Revista Brasileira de Geografia Física

ISSN:1984-2295

Homepage:https://periodicos.ufpe.br/revistas/rbgfe

Functional analysis of soil chemical attributes using Geographic Information Systems to assess nutrient deficiencies

Manuella Vieira Barbosa Neto[1], Maria do Socorro Bezerra de Araújo[2], José Coelho de Araújo Filho[3], Cristiane Barbosa da Silva[4], Everardo Valadares de Sá Barretto Sampaio[5]

[1]Professor of Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco-IFPE, Curso de Licenciatura em Geografia, Av. Prof. Luís Freire, 500, 50740-540, Recife – PE, Brasil, manuellaneto@recife.ifpe.edu.br, (autor correspondente) https://orcid.org/0000-0003-1859-6183. [2]Professor of Universidade Federal de Pernambuco-UFPE, Departamento de Ciências Geográficas, Av. Ac. Hélio Ramos, s/n, 50740-530, Recife, Pernambuco, Brasil, maria.baraujo@ufpe.br, https://orcid.org/0000-0001-8816-8569. [3]Researcher of Empresa Brasileira de Pesquisa Agropecuária-EMBRAPA. Embrapa Solos UEP Recife, Rua Antônio Falcão, 402, 51020-240, Recife, Pernambuco, Brasil. jose.coelho@embrapa.br, https://orcid.org/0000-0002-8318-7418. [4]Doctoral student in Geografia by Universidade Federal de Pernambuco-UFPE, Departamento de Ciências Geográficas, Av. Ac. Hélio Ramos, s/n, 50740-530, Recife, Pernambuco, Brasil, cristianebarbosa2@yahoo.com.br, https://orcid.org/0000-0002-1367-5854. [5]Professor of Universidade Federal de Pernambuco-UFPE, Departamento de Energia Nuclear, Av. Prof. Luiz Freire, 1000,50740-540, Recife, Pernambuco, Brasil, sampaio.everardo@gmail.com, https://orcid.org/0000-0002-4745-016X

Artigo recebido em 09/11/2014 e aceito em 24/02/2015

A B S T R A C T

Information on soil fertility is essential to determine the need for correcting measures. However, the use of appropriate techniques to provide information on the specific potential of each soil in many agricultural areas is scarce. Soil fertility in an area with family farming was evaluated based on spatialization of soil chemical attributes to indicate their usage limitations. The study area was on the water basin of the Natuba River, in the Mata Centro Zone, Pernambuco state, Brazil. Samples were taken from soils under the most representative agricultural uses and under native vegetation following a slope gradient (top, middle and bottom). Samples were analyzed for their base saturation, cation exchange capacity, aluminum saturation and phosphorus concentration. These parameters were used to indicate their degree of limitation to agricultural use in order to create a georeferenced database and were mapped using a Geographic Information System (GIS). The cultivated Rhodic Acrisol and Eutric Gleisolhad the highest fertility, while the Xanthic Acrisol, Chromic Acrisol and Xanthic Ferralsol had the highest usage limitations. Areas used to grow vegetables had higher nutrient availability than those cropped to sugarcane. Spatialization in the GIS system contributed to the overall fertility analysis, allowing a clear visualization of areas that need soil improvement.

Keywords: Soil fertility; Agricultural potential; Mapping.

Análise funcional dos atributos químicos do solo usando Sistemas de Informação Geográfica para avaliar as deficiências de nutrientes

R E S U M O

Informações sobre a fertilidade do solo são essenciais para determinar a necessidade de medidas corretivas. No entanto, o uso de técnicas adequadas para fornecer informações sobre o potencial específico de cada solo em muitas áreas agrícolas é escasso. A fertilidade do solo em uma área com agricultura familiar foi avaliada com base na espacialização dos atributos químicos do solo para indicar suas limitações de uso. A área de estudo localiza-se na bacia hidrográfica do rio Natuba, na Zona da Mata Centro, estado de Pernambuco, Brasil. As amostras foram retiradas de solos sob os usos agrícolas mais representativos e sob vegetação nativa seguindo um gradiente de declive (topo, encosta e várzea). As amostras foram analisadas quanto à saturação de bases, capacidade de troca catiônica, saturação de alumínio e concentração de fósforo. Esses parâmetros foram utilizados para indicar seu grau de limitação ao uso agrícola para a formação de um banco de dados georreferenciado e foram mapeados em Sistema de Informações Geográficas (SIG). O Argissolo Vermelho e o Gleissolo Háplico cultivados apresentaram a maior fertilidade, enquanto o Argissolo Amarelo, o Argissolo Vermelho - Amarelo e o Latossolo Amarelo apresentaram as maiores limitações de uso. As áreas destinadas ao cultivo de hortaliças apresentaram maior disponibilidade de nutrientes do que as plantadas com cana-de-açúcar. A espacialização no sistema GIS contribuiu para a análise geral da fertilidade, permitindo uma visualização clara das áreas que precisam de melhoramento do solo.

Palavras-chave: Fertilidade do solo; Potencial agrícola; Mapeamento.

Introduction

Information on soil fertility is essential to determine the need for correcting measures to assure proper nutrient availability and adequate crop productivity (Lopes and Guilherme, 2007; Cardoso et al., 2013; Tahat et al., 2020). However, the use of appropriate techniques to provide information on the specific potential of each soil in many agricultural areas is scarce (Soares Filho and Cunha, 2015). This is especially true in areas covered by a mosaic of small properties of relatively low income, whose owners do not have the capital and/or expertise to implement a good soil analysis system (Miranda et al., 2014).

With the development of Geographic Information Systems (GIS), data on soil chemical and physical properties can be represented in a way, which facilitates implementing and updating their features. It is possible to map the spatial variability of soil attributes by recognizing the geographical location of the sampling points (Oliveira et al., 2008; Kumar et al., 2013; Were et al., 2016). In this sense, the inputs needed for better soil environmental and economic management could be applied with greater efficiency in a precision agriculture approach (Bolfe et al., 2020). These techniques have mainly been used by producers with access to advanced technologies (Tschiedel and Ferreira, 2002; Bolfe et al. 2020). Producers of small-scale agriculture have little access to such knowledge, but low-cost mapping techniques could contribute to a better understanding of the agricultural potential and better land use in their farms.

