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Spatial variability of Regosol chemical attributes in guava management with neem under semi-arid conditions

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ABSTRACT

Considering the relevant importance of guava (*Psidium guajava*) in Northeastern Brazil along with the benefits of neem cake amendments on soil characteristics, this work evaluated the effects of neem cake on chemical attributes of a Regosol under irrigated guava orchard in an alluvial valley of Pernambuco semi-arid region. Evaluations were carried out in two areas (area 1 – with neem cake; area 2 – without neem cake) at three periods: before the first application of neem cake, 90 days after the first application and 90 days after the second application. A regular 8 × 6-point grid was designed in each area and the soil was sampled for total organic carbon, pH, soluble salts (Na^+, K^+, Ca^{2+} and Mg^{2+}) and total nitrogen contents, as well as soil C-CO_2 evolution rate in soil. Geostatistical analysis pointed out the spherical model as the best fit to the studied variables, followed by the Gaussian model, with ranges from 12 to 60.5 m. Neem cake incorporation increased spatial variability and the contents of the evaluated soil chemical attributes.

Palavras-chave:
Azadirachta indica
manejo
qualidade do solo
Psidium guajava

Variabilidade espacial de atributos químicos em Neossolo no manejo da goiabeira com nim no semiárido

RESUMO

Considerando a importância do cultivo de goiabeiras (*Psidium guajava*) para o nordeste do Brasil e os benefícios da aplicação da torta de nim nas características do solo, avaliou-se o efeito da aplicação de torta de nim nos atributos químicos de um Neossolo Regolítico cultivado com goiabeiras irrigadas no semiárido de Pernambuco. Para as avaliações foram usadas duas áreas (área 1 – com nim; área 2 – sem nim) e três períodos, antes da aplicação do nim, 90 dias após a primeira aplicação e 90 dias após a segunda aplicação; assim, 96 amostras de solo foram coletadas em duas malhas regulares de 8 × 6 pontos amostrais e realizadas análises do teor de carbono orgânico total, pH, teores de sais solúveis (Na^+, K^+, Ca^{2+}e Mg^{2+}), nitrogênio total e taxa de evolução C-CO_2 do solo. O modelo esférico foi o que melhor se ajustou às variáveis estudadas seguido pelo gaussiano, com alcances que variaram de 12 a 60,5 m. A incorporação da torta de nim aumentou a variabilidade espacial e a oferta dos atributos de solo estudados.

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Introduction

Guava (*Psidium guajava* L.) is a rustic fruit crop, with good capacity of dispersion and rapid adaptation to different environments. Guava fruits have excellent acceptance in the market due to the great variety of products, by-products and forms of consumption (Campos et al., 2013). In Brazil, the crop is predominantly grown using family labor, on 3 to 5 ha farms. In the Northeast, the regional production is concentrated in the irrigated districts of Pernambuco and Bahia, due to the water availability, favorable conditions of soil and climate and advanced mechanization techniques (Araújo et al., 2013). With adequate irrigation and phytosanitary management, the orchards may reach yields higher than 40 t ha^{-1}; however, half of this yield has been reported in the country. The concern about the use of agrochemicals, not only for the risks to humans and the environment, but also for the increments in production costs (Soares & Porto, 2012), has stimulated the search for more sustainable management alternatives, such as the incorporation of neem (*Azadirachta indica* A. Juss) cake to the soil.

Known as an important medicinal plant since the medieval period, neem has activity against more than 430 species of pests (Martinez, 2002) and is used for pest management due to the low cost and ecological viability; however, despite the effectiveness of neem by-products in the integrated management of pests and diseases (Chaves et al., 2012), there is little information on how these products affect soil chemical quality, particularly under semiarid conditions. This study aimed to evaluate variations in spatial-temporal distributions of soil chemical attributes after the incorporation of neem cake in a guava orchard in the Pernambuco semiarid region.

