernambuco-PE (2010). The city has a total area of 379 km², located at 663 m an altitude and according to Köppen, a predominance of the climate 'BSHS' type (dry steppe climate of low latitude with rains between autumn-winter) with annual average temperature of 24°C, 1058.8 mm annual average rainfall, with the rainy season in March and April.

The "Portal do Sertão" as Arcoverde is known, is located in the microregion of the Sertão de Moxotó, transition between the Agreste and Sertão. The city is 256 km away from Recife, bordered by the BR-232, having as limits: the State of Paraíba to the north, the cities of Pernambuco Buíque and Pedra to the south, Pesqueira to the east and Sertânia the west. It presents a basin bounded by the rivers Moxotó, Ipanema and Ipojuca with subperenifolia forest vegetation and a clay soil type (Ibge, 2000).

The total area of the studied fragment has 35 ha in length, with hypoxerophytic caatinga vegetation that according to the owner has not been clear cut or burned for about 56 years; however it has been used for cattle grazing. The fragment is cut by a temporary stream, whose width varies from 2-24 m, which is called the Riacho da Beija Mão. The aforementioned area, belonging to the Cavalcanti farm, is located near the town of Ipojuca at the margins of PE 219, 22 km distant from the county seat, Arcoverde/PE.

To determine the number of samples that theoretically should be used to form a representative composite sample representative for chemical characteristics (pH, P, K⁺, Ca²⁺ and Mg²⁺), samples were collected from 40 plots installed in the fragment of 10.0 m × 25, 0 m. In these plots were performed samplings via auger at 0-10, 10-20 and 20-30 cm depth with three replicates each, totaling 120 samples for each depth. Subsequently for each plot, subsamples of the three samples collected were used to form a composite sample.

Soil samples were packed in plastic bags, properly identified and then taken to the Department of Soil Chemistry-UFRPE, in which they were air dried and sieved in 2 mm mesh sieve, obtaining the air-dried fine soil (ADFS).

From the ADFS, Ca²⁺ and Mg²⁺ were determined by titration (Embrapa, 1997), P was measured by colorimetry (Braga and Defelipo, 1974), K⁺ was determined by flame photometry and pH

Table 1. Number of samples (n) per soil collection at different depths in a caatinga area, considering different ranges of variation (f) to estimate mean values of soil chemical characteristics (pH, P, K, Ca and Mg) at 95% probability (Arcoverde - PE, 2011).

f (%)	Error compared to the mean value														
	0-10					10-20					20-30				
	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg
10	1	66	31	30	57	1	67	61	22	49	1	146	144	22	29
20	1	17	8	7	14	1	17	15	6	12	1	37	36	5	7
30	1	7	3	3	6	1	7	7	2	5	1	16	16	2	3
40	1	4	3	2	4	1	4	4	1	3	1	9	9	1	2
50	1	3	1	1	2	1	3	2	1	2	1	6	6	1	1
60	1	2	1	1	2	1	2	2	1	1	1	4	4	1	1
70	1	1	1	1	1	1	1	1	1	1	1	3	3	1	1
80	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1
90	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CV(%)	4	40	26	26	37	4	40	38	23	34	4	59	60	23	26

$n = [(t\alpha/2.CV)/f]^2$; $t_{0.05}$ (39DF) = 2.03; CV, Coefficient of variation.

by the soil:water (1:2.5) (Embrapa, 1997).

From this data, the mean and coefficient of variation for each of the sampled depths were determined. Subsequently, the minimum number of simple samples that theoretically should be used to form a composite sample representative of the plot were determined according to the statistical procedure adopted by Barreto et al. (1974): $n = [(t\alpha/2.CV) / f]^2$, where n = number of simple samples to form a representative composite $t\alpha/2$ = tabulated value of the Student's t distribution which depends on the $\alpha/2$ probability level (two-tailed), with a significance level of 95% and the number of degrees of freedom (df = n-1), which was calculated by DF interpolation corresponding to 30 and 40, and its adopted value of 2.03, CV = coefficient of variation of the soil characteristic to be measured; f = angular error around the mean (%).

In order to try to show that the average fertility estimated from the arithmetic mean of the results of simple samples does not differ statistically from that estimated from the chemical analysis of the composite sample, composite samples were formed from each replicate subsamples collected at each of 40 plots. Thus, there was the additional formation of more than 40 samples for each depth. The samples were analyzed (pH, Ca^{2+} , Mg^{2+} , K^+ and P) and data compared with the simple samples by applying the Student's t test.