Information on soil fertility analyzes can be difficult to be interpreted by small-scale, often illiterate, farmers. Therefore, producing maps illustrating the nutrient deficiencies of a given area indicating its degrees of limitation to agricultural use can contribute to a better communication between agricultural technicians and small-scale farmers. In a GIS environment, it is possible to create a database with information on soil fertility, elaborate maps that indicate potentialities and limitations, and produce a more comprehensible soil quality classification for small-scale producers (Finch et al., 2014; Abdel Rahman and Arafat, 2020).

Pereira and Lombardi (2004) adapted the method of Oliveira and Berg (1985)to evaluate soil fertility based on the aggregate analysis of nutrient availabilities, aluminum toxicity base saturation (V%) and cation exchange capacity (CEC).This methodology helps to interpret soil fertility data in a way which reduces subjectivity and facilitates understanding.

Considering the advantages of joining this methodology with GIS, we developed the analysis for an area occupied by poor small-scale family farmers in Pernambuco state, Brazil, who are the main vegetable producers for the large Recife market.

Material and methods

Study Area

The study area was on the water basin of the Natuba river, in the Mata Centro Zone, Pernambuco state, Brazil (Figure 1). The drainage area is approximately 39 km^2 and the middle basin is approximately 23 km², from 8° 00’ 00” to 8º 10’ 00” S, and from 35º 05’ 00” to 35º30’00” W, with altitudes from 150 to 590 m.

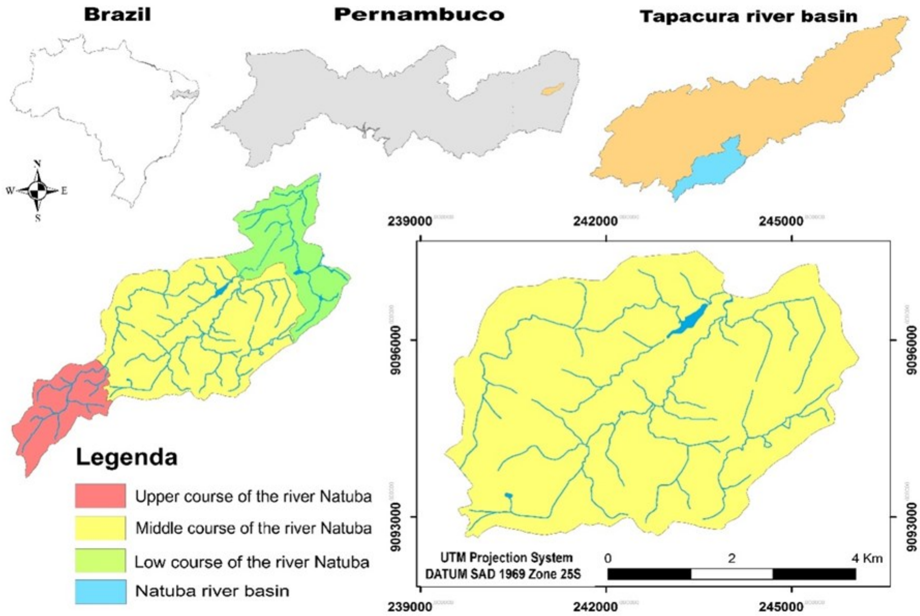

Figure 1. Geographic location of the medium course of the river Natuba, state of Pernambuco, Brazil. Source: Barbosa Neto et al. (2017).

The area is mainly used for vegetable production, after being intensively planted with sugarcane for many decades, which had replaced almost all the original Atlantic rainforest (Souza et al., 2008). The dominant climate is tropical rainy or wet megathermic, with average annual temperature of 23.8ºC, varying between the minimum of 19.3ºC and the maximum of 30.9ºC. The average annual rainfall varies between 1008 mm and 1395 mm, with about 70% concentrated between March and July (Souza et al., 2008). The main soils of the area (Santos et al., 2013) are Xanthic Acrisols, Chromic Acrisols, Rhodic Acrisols, Eutric Gleisols, Xanthic Ferralsols and Dystric Leptosols (Araújo Filho et al., 2013), in the classification of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015).

Soil Sampling

Soil samples were collected at sites of the most representative soils (Araújo Filho et al., 2013), and land uses (Barbosa Neto et al., 2011), including agricultural uses and adjacent locations with native vegetation at the top, slope and bottom positions based on the digital elevation model, all mapped in the 1:25,000 scale, in addition to field observations (Figure 2).

Soil samples were collected from the top position(where Xanthic Ferralsol predominates)at six sites in the larger sugarcane area and at four sites in an adjacent smaller forest area (Table 1). The soil sampling sites followed a linear transect in both areas, with each site being separated from the following one by 100 m (Figure 2). Samples were taken at three points at each site, one on the transect line and two 20 m way at a perpendicular distance from each side of the line. Asoil profile was opened at each point and samples were taken from layers0 to 5 cm, 5 to 20 cm, 20 to 35 cm and 35 to 50 cm deep. The samples from each depth at the three points of each site were mixed to form a single composite sample (Figure 2).