Material and Methods

The experiment was carried out from April to October 2013 in a commercial orchard of ‘Paluma’ guava, with six months of planting, in a rural settlement in the Ipanema River sub-basin, in the municipality of Pesqueira-PE, Brazil. The experimental area has 0.84 ha and is situated between the coordinates of 8º 23.835’ and 8º 23.903’ S and 36º 51.515’ and 36º 51.475’ W, with south-north slope of 0.4%. The soil in the area was predominantly described as Fluvent Entisol, with 751.32, 169.13 and 79.55 g kg^{-1} of sand, silt and clay, respectively. The climate in the region, according to Köppen’s classification, is BSh (extremely hot, semiarid). Mean annual temperature is 23 ºC, mean annual rainfall is 700 mm and mean annual evapotranspiration is 2000 mm (Santos et al., 2012).

The orchard was planted by the farmer between the months of September and October 2012. The experimental area was divided into two areas of equal size, Area 1 and Area 2, and the sampling grids were designed according to the position of the plants, alternately along the X and Y axes, totaling 48 (8 × 6) points per area, each one with approximately 200 plants.

Area 1 was randomly drawn to be amended with the neem cake applied in guava plants according to the sampling grid points each application soil pits were open around the plant, following the canopy projection area, with depth of approximately 25 cm, and the product was uniformly amended at the dose of 1 kg plant^{-1} and, then, soil pits were filled with soil. The neem cake was provided by the Cruangi Mill and showed contents of 23.92, 14.335, 0.569, 0.966, 1.145, 1.049, 0.512 and 1.041 g kg^{-1} of N, K^+, Na^+, Ca^{2+}, Mg^{2+}, Zn^{2+}, Cu^+ and Mn^{2+}, respectively.

Along the experimental period, the orchard was drip-irrigated according to the need and did not receive any type of chemical fertilizer. The control of invasive plants was manually performed, without the application of commercial herbicides.

Approximately 2 kg of soil were sampled from each grid point, at the beginning of the study (s1); 90 days after the first sampling (s2) and 90 days after the second sampling (s3), totaling 180 experimental days. Neem cake was immediately amended after the first (s1) and second (s2) samplings, after which the samples were placed in plastic bags, protected from heat sources, identified and taken to the Laboratory of Soil Chemistry of the Federal Rural University of Pernambuco for chemical analyses of total organic carbon (OC), pH, soluble salts (Na^+, K^+, Ca^{2+} and Mg^{2+}), total nitrogen (TN) and C-CO_2 evolution rate of the soil.

OC was determined through oxidation of organic matter using the wet method; soil pH was determined using 10 g of air-dried sieved soil (ADSS) in water (1:2.5); soil contents of soluble K^+, Na^+, Ca^{2+} and Mg^{2+} were based on the respective saturation extracts using an atomic absorption spectrophotometer with flame for the reading of divalent cations and a flame photometer for the reading of monovalent cations. Soil TN was quantified from 0.5 g of ADSS and N reading (dag kg^{-1}) performed through titration with diluted HCl, all according to EMBRAPA (2009).

For determination of soil C-CO_2 evolution rate, 100-g soil samples were placed in plastic containers at the moment of the samplings and immediately taken to the laboratory, placed along with another container with 10 mL of 0.5 N KOH in a sealed glass chamber for 15 days at 25 ± 2 ºC in an environment protected from the light. The CO_2 absorbed by KOH was determined through titration with 0.1 N HCl, using phenolphthalein and methyl orange as indicators.

Data were evaluated through analysis of variance and descriptive statistical analyses, with values of maximum, minimum, mean, median, coefficient of variation, standard deviation and kurtosis, and normality tested by the Kolmogorov-Smirnov analysis.

The variability of the analyzed attributes was classified according to Warrick & Nielsen (1980), as low (CV < 12%), moderate (12% < CV > 24%) or high (CV > 24%). Spatial dependence was analyzed through the fit of the classic semivariogram based on the estimate of the semivariances using the program GEO-EAS. The data were fitted to experimental semivariograms and, subsequently, spherical, Gaussian and exponential models were tested. The mathematical fit enabled the definition of the nugget effect (C_0), spatial range (A) and sill (C_0 + C1).

The fitted models were subjected to cross-validation and the degree of spatial dependence was evaluated based on the classification proposed by Cambardella et al. (1994). Values of the relationship between the nugget effect and the sill of their fitted semivariogram lower than 25% characterize strong dependence; between 25 and 75%, moderate dependence; and above 75%, weak dependence. The parameters of the semivariance function after fitting to the theoretical models were used in the construction of isoline maps through kriging, in order to define zones of similar variability and divide the area into more homogeneous sub-regions. Isoline maps were constructed using the program Surfer 9.9.785 (Golden Software®).