To evaluate the effects of the different data collection instruments (auger, cut-shovel and cup-auger) on the main indices of soil fertility, additional samples were collected at a depth of 0 to 10 in 16 plots of the original 40 plots delineated. Subsequently, the samples were stored, identified and taken for analysis. The following parameters were evaluated: pH, Ca^{2+} , Mg^{2+} , K^+ and P and the Tukey test was applied after data tabulation. Testing was performed using the Assistat software.

RESULTS AND DISCUSSION

The minimum number of individual samples that should be used to form a composite sample representative for fertility rates of the sampled area was calculated by the coefficient of variation for an error and around the mean of 10 to 100%. In this study, it is observed that as the

angular error decreases from 100 to 10%, the minimum number of samples increases to all parameters evaluated, except for pH, where it was noted less spatial variability at all depths analyzed (Table 1). This indicates that this feature should not be used as an indicator to determine the number of simple samples to make a composite sample (Araujo and Oliveira, 2003).

Among the fertility attributes evaluated, the one that estimated the highest number of simple samples required for the soil composite sample was phosphorus, corroborating the results of Hernandez et al. (2011), Silveira et al. (2000), Alvarez and Guarçoni (2003) and Oliveira et al. (2007). For this variable, the number of samples remained constant depth for the first 2 depths (0-10 and 10-20 cm) considering f between 10 and 20%, which had its value more than doubled in the depth of 20-30 cm, requiring 146 samples. Increasing the sampling depth increases the number of samples to be collected for K^+ by more than 50%, being necessary respectively for each depth 31, 61 and 144 samples (Table 1). This result confirms the data of Salet et al. (1996) for evaluations of P and K^+ in a given crop area considering 10% error, where the authors found a high number of samples were required to obtain reliable results.

Contrary to this observation, it was noted that a decreased number of samples would be required to form a composite sample for Ca^{2+} and Mg^{2+} . Assuming 10% for f to determine the sampling of Ca^{2+} and Mg^{2+} , 30 and 57 samples, respectively, would be needed for the 0 to 10 cm depths, while for the 20 to 30 cm depths, this number decreases to 22 and 29, respectively (Table 1).

The average values for P, K, Mg and pH were consistently higher for samples collected with Dutch auger and cup-auger when compared with the cut-shovel, indicating that this sampling method is better suited for

Table 2. Means (Y) for phosphorus, potassium, calcium, magnesium and pH in soil samples collected in the caatinga area of 16 plots with different data collection instruments (Arccoverde - PE, 2011).

Data collection instrument	pH	P	K	Ca	Mg
		mg dm ⁻³		cmolcdm ⁻³	
	Y (means)				
Dutch auger	6.21 ^a	2.892 ^a	0.297 ^a	4.8739 ^a	1.9479 ^a
Cut-shovel	5.96 ^b	1.718 ^b	0.2089 ^a	5.0093 ^a	1.5437 ^b
Cup-auger	6.09 ^{ab}	2.664 ^a	0.2104 ^a	5.7606 ^a	1.9268 ^a
F	3.211 [*]	19.5635 ^{**}	3.048 ^{ns}	1.992 ^{ns}	4.2599 [*]
CV%	4.638	23.207	48.73946	25.95966	24.41272

Means followed by same letter for each data collection instrument do not differ significantly by the Tukey test at 5%.

^{**}, Significant at 1% probability (p < .01); ^{*}, significant at 5% probability (.01 = <p < .05); ns, not significant (p > .05)

the three depths studied, except for calcium analysis. Oliveira et al. (2007) also found that the variability of soil fertility indices were similar among the data collection instruments, observing higher values for the cup-auger than cut-shovel, except for K⁺ and Ca. However, in soybean and corn crop areas, Salet et al. (2005) observed lower values of fertility rates in samples collected with the Dutch auger compared with the cut-shovel.