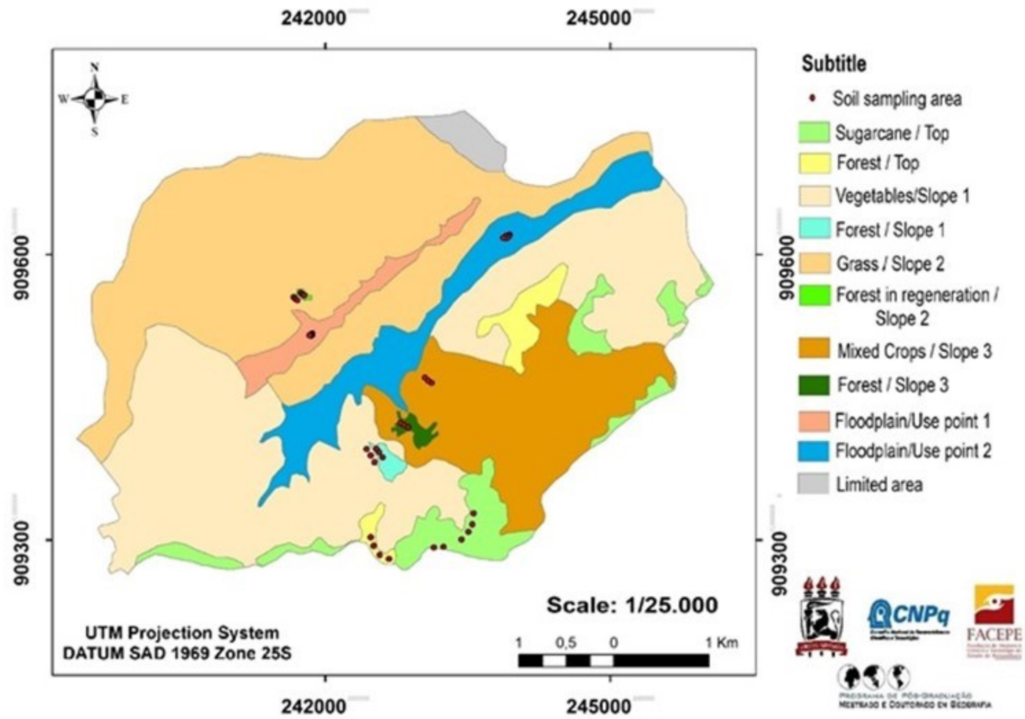

Figure 2. Spatialization of land uses, in the middle course of the Natuba river basin, Pernambuco state, Brazil. Red dots indicate soil sampling areas.

Table 1. Sampling scheme in each environmental unit (Top, Slope and Bottom) of cultivated and native vegetation adjacent area carried out in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Sampling area	Number of sites	Number of points per site	Model and local of the transects	*Number of layers	Number of composite samples
		TOP			
Sugarcane (FRxa)	6	3	Linear/along the top	4	24
Forest (FRxa)	4	3	Linear/along the top	4	16
		SLOPE 1			
Vegetables (ACcr)	3	3	Linear/Upper, middle and lower slope	4	12
Forest (ACcr)	3	3	Linear/Upper, middle and lower slope	4	12
		SLOPE 2			
Grass (ACxa)	3	3	Linear/Upper, middle and lower slope	4	12
Forest in regeneration (ACxa)	3	3	Linear/Upper, middle and lower slope	4	12
		SLOPE 3			
Mixed crops (ACro)	3	3	Linear/Upper, middle and lower slope	4	12
Forest (ACro)	3	3	Linear/Upper, middle and lower slope	4	12
		BOTTOM			
Vegetables/Grass point 1 (GL)	1	5	Zig-zag along the bottom	4	4
Vegetables point 2 (GL)	1	5	Zig-zag along the bottom	4	4
		Total of soil samples			**120**

The abbreviations used were: *Soil Classes: (FRxa) Xanthic Ferralsol, (ACcr) Chromic Acrisol, (ACxa) XanthicAcrisol, (ACro) RhodicAcrisol and (GL) Gleysol. *Depths of layers: (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm).

Soil samples were collected from three positions in the slope position (upper, middle, and lower) in places with the most representative agricultural uses and in an adjacent forest area. Soil sampling followed linear transects at each slope position, parallel to the base of the slope, with three points per transect. Three slopes were selected to sample: Chromic Acrisol predominates in the first slope, cultivated with vegetables; Xanthic Acrisol predominates in the second slope, cultivated with vegetables and pastures; and Rhodic Acrisol predominates in the third slope, cultivated with maize and banana. Eutric Gleisol is the main soil class in the bottom position, and samples were collected in two sites (Table 1). Thus, five points were sampled at each site, spaced 20 m apart in a sinuous line along the bottom position. The first site was cultivated with vegetables and pastures, and the second only with vegetables. No native vegetation was found in the bottom position which could serve as reference of the natural fertility of the area (Figure 2).

The composite samples were analyzed for pH and extractable Ca, Mg, Na, K and P concentrations, following the methodology recommended by Embrapa (1997). Sum of exchangeable bases (S), cation exchange capacity (CEC), percentage of saturation by bases (V) and percentage of saturation by aluminum (m) were calculated from these concentrations. Fertility deficiency was evaluated using the proposal of Pereira and Lombardi Neto (2004) and the degrees of limitation related to nutrient availability and aluminum toxicity followed the recommendation of Oliveira and Berg (1985), which related the base saturation (V%) with the cation exchange capacity (CEC) and saturation by aluminum (m) with CEC (Tables 2 and 3). Fertility deficiency was also evaluated by the concentration of extractable phosphorus (Table 4) with Mehlich's solution (Embrapa, 1997), according to the levels recommended by Almeida et al. (1988).

Table 2. General classification of limitation degrees concerning nutrient availability in relation to percentage base saturation in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Base saturation (V%)	Cationexchange capacity (CEC, cmol$_c$ kg^{-1})		
	> 5	3 - 5	2 - 3
	Degree of nutrient limitation*		
50 - 100	0	1	2
25- 50	1	2	3
10 -25	3	3	4
0 -10	4	4	4

Source: Oliveira and Berg (1985).*Degree of nutrient limitation: 0 = null; 1 = slight; 2 = moderate; 3 = strong; 4 = very strong

Table 3. General classification of limitation degrees concerning aluminum toxicity in relation to aluminum saturation in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Al saturation (m%)	Cation exchange capacity (CEC, cmol$_c$ kg^{-1})	
	5 -10	1 - 5
	Degree of limitation*	
0 – 10	0	0
10 – 30	1	1
30 – 50	2	1
50 – 70	3	2
70 – 100	4	3

Source: Oliveira and Berg (1985).*Degree of nutrient limitation: 0 = null; 1 = slight; 2 = moderate; 3 = strong; 4 = very strong

Table 4. General classification of limitation based on Mehlich extractable phosphorus in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Degree of limitation	Classes	P(mg kg^{-1})
0: null	Very high	> 30
1: slight	High	21 - 30
2: moderate	Medium	11 - 20
3: strong	Low	6 - 10
4: very strong	Very low	≤ 5

Source: Almeida et al. (1998).