Results and Discussion

When little close, the values of mean and median may indicate non-normality of the data, since they characterize an asymmetric distribution. From the 48 probable combinations for the eight chemical variables analyzed (two areas and three samplings), 23 combinations did not present normal distribution, by Kolmogorov-Smirnov at 0.05 probability level (Table 1). Based on the CV

Table 1. Descriptive summary of soil chemical attributes in two areas, with (Area 1) and without (Area 2) the addition of neem cake, in guava orchard before the application (Sampling 1), 90 days after the first application (Sampling 2) and 90 days after the second application (Sampling 3)

	Maximum	Minimum	Mean	Median	Kurtosis	CV (%)	SD	KS
				Area 1 – Sampling 1				
K^+	2.6010	0.3597	0.9829	0.8741	1.4168	49.0461	0.4820	*
Na^+	9.5256	1.6421	4.0050	3.7572	0.9805	46.1420	1.8480	*
Mg^{2+}	3.7029	0.1152	1.8455	1.8308	-1.0417	52.9894	0.9779	*
Ca^{2+}	5.3771	0.6253	2.9078	2.9863	0.4836	34.4821	1.0026	*
C-CO_2	28.546	0.1805	10.678	9.0206	-0.4198	74.8757	7.9952	ns
OC	0.9400	0.0947	0.4580	0.4453	0.0803	37.2987	0.1708	*
TN	0.8386	0.3909	0.6139	0.6156	-0.3287	16.7827	0.1030	ns
pH	8.66	5.66	7.2158	7.19	0.3218	8.2306	0.5939	*
				Area 1 – Sampling 2				
K^+	1.4640	0.5001	0.9042	0.8730	-0.2315	24.8189	0.2244	*
Na^+	4.2855	1.2622	2.2919	2.1293	0.1621	36.5822	0.8384	ns
Mg^{2+}	6.6455	0.2468	2.5101	1.6161	-0.5374	77.4354	1.9437	ns
Ca^{2+}	5.3196	0.1257	1.6592	1.1916	0.7209	81.3098	1.3491	ns
C-CO_2	55.8352	1.7018	12.810	8.2934	4.1743	89.9790	11.527	ns
OC	0.9602	0.5782	0.7327	0.7259	-0.0382	12.4799	0.0914	*
TN	9.5067	3.9129	6.2283	6.1556	1.3007	17.7099	1.1030	ns
pH	7.1800	5.22	6.1739	6.14	-0.2549	7.8679	0.4857	*
				Area 1 – Sampling 3				
K^+	3.0679	0.3034	1.2442	1.1218	0.3894	53.3002	0.6631	ns
Na^+	43.5789	4.2821	15.015	9.7589	-0.0208	67.3286	10.11	ns
Mg^{2+}	5.9046	1.4749	3.4398	3.2974	-0.2030	29.2292	1.0054	*
Ca^{2+}	5.8026	1.5270	3.1327	3.0699	0.2018	30.8336	0.9659	*
C-CO_2	59.3106	0.3837	19.012	16.0067	2.6708	66.2389	12.5934	ns
OC	1.2181	0.5378	0.8766	0.8617	0.6648	15.6121	0.1368	*
TN	12.0995	3.7258	7.7379	7.6479	0.3239	22.6686	1.7540	ns
pH	7.9800	6.2	7.2335	7.33	-0.5253	6.62554	0.4792	ns
				Area 2 – Sampling 1				
K^+	2.0953	0.2863	1.0074	0.9108	-0.0733	48.0791	0.4843	ns
Na^+	7.9874	1.6867	3.6232	3.1804	0.7011	45.8461	1.6611	ns
Mg^{2+}	5.2768	0.0494	1.8364	1.6679	0.4484	62.8046	1.1533	*
Ca^{2+}	3.7297	0.2318	1.7497	1.6302	0.0518	45.2120	0.7910	*
C-CO_2	101.4208	0.1780	17.212	11.3681	8.7955	108.2078	18.6244	ns
OC	0.8270	0.0314	0.3850	0.4091	-0.164	45.2369	0.1741	*
TN	0.7838	0.3912	0.5652	0.5592	-0.3933	17.0447	0.0963	*
pH	7.77	6.57	7.1620	7.21	-0.0243	3.9122	0.2801	*
				Area 2 – Sampling 2				
K^+	2.6373	0.3374	1.1322	1.0452	1.4507	42.9599	0.4864	*
Na^+	5.1527	1.2622	2.4301	2.0054	0.0528	45.2244	1.0990	ns
Mg^{2+}	15.9441	0.5299	3.5143	2.3566	4.3123	88.7554	3.1191	ns
Ca^{2+}	23.9859	0.1057	3.0381	1.7645	19.954	124.6167	3.7860	ns
C-CO_2	61.6645	1.6527	16.251	11.9606	5.2632	75.0539	12.1967	ns
OC	0.9193	0.3712	0.6498	0.666	0.3433	27.3598	0.1128	*
TN	6.7200	4.4692	5.3267	5.3132	-0.1455	10.1773	0.5421	ns
pH	7.2100	5.01	6.2191	6.4	0.0145	7.6054	0.4808	*
				Area 2 – Sampling 3				
K^+	2.9935	0.3530	1.3007	0.9978	-0.4236	60.0712	0.7813	ns
Na^+	44.2309	4.4125	16.462	9.6285	-0.4871	72.0765	11.8649	ns
Mg^{2+}	6.9404	1.6539	3.6254	3.6188	0.3515	32.4614	1.1768	ns
Ca^{2+}	8.3756	1.9441	5.2473	5.3425	0.0628	27.0470	1.4192	*
C-CO_2	80.0943	5.4827	20.575	15.835	5.6447	73.0709	15.0345	ns
OC	1.0586	0.4363	0.6968	0.6626	-0.4368	32.2322	0.1549	*
TN	9.4953	3.1695	5.8305	5.9554	0.2254	23.6288	1.3777	ns
pH	8.2200	6.75	7.5685	7.625	0.4287	4.2053	0.3182	*