Thus, the results obtained in this study depending on the sampling method have a clear influence on the results of soil analysis, as reported by several authors (Bacchi et al., 1995; Alvarez and Guarçoni, 2003; Lin et al., 2005; Guarçoni et al., 2007; Oliveira et al., 2007; Wang et al., 2008). Significant differences among instruments were observed for pH, P and Mg and regardless of the instruments, the lowest variability was observed for pH. The variability order was different for both collection instruments, being represented indecreasing order as follows: Dutch auger Ca²⁺ > P > Mg²⁺ > K > pH; Cut-shovel K > Mg²⁺ > P > Ca²⁺ > pH and cup-auger K > Ca²⁺ > P > Mg²⁺ > pH (Table 2).

Comparing the fertility indices for the average of single samples (120 samples) with the average of composite samples consisting of three simple subsamples, no significant differences were found when using the Student's t test at 5%. Samples collected from the 20 to 30 cm depth resulted in higher values of Ca²⁺ and Mg²⁺, though not significantly different compared to the average of composite samples (Table 3). These results indicate that, probably, if a smaller number of single samples is collected, the averages of these characteristics would not be different regardless of the evaluation method of average soil fertility. Oliveira et al. (2007) reported that regardless of the sampling method for assessment of average soil fertility (arithmetic mean of simple samples or chemical analysis of the composite sample), the number of single samples to form one composite sample does not influence the estimate of the average contents of evaluated characteristics of fertility, as observed in this work. However, this author emphasizes that the collection of at least eight individual soil samples would be sufficient

to form a representative composite sample for evaluation of the average soil fertility in an apparently homogeneous sampling unit. With other later studies, similar results were observed (Santos et al., 2009).

Considering the most limiting attribute and the percentage error in estimating the average of 20%, the number of simple samples can range from 50-188 (Silveira et al., 2000); from 11-183 (Schlindwein and Anghinon, 2002); 20-39 (Guarçoni et al., 2006), 5 to 20 (Guarçoni et al., 2007), 18-31 (Amaro Filho et al., 2007). Guarçoni et al. (2006) recommend, for the characterization of the soil individual (sample unit), a collection of 25 simple samples to compose a representative composite sample, taking into account "f" around 20%.

According to the statistical formula that determines the number of simple samples to form a representative composite (Barreto et al., 1974), the collection of more simple samples (higher n value) has no influence on the average value of the chemical characteristic of the soil evaluated, but increases the reliability or accuracy of this mean value obtained by decreasing the "f" value.

Conclusion

Increasing the depth of sampling required increases the quantity of collected samples for P and K⁺, while for Ca²⁺ and Mg²⁺, this number is expected to decline and remains stable for pH. There were significant differences in fertility values obtained with the three instruments used in the collection for pH, P and Mg²⁺ with the cut shovel instrument giving the lowest fertility values.

The reliability of the sample was influenced by soil depth and instrument used. As regards the depth, below 0.2 m, the number samples to be at maximum for proper estimations of phosphorus and potassium levels in soils.

Considering the major homogeneity of subsurface layer, due to the minor influence of topsoil, a smaller number of samples can be taken for de variables pH, Ca²⁺ and Mg²⁺, as published by other research.

The instruments used have changed the contents the

Table 3. Mean values for phosphorus, potassium, calcium, magnesium and pH in relation to average fertility estimated from the arithmetic mean of the results of simple samples and estimated from the chemical analysis of the composite sample (Arcoverde - PE, 2011).

Depth	0 - 10					10-20					20-30				
	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg
	mg dm ⁻³	mg dm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³	mg dm ⁻³	mg dm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³	mg dm ⁻³	mg dm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³	cmolcdm ⁻³
Simple samples	6.18 ^a	2.385 ^a	0.28951 ^a	4.80667 ^a	2.05917 ^a	6.17 ^a	1.630 ^a	0.28951 ^a	4.70583 ^a	2.22792 ^a	6.07 ^a	0.907 ^a	0.29423 ^a	4.56075 ^a	2.00392 ^a
Composite samples	6.18 ^a	2.409 ^a	0.31706 ^a	4.92500 ^a	1.99525 ^a	6.15 ^a	1.789 ^a	0.31706 ^a	4.62750 ^a	2.10750 ^a	6.09 ^a	1.115 ^a	0.31841 ^a	4.80125 ^a	2.20925 ^a

Means followed by same letter in column do not differ significantly by the Student's t test at 5%.

elements obtained in sampling, interfering in the evaluation of levels available, performing as an important component to be considered in sampling of soils. There was no significant difference between the average of simple samples and the average of composite samples in relation to fertility rates.

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