The degrees of limitation of base saturation (V%) related to CEC, aluminum saturation (m%) related to CEC and available phosphorus in the three soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm deep) were mapped using the ArcGIS 9.3 software program to construct a georeferenced database of the analyzed fertility attributes.

Results and discussion

Base saturation andCEC

The areas with agricultural use (where Eutric Gleisol and Rhodic Acrisol predominate) had the least degree of nutrient limitation in all four soil layers (Table 5 and Figure 3).This could be due to the high organic matter content characteristic of the Eutric Gleisol soil class. Santos and Salcedo (2010) reported high organic matter levels in Eutric Gleisol at the bottom position of the Brava river basin in the neighboring Paraíba state.The richness of nutrients in areas where Rhodic Acrisol predominates could be related to its rich ferromagnesian parent material (Gomes and Santos, 2001).

The highest nutrient reserves, and consequently the lowest limitation, occurred in the 0-5 and 5-20 cm deep layers (Table 5 and Figure 3). The soil surface layers generally have a larger quantity of organic material due to litter deposition. In addition, the soils of these cultivated areas may have been enriched by the recurrent application of bovine manure and eventually application of chemical fertilizers.

The EutricGleisol area represents 9.5% of the studied area and is intensively used with horticulture. Its impediments varied from null to light, probably due to the good cultivation conditions (Figure 3). The Rhodic Acrisol area is equivalent to 14.2% of the studied area and has little limitation where it is cultivated with maize and banana, but there are strong impediments at all four soil layers in the forest reference area, indicating that the natural fertility is low, and the cultivation has increased the nutrient availability (Figure 3).The same seems to have happened in the Chromic Acrisol area, which occupies about a third of the total area (32.9%), and is cultivated with vegetables. Nutrient reserves are higher than in the forest reference area. On the contrary, cultivation of the large Xanthic Acrisol area (34.1% of the total) with varied crops maintained the low nutrient reserves that were registered in the regenerating forest nearby from the superficial soil layer down. The Xanthic Ferralsol area is equivalent to 5.3% of the studied area, it is still cultivated with sugarcane and has high limitation levels, especially in the deeper soil layer, in a similar way as the forest reference area. Therefore, sugarcane cultivation has not contributed to improving nutrient reserves, the opposite of what happened with maize and banana cultivation in the Rhodic Acrisol and vegetables in the Chromic Acrisol areas (Figure 3).

Aluminum saturation and CEC

No severe impediments due to aluminum toxicity (Table 6) were present in soil layers down to 20 cm in all areas, and soils with higher base saturation generally had lower degrees of aluminum toxicity (Nicolodi et al., 2008). Cultivated Eutric Gleisol and Rhodic Acrisol areas had the lowest impediment degrees in the four soil depths, while those of Xanthic Acrisol, Chromic Acrisol and Xanthic Ferralsol had the highest impediments because of stronger limitations in layers below 20 cm. Considering that the forest reference areas of Xanthic Acrisol, Chromic Acrisol and Xanthic Ferralsol had limitations reaching up to the strong degree, mainly in the deeper soil layers, cultivation has contributed to soil improvement. The opposite occurred in the Xanthic Acrisolarea, where the limitations due to aluminum toxicity were lower in the forested than in the cultivated areas, mainly in the deeper soil layers, and may have contributed to their low performance.

Table 5. Average values of soil attributes and limitation degrees as a function of base saturation (V%) related tocation exchange capacity (CEC)in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Land use/soil class	V (%)	CEC (cmol$_c$ kg)	Degree of limitation	V (%)	CEC (cmol$_c$ kg)	Degree of limitation
	---------- 0-5 cm Layer ----------			---------- 5-20 cm Layer ----------		
TOP						
Sugarcane (FRxa)	43.1	4.80	M	24.6	4.38	S
Forest (FRxa)	19.6	7.33	S	10.6	5.37	S
SLOPE						
Vegetables/slope 1 (ACcr)	41.9	4.58	M	22.1	4.54	S
Forest/1 (ACcr)	20.6	5.81	S	11.9	5.23	S
Grass/slope 2 (ACxa)	50.7	2.77	M	27.0	3.17	M
Forest/slope 2 (ACxa)	45.0	3.57	M	32.2	3.72	M
Mixed crops/slope 3 (ACro)	54.4	4.76	Sl	45.1	3.98	M
Forest/slope 3 (ACro)	24.0	8.02	S	15.7	6.67	S
BOTTOM						
Vegetables/Grass point 1 (GL)	54.0	6.91	N	47.6	6.54	L
Vegetables point 2 (GL)	62.2	6.51	N	62.2	5.31	N
	---------- 20-35 cm Layer ----------			---------- 35-50 cm Layer ----------		
TOP						
Sugarcane (FRxa)	18.1	3.52	S	15.8	2.91	VS
Forest (FRxa)	10.8	3.78	S	11.0	2.94	VS
SLOPE						
Vegetables /slope 1 (ACcr)	17.2	3.79	S	17.1	3.15	VS
Forest/ 1 (ACcr)	9.5	4.62	VS	8.6	3.63	VS
Grass/slope 2 (ACxa)	11.7	2.88	VS	10.6	3.46	S
Forest/slope 2 (ACxa)	17.9	3.19	S	13.1	2.98	VS
Mixed crops /slope 3 (ACro)	33.0	3.37	M	31.4	3.15	M
Forest/slope 3 (ACro)	13.0	5.70	S	15.7	4.58	S
BOTTOM						
Vegetables/Grass point 1 (GL)	56.2	4.27	Sl	71.7	3.40	L
Vegetables point 2 (GL)	66.3	3.76	Sl	71.3	3.86	L

The abbreviations used are: *Soil Classes: (FRxa) Xanthic Ferralsol, (ACcr) Chromic Acrisol, (ACxa) XanthicAcrisol, (ACro) RhodicAcrisol and (GL) Gleysol. *Nutrient limitation Degrees: N = null; Sl = slight; M = moderate; S = strong; and VS = very strong.