K^+ ($cmol_c$ L^{-1}); Na^+ ($cmol_c$ L^{-1}); Mg^{2+} ($cmol_c$ L^{-1}); Ca^{2+} ($cmol_c$ L^{-1}); C-CO_2 – C-CO_2 evolution rate (mg CO_2); OC – Organic carbon (dag kg^{-1}); TN – Total nitrogen (g kg^{-1}); pH – Hydrogen potential; CV – Coefficient of variation; SD – Standard deviation; KS – Kolmogorov-Smirnov normality test at 0.05 probability level; ns – Not significant; *Significant limits proposed by Warrick & Nielsen (1980), only pH showed low variability in both areas and in all sampling periods (Table 1). TN showed moderate variability and OC, moderate to strong; the other chemical variables showed high variability (CV > 24%), corroborating with Leão et al. (2011).

In Area 1 (Table 1), the variation in the OC contents decreased over time, from a CV of 37.3%, before neem application, to 12.5% at 90 days after the first application (sampling 2) and 15.6% at 90 days after the second application (sampling 3), indicating that the uniform application of neem cake in that area may have reduced OC variability, although this reduction in variability also occurred over time in the Area 2, but at lower proportions.

The best fits for the soil attributes (Table 2) were obtained with the spherical model; seven out of eight analyzed soil

Table 2. Parameters of the theoretical semivariograms, degree of spatial dependence and cross-validation of chemical variables of a Regolithic Neosol in two areas, with (Area 1) and without (Area 2) the addition of neem cake, in guava orchard before application (Sampling 1), 90 days after application (Sampling 2) and 90 days after the second application (Sampling 3)