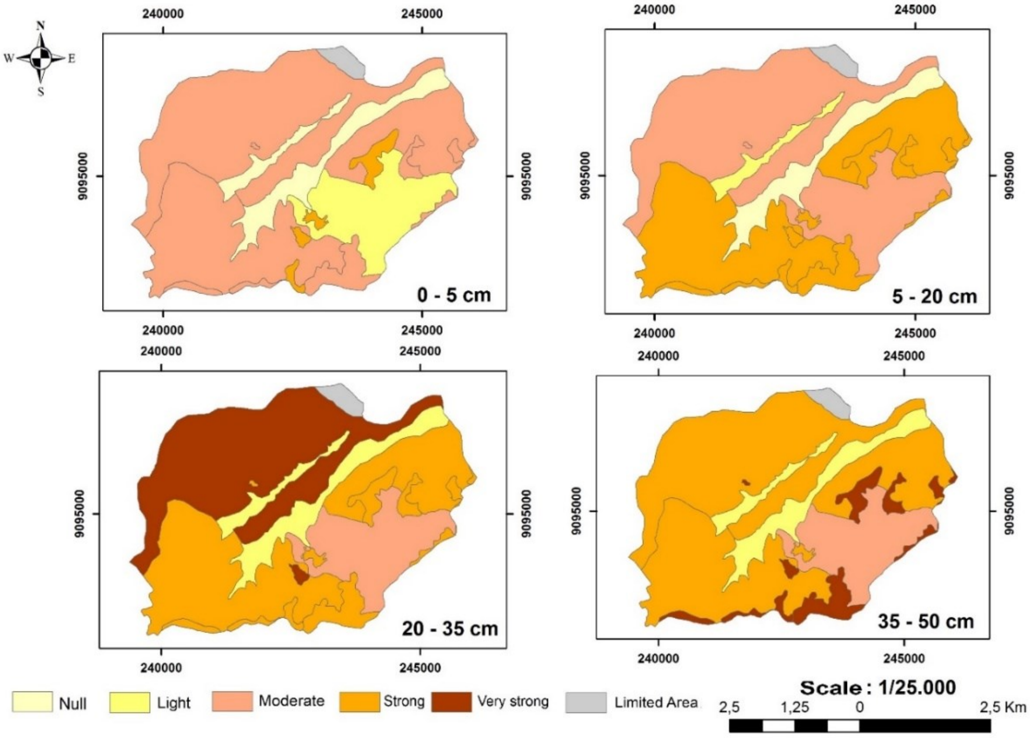

Figure 3. Spatialization of soil nutrient deficiency degrees based on base saturation (V%) related to cation exchange capacity (CEC) in three soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm deep) in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

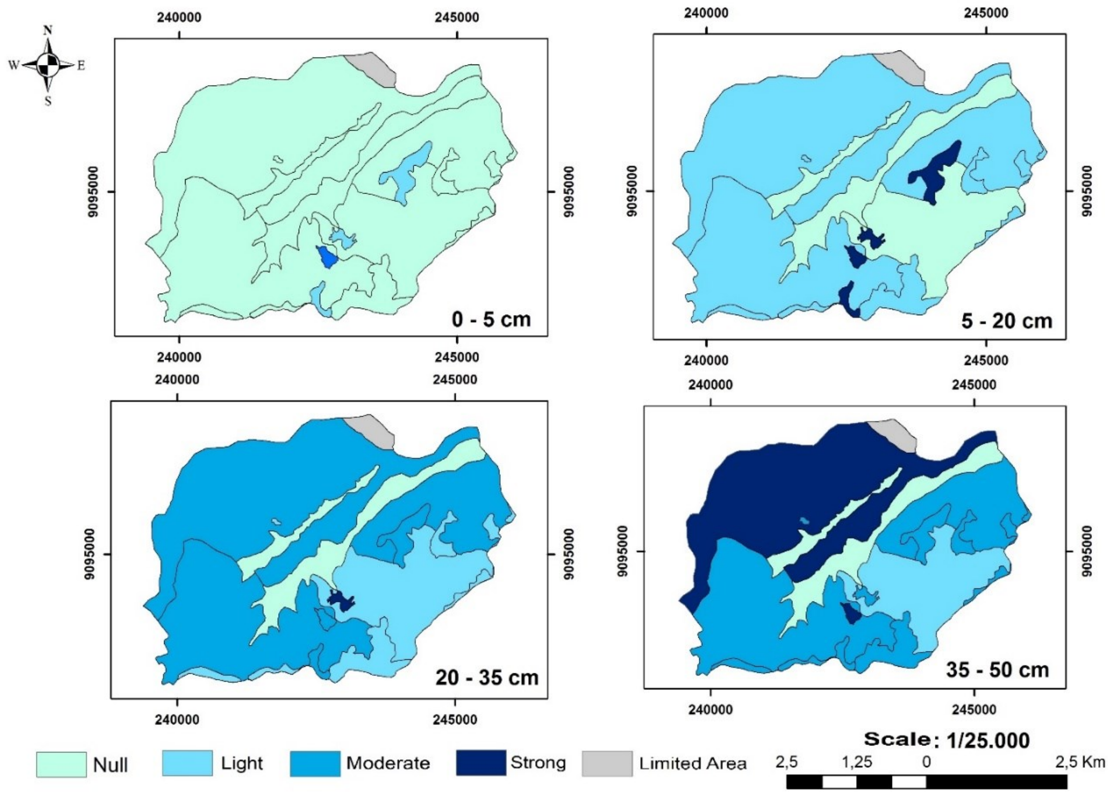

Figure 4. Spatialization of soil nutrient deficiency degrees based on aluminum saturation (m%) conjugated to the cation exchange capacity (CEC) in three soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm deep) in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Table 6. Average values of soil attributes and limitation degrees due to aluminum toxicity related to cation exchange capacity (CEC) in different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

Land use/soil class	m (%)	CEC ($cmol_c$ kg)	Degree of limitation	m (m%)	CEC ($cmol_c$ kg)	Degree of limitation
	----------- 0-5 cm Layer --------------			----------- 5-20 cm Layer --------------		
			TOP			
Sugarcane (FRxa)	5.2	4.80	N	23.2	4.38	L
Forest (FRxa)	29.4	7.33	Sl	63.8	5.37	S
			SLOPE			
Vegetables/slope 1 (ACcr)	4.0	4.58	N	36.4	4.54	L
Forest/1 (ACcr)	33.3	5.81	M	58.8	5.23	S
Grass/slope 2 (ACxa)	9.0	2.77	N	35.7	3.17	L
Forest/slope 2 (ACxa)	2.5	3.57	N	17.5	3.72	L
Mixed crops/slope 3 (ACro)	2.4	4.76	N	6.76	3.98	N
Forest/slope 3 (ACro)	28.8	8.02	Sl	55.8	6.67	S
			BOTTOM			
Vegetables/Grass point 1 (GL)	1.9	6.91	N	6.6	6.54	N
Vegetables point 2 (GL)	0.0	6.51	N	0.0	5.31	N
	--------- 20-35 cm Layer ---------			---------35-50 cm Layer ---------		
			TOP			
Sugarcane (FRxa)	43.4	3.52	Sl	52.2	2.91	M
Forest (FRxa)	67.2	3.78	M	68.2	2.94	M
			SLOPE			
Vegetables/slope 1 (ACcr)	55.2	3.79	M	57.3	3.15	M
Forest/1 (ACcr)	69.05	4.62	M	76.1	3.63	S
Grass/slope 2 (ACxa)	69.4	2.88	M	75.0	3.46	S
Forest/slope 2 (ACxa)	43.9	3.19	Sl	63.1	2.98	M
Mixed crops/slope 3 (ACro)	24.7	3.37	Sl	29.7	3.15	L
Forest/slope 3 (ACro)	64.3	5.70	S	64.9	4.58	M
			BOTTOM			
Vegetables/Grass point 1 (GL)	8.9	4.27	N	0.0	3.40	N
Vegetables point 2 (GL)	0.0	3.76	N	0.0	3.86	N

The abbreviations used are: *Soil Classes: (FRxa) Xanthic Ferralsol, (ACcr) Chromic Acrisol, (ACxa) XanthicAcrisol, (ACro) RhodicAcrisol and (GL) Gleysol. *Degree of nutrient limitation: N - Null;Sl-Slight; M - Moderate; and S - Strong.

Phosphorus availability

Soils of the middle course of the basin are generally naturally poor in phosphorus, as seen in all forested areas. This deficiency also occurred in the cropped areas, especially in the two deeper soil layers, which commonly receive fewer nutrient inputs (Table 7 and Figure 5). The superficial layers down to 20 cm of the Rhodic Acrisol and Eutric Gleisol cultivated areas had no significant impediments, possibly because the crops received phosphate mineral fertilizer or more likely manure, which is rich in P (Primo et al., 2017). Manure may have also formed complexes with iron and aluminum, preventing them from forming insoluble compounds with P (Abdala et al., 2015; Hansel et al., 2014).

Table 7. Labile phosphorus concentrations and limitation degrees in three soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm deep) of different soil classes in the middle course of the Natuba river basin,Pernambuco state, Brazil.

Land use/soil class	**P (mg kg^{-1})**	**Degree of limitation**	**P (mg kg^{-1})**	**Degree of limitation**
	------- 0-5 cm Layer ------		-------- 5-20 cm Layer -------	
		TOP		
Sugarcane (FRxa)	6.99	S	4.95	VS
Forest (FRxa)	1.45	VS	1.07	VS
		SLOPE		
Vegetables/slope 1 (ACcr)	5.82	S	1.84	VS
Forest/ 1 (ACcr)	2.29	VS	1.44	VS
Grass/slope 2 (ACxa)	1.89	VS	1.61	VS
Forest/slope 2 (ACxa)	1.81	VS	1.65	VS
Mixed crops/slope 3 (ACro)	60.50	N	16.76	M
Forest/slope 3 (ACro)	3.56	VS	3.23	VS
		BOTTOM		
Vegetables/Grass point 1 (GL)	15.44	M	30.82	N
Vegetables point 2 (GL)	77.14	N	73.71	N
	------- 20-35 cm Layer -------		--------- 35-50 cm Layer ---------	
		TOP		
Sugarcane (FRxa)	2.04	VS	0.69	VS
Forest (FRxa)	0.61	VS	0.60	VS
		SLOPE		
Vegetables/slope 1 (ACcr)	0.80	VS	0.81	VS
Forest/1 (ACcr)	0.81	VS	0.60	VS
Grass/slope 2 (ACxa)	0.99	VS	0.84	VS
Forest/slope 2 (ACxa)	1.39	VS	0.82	VS
Mixed crops/slope 3 (ACro)	2.40	VS	1.66	VS
Forest/slope 3 (ACro)	1.55	VS	1.48	VS
		BOTTOM		
Vegetables/Grass point 1 (GL)	17.33	M	5.67	VS
Vegetables point 2 (GL)	24.16	Sl	5.70	VS

Abbreviations used are: * Soil Classes: (FRxa) Xanthic Ferralsol, (ACcr) Chromic Acrisol, (ACxa) XanthicAcrisol, (ACro) RhodicAcrisol and (GL) Gleysol. *Limitation degrees: N - Null, Sl - Slight, M - Moderate, S - Strong and VS - Very Strong.