	Model	C_0	C_1	A	R^2	$C_0/(C_0 + C1)$	DSD	Jack-Knifing	
								Mean	SD
				Sampling 1 - Area 1					
K^+	Pure nugget effect								
Na^+	Exp.	2.0043	1.7263	16.7632	0.5423	53.73	Mod.	-0.019	0.934
Mg^{2+}	Gauss.	0.5948	0.4968	26.2622	0.8785	54.49	Mod.	0.009	1.013
Ca^{2+}	Gauss.	0.5678	0.6742	31.3567	0.9339	45.72	Mod.	-0.004	1.084
$C-CO_2$	Gauss.	0.0917	0.0277	20.8691	0.6381	76.80	Weak	-0.050	0.947
OC	Pure nugget effect								
TN	Gauss.	0.0074	0.0097	60.4925	0.973	43.27	Mod.	0.007	1.018
pH	Pure nugget effect								
				Sampling 1 - Area 2					
K^+	Pure nugget effect								
Na^+	Spher.	0.0025	0.0160	16.19370	0.9074	13.51	Strong	0.026	1.070
Mg^{2+}	Spher.	0.5673	0.7792	18.0059	0.8857	42.13	Mod.	-0.010	1.006
Ca^{2+}	Spher.	0.3643	0.2731	24.4869	0.5910	57.15	Mod.	-0.023	1.013
$C-CO_2$	Pure nugget effect								
OC	Pure nugget effect								
TN	Spher.	0.0072	0.0018	38.0168	0.8840	80.00	Weak	-0.003	1.035
pH	Pure nugget effect								
				Sampling 2 - Area 1					
K^+	Pure nugget effect								
Na^+	Pure nugget effect								
Mg^{2+}	Spher.	2.2362	2.1406	58.4262	0.9855	59.43	Mod.	-0.040	1.004
Ca^{2+}	Gauss.	1.1948	0.8026	39.3440	0.9249	59.43	Mod.	-0.043	0.949
$C-CO_2$	Spher.	89.0934	60.8257	38.7603	0.8757	59.43	Mod.	0.001	1.149
OC	Spher.	0.0064	0.0026	54.6216	0.9206	71.11	Mod.	-0.033	1.064
TN	Spher.	0.9679	0.1534	51.4044	0.8001	86.32	Weak	-0.066	1.087
pH	Spher.	0.0203	0.1964	16.9613	0.6672	9.37	Strong	-0.031	1.050
				Sampling 2 - Area 2					
K^+	Spher.	0.0644	0.0973	53.1051	0.8416	39.83	Mod.	0.027	1.048
Na^+	Spher.	0.0154	0.0212	34.3375	0.6986	42.08	Mod.	0.005	1.030
Mg^{2+}	Spher.	0.0259	0.0495	36.6484	0.9526	34.35	Mod.	0.003	1.076
Ca^{2+}	Gauss.	1.4398	2.0341	23.3399	0.8892	41.45	Mod.	-0.019	0.901
$C-CO_2$	Gauss.	82.6639	119.177	42.8046	0.9807	40.95	Mod.	-0.018	1.076
OC	Spher.	0.0030	0.0103	27.9968	0.9688	22.56	Strong	-0.015	1.029
TN	Spher.	0.1438	0.1567	18.4857	0.7283	47.85	Mod.	-0.002	1.058
pH	Pure nugget effect								
				Sampling 3 - Area 1					
K^+	Pure nugget effect								
Na^+	Pure nugget effect								
Mg^{2+}	Spher.	0.5376	0.5234	27.4973	0.9016	50.67	Mod.	-0.008	1.008
Ca^{2+}	Exp.	0.5312	0.4202	12.0180	0.7827	55.83	Mod.	-0.051	0.908
$C-CO_2$	Pure nugget effect								
OC	Spher.	0.0148	0.0237	17.159	0.6654	38.44	Mod.	-0.039	1.075
TN	Spher.	2.2807	0.7199	29.0486	0.7319	76.01	Weak	-0.023	1.082
pH	Pure nugget effect								
				Sampling 3 - Area 2					
K^+	Pure nugget effect								
Na^+	Spher.	94.5951	48.8706	32.4872	0.9861	65.94	Mod.	-0.013	1.106
Mg^{2+}	Spher.	0.0200	1.3431	18.6182	0.9428	1.47	Strong	-0.023	1.059
Ca^{2+}	Pure nugget effect								
$C-CO_2$	Spher.	65.1699	149.783	21.4709	0.6508	30.32	Mod.	0.019	1.246
OC	Pure nugget effect								
TN	Pure nugget effect								
pH	Pure nugget effect								