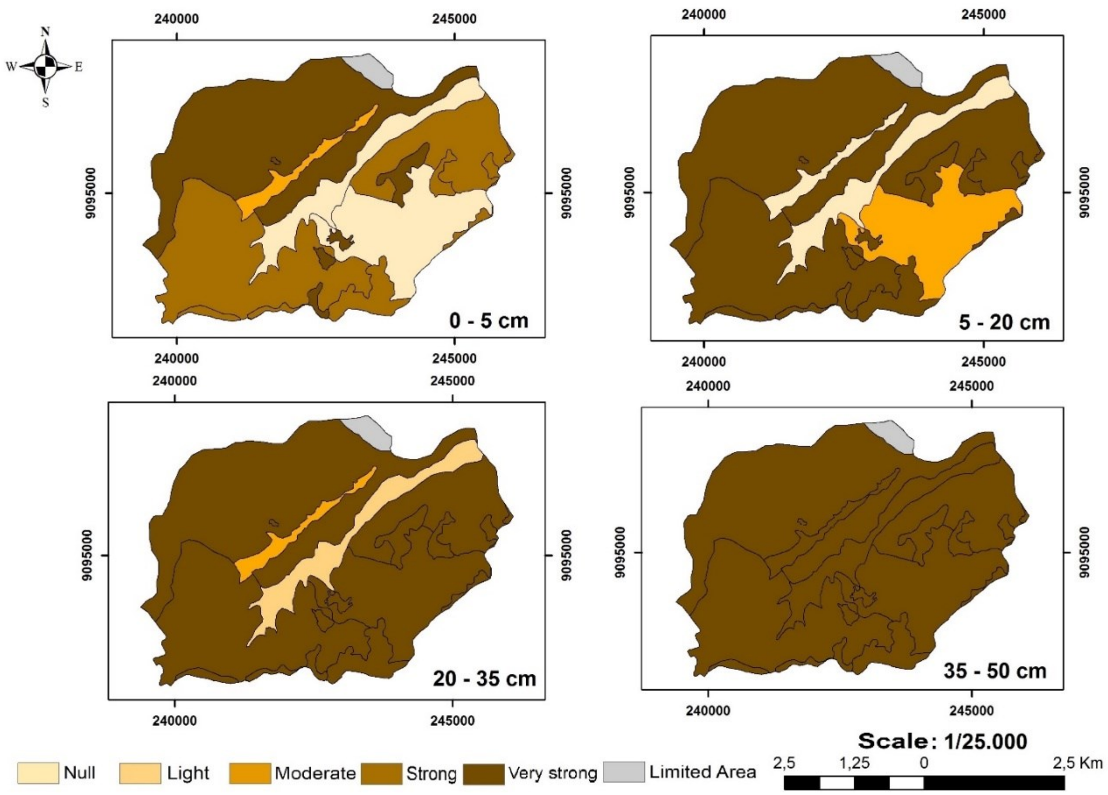

Figure 5. Spatialization of soil labile phosphorus deficiency degrees in three soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35-50 cm deep) of different soil classes in the middle course of the Natuba river basin, Pernambuco state, Brazil.

The nutrient limitation in the Xanthic Acrisol area varied from null to light in the two superficial layers, while in the two deep ones it varied from moderate to strong. The limitations due to aluminum toxicity were lower in the forest area growing on the same soil class, reaching the maximum at the moderate level. This result indicates that crops in this area are increasing aluminum saturation, which may contribute to their poor performance. The area corresponding to the Chromic Acrisol cultivated with vegetables reached maximum to moderate limitation, while in the reference area they varied from moderate to strong (Figure 4).

Conclusions

Analysis of base saturation conjugated with Cation Exchange Capacity and saturation by aluminum provided a more direct classification of soil fertility, both real and potential, in the area than the isolated parameters. The analysis indicated that soils in the forested areas had limitations ranging from moderate to very strong in all three analyzed soil features (nutrient deficiency, aluminum toxicity and phosphorus lability), indicating that the natural fertility of the area is very low. The cultivated Rhodic Acrisol and Eutric Gleisol were the most fertile in the middle course of the Natuba river basin, with the lowest limitation degrees considering the four analyzed soil layers (0-5 cm, 5-20 cm, 20-35 cm and 35 -50 cm deep). The Xanthic Acrisol, Chromic Acrisol and Xanthic Ferralsol had the highest limitations. Soils cultivated with vegetables had greater nutrient availability than those grown with sugarcane. The data spatialization with the use of geoprocessing tools contributed to analyzing the fertility data, enabling visualization of places which need greater soil improvement.

Acknowledgments

The authors thank *CNPq* and *FACEPE* for the funding and scholarships granted for conducting the research, the Remote Sensing and Geoprocessing Laboratory-SERGEO of the UFPE for the availability of the ArcGis software and Embrapa Solos UEP-Recife for the scientific and field work support.

References

Abdala, D.B.; Silva, I.R.;Vergutz, L.; Sparks, D.L., 2015. Long-term manure application effects on phosphorus speciation, kinetics and distribution in highly weathered agricultural soils. Chemosphere 119, 504-514. DOI: https://doi.org/10.1016/j.chemosphere.2014.07.029.

Abdel Rahman, M.A.E.; Arafat, S.M., 2020. An Approach of Agricultural Courses for Soil Conservation Based on Crop Soil Suitability Using Geomatics. Earth Syst Environ. 4, 273–285. DOI: https://doi.org/10.1007/s41748-020-00145-x.

Almeida, D.L.; Santos, G. A.; De-Polli, H.; Cunha, L.H.; Freire, L.R.; Amaral Sobrinho, N.M.B.; Pereira, N.N.C.; Eira, P.A.; Bloise, R.M.; Salek, R.C., 1988. Manual de adubação para o Estado do Rio de Janeiro. Coleção Universidade Rural do Rio de Janeiro. Ciências Agrárias, n. 2, 1 ed. Ed. Universidade Rural, Itaguaí.

Araújo Filho, J.C.; Barbosa Neto, M.V.; Silva, C.B.; Araújo, M.S.B.; Menezes, J.B., 2013. Levantamento semidetalhado dos solos da bacia hidrográfica do rio Natuba, Pernambuco. Revista Brasileira de Geografia Física 6, 384-397. DOI: https://doi.org/10.26848/rbgf.v6.3.p384-397.

Barbosa Neto, M.V.; Araújo, M.S.B.; Araújo Filho, J.C., 2017. Zoneamento do potencial agrícola dos solos de uma área de cultivo na Zona da Mata de Pernambuco. Sociedade e Natureza 29, 295-308. DOI: https://doi.org/10.14393/SN-v29n2-2017-8.

Barbosa Neto M.V.; Silva, C.B.; Araújo Filho, J.C.; Araújo, M.S.B.; Braga, R.A.P., 2011. Uso da Terra na Bacia Hidrográfica do Rio Natuba, Pernambuco. Revista Brasileira de Geografia Física 4, 961-973. DOI: https://doi.org/10.26848/rbgf.v4i5.232759.

Bolfe, E.L.; Jorge, L.A.C.; Sanches, I.D.A.; Luchiari Júnior, A.; Costa, C.C.; Victoria, D.C.; Inamasu, R.Y.; Grego, C.R.; Ferreira, V.R.; Ramirez, A.R., 2020. Precision and digital agriculture: adoption of technologies and perception of Brazilian farmers. Agriculture 10, 3-16. DOI: https://doi.org/10.3390/agriculture10120653.

Cardoso, E.J.B.N.; Vasconcellos, R.L.F.; Bini, D.; Miyauchi, M.Y.H.; Santos, C.A.; Alves, P.R.L.; Paula, A.M.; Nakatani, A.S.; Pereira, J.M.; Nogueira, M.A., 2013. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Scientia Agricola 70, 274-289. DOI: https://doi.org/10.1590/S0103-90162013000400009.

Embrapa- Empresa Brasileira de Pesquisa Agropecuária, 1997. Manual de métodos de análises de solo. SNLCS (Serviço Nacional de Levantamento e Conservação de Solos), Rio de Janeiro.

Finch, H.J.S.; Samuel, A.M.; Lane, G.P.F., 2014. Precision farming, In: Finch HJS, Samuel AM, Lane GPF (Eds.). Lockhart & Wiseman's Crop Husbandry Including Grassland, Woodhead Publishing, Sawston, Cambridge, pp. 235-244. DOI: https://doi.org/10.1533/9781782423928.2.235.

Gomes, H.A.; Santos, E.J. (org). 2001. Geologia e recursos minerais do Estado de Pernambuco. Recife: CPRM. 214 p.2001.

Hansel, F.D.; Amado, T.J.C.; Bortolotto, R.P.; Trindade, B.S.; Hansel, D.S.S., 2014. Influence of different phosphorus sources on fertilization efficiency. Applied Research & Agrotechnology 7, 103-111. DOI: https://doi.org/10.5935/PAeT.V7.N1.12.

IUSS Working Group WRB. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. 2015. DOI: http://www.fao.org/3/i3794en/I3794en.pdf.

Kumar, S.; Lal, R.; Liu, D.; Rafiq, R., 2013. Estimating the spatial distribution of organic carbon density for the soils of Ohio, USA. Journal of Geographic Science 23, 280-296. DOI: https://doi.org/10.1007/s11442-013-1010-1.

Lopes, A. S.; Guilherme, L.R.G., 2007. Fertilidade do solo e produtividade agrícola. In: Novais. R.F. et al. Fertilidade do Solo. Sociedade Brasileira de Ciência do Solo, Viçosa, pp. 1-64.

Miranda. E.C.; Araújo, M.S.B.; Sampaio, E.V.S.B., 2014. Comparação das condições socioeconômicas de assentados na Zona da Mata de Pernambuco, praticando horticultura em sistemas orgânico e convencional. Gaia Scientia 8, 204-214.

Nicolodi, M.; Anghinoni, I.; Gianello, C., 2008. Indicadores da acidez do solo para recomendação de calagem no sistema plantio direto. Revista Brasileira de Ciência do Solo 32, 237-247. DOI: https://doi.org/10.1590/S0100-06832008000100023.

Oliveira, R.B.; Lima, J.S.S.; Xavier, A.C.; Passos, R.R.; Silva, S.A.; Silva, A.F., 2008. Comparação entre métodos de amostragem do solo para recomendação de calagem e adubação do cafeeiro Conilon. Engenharia Agrícola 28, 176-186. DOI: https://doi.org/10.1590/S0100-69162008000100018.

Oliveira, J.B.; Berg, M.V.D. Aptidão agrícola das terras do Estado de São Paulo: quadrícula de Araras II. Memorial descritivo. Campinas: Instituto Agronômico. 60 p. (IAC. Boletim Técnico, 102).1985.

Pereira, L.C.; Lombardi Neto, F. Avaliação da aptidão agrícola das terras:proposta metodológica. Jaguariúna: Embrapa Meio Ambiente. 36 p. (Embrapa Meio Ambiente. Documentos, 43). ISSN 1516-4691.2004.

Primo, D.; Menezes, R.S.C.; Silva, W.T.L.; Oliveira, F.F.; Dubeux Jr, J.C.B.; Sampaio, E.V.S.B., 2017. Characteristics of soil organic matter in a semiarid Fluvic Entisol fertilized with cattle manure and/or gliricidia. Soil Research 55, 354-362. DOI: https://doi.org/10.1071/SR16106.

Santos, H.G.; Jacomnine, P.K.T.; Anjos, L.H.C.; Oliveira, V.A.; Lumbreras J.F.; Coelho, M.R.; Almeida, J.A., 2013. Sistema brasileiro de classificação de solos, 3 ed. Embrapa, Brasília.

Santos, A.C.; Salcedo, I.H., 2010. Fertilidade nas áreas de várzea e topo em função do uso do solo e posição do relevo. Revista de Biologia e Ciências da Terra 10, 83-90. DOI: https://www.redalyc.org/pdf/500/50016922009.pdf.

Silva, F.B.R.; Silva, M.A.V.; Barros, A.H.C.; Santos, J.C.P.; Silva, A.B.; Cavalcanti, A.C.; Silva, F.H. B.B.; Burgos, N.; Parahyba, R.B.V.; Oliveira Neto, M.B.; Souza Neto, N.C.; Araújo Filho, J.C.; Lopes, O.F.; Luz, L.R.Q.P.; Leite, A.P.; Costa, L.G.M.; Silva, C.P., 2001. Zoneamento agroecológico de Pernambuco-ZAPE. Embrapa Solos-Unidade de Execução de Pesquisa e Desenvolvimento-UEP, Recife. (Embrapa Solos. Documentos n. 35).

Soares Filho, R.; Cunha, J.P.A.R., 2015. Agricultura de precisão: Particularidades de sua adoção