K^+- Potassium ($cmol_c$ L^{-1}); Na^+ - Sodium ($cmol_c$ L^{-1}); Mg^{2+}- Magnesium ($cmol_c$ L^{-1}); Ca^{2+}- Calcium ($cmol_c$ L^{-1}); $C-CO_2$ – Evolution $C-CO_2$ (mg CO_2); OC – Organic carbon (dag kg^{-1}); TN – Total nitrogen (g kg^{-1}); pH – Hydrogen potential; C_0 – Nugget effect; C_1 – Contribution; $C_0 + C_1$ – Sill; R^2 – Coefficient of determination; DSD – Degree of spatial dependence; SD – Standard deviation; Spher. – Spherical; Gauss. – Gaussian; Exp. – exponential attributes showed nugget effect in at least one of the areas and one of the samplings, except for Mg^{2+}, which were fitted to the spherical or Gaussian models for all areas and sampling periods. The nugget effect is an important measurement of the semivariogram and indicates unexplained variability, which may be due to measurement errors or even undetected microvariation, considering the sampling distance used (Carrasco, 2010).

The ranges obtained for soil chemical attributes (Table 2) showed wide variation with minimum of 12.02 m for Ca^{2+} in the third sampling of Area 1 and maximum of 60.49 m for TN in the first sampling of Area 1. High range values characterize higher continuity in the distribution of the variable, possibly due to the management (Souza et al., 2004).

The isoline maps for the chemical variables that showed spatial dependence in Area 1 are shown in Figure 1. The spatial distributions of Ca^{2+}, Mg^{2+}, TN, Na^{+} and pH in the first sampling (Figure 1-C1) showed higher levels in the northeast region of the area and lower levels in the central region; coincident regions for these attributes are explained by the greater availability of these ions in the solution of soils with higher pH (Natale et al., 2012).

At 90 days (sampling 2), the pattern of spatial distribution for Ca^{2+} and Mg^{2+} still showed central region with the

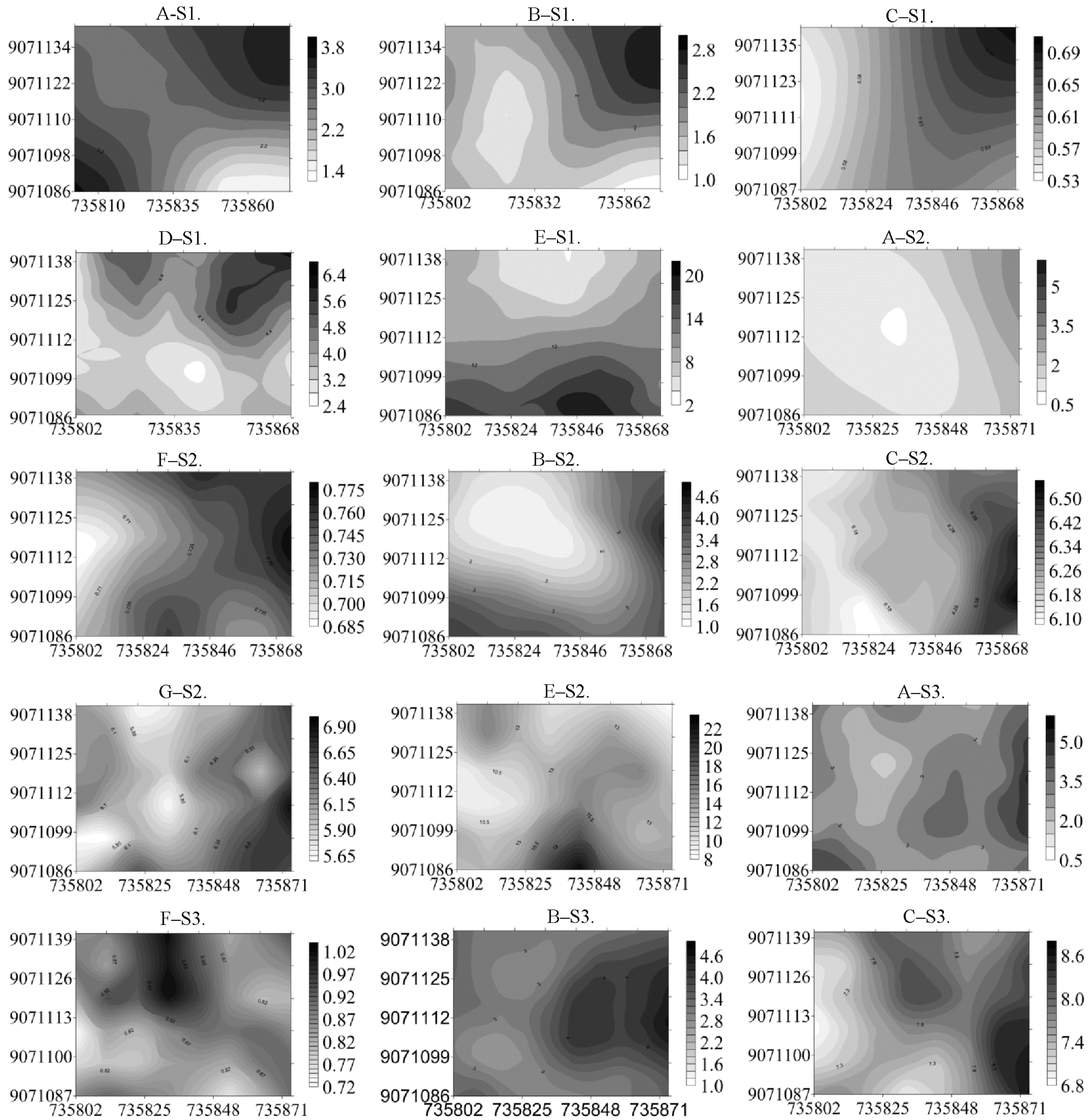

Figure 1. Isoline maps of Area 1 for the contents of calcium (A), magnesium (B), total nitrogen (C), sodium (D), $C\text{-}CO_2$ evolution rate (E), organic carbon (F) and pH (G) at six months, before the application of neem cake (S1) and after 90 (S2) and 180 (S3) days

lowest levels of these nutrients (Figures 1A-C1 and 1B-C2), such as in sampling 1 (Figures 1A-C1 and 1B-C1). This demonstrates that, at first, the incorporation of neem cake did not interfere with the spatial distribution of these nutrients; the spatial distributions of OC and TN (Figures 1F-C1 and 1C-C1) indicate higher concentrations on the east region, demonstrating that a great part of soil N was immobilized in the organic form. Comparing the maps of TN for sampling 1 (Figure 1C-C1) and sampling 2 (Figure 1C-C2), higher values were concentrated in the east region of the area, indicating that, at 90 days, the neem cake did not interfere with the spatial distribution of TN.

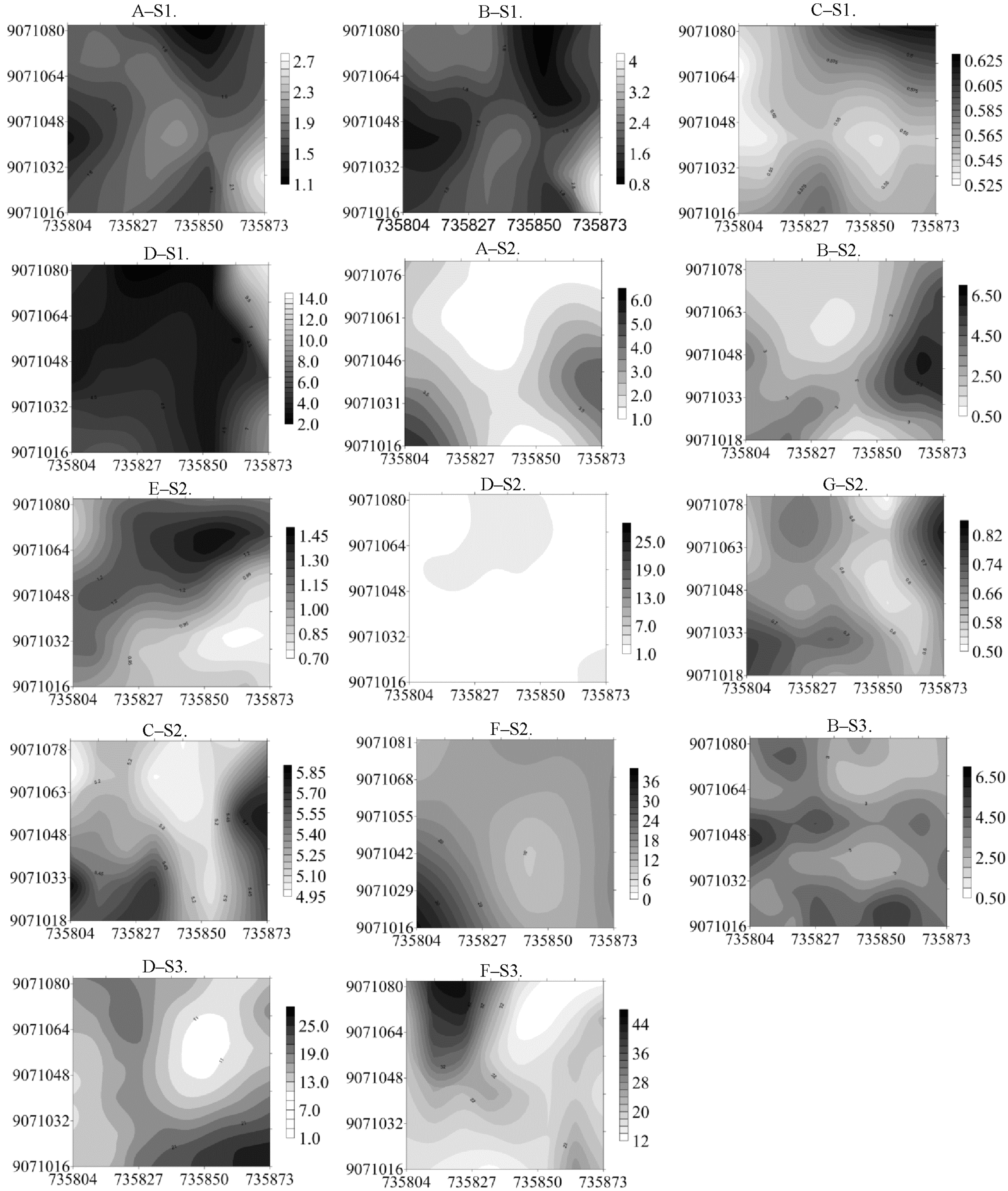

Figure 2. Isoline maps of Area 2 for the contents of calcium (A), magnesium (B), total nitrogen (C), sodium (D), potassium (E), $C\text{-}CO_2$ evolution rate (F), organic carbon (G) and pH (H) at six months (S1) and after 90 (S2) and 180 (S3) days without neem cake

The nearer lines showing narrower strips for this type of map characterize higher spatial variability, while wider strips present greater uniformity. Comparing the maps for each element, before and after application, there were a few similarities in the patterns of spatial distribution, indicating that the incorporation of neem cake must have influenced the dynamics of these nutrients in the treated area. The increase in the variability of C-CO_2 evolution rate due to neem cake incorporation possibly results from the influence of the organic matter on the different microbial communities (Gleixner, 2013). For OC (Figures 1F-C1, 1F-C2 and 1F-C3), neem cake application increased the variability and the contents in the soil, showing narrower lines at the end of the study. Menezes & Silva (2008) reported similar behavior to the effects of organic fertilizers on soil fertility.

In the maps of samplings 1, 2 and 3 in Area 2 (Figure 2), there was no narrowing of the strips for any of the chemical variables over time, indicating that there were no great chemical alterations in the soil. The highest variabilities were observed for TN in samplings 1 and 2, OC in sampling 2 and C-CO_2 evolution rate in sampling 3. The amount of carbon in the soil under cultivation systems is the response between the rates of residue addition, mineralization and humification.

Less aggressive and more efficient techniques in an integrated management system for guava are necessary, especially in the Brazilian Northeast region, where edaphoclimatic conditions are less favorable to the crop. The incorporation of neem cake as an alternative measure proved to be viable not only to improve soil quality, but also due to the need for a sustainable agriculture, with high yield, quality and low economic and environmental impact.

Conclusion

Neem cake incorporation promoted chemical alterations in the soil, increasing the spatial variability and the supply of organic carbon, nitrogen and soluble salts to plants.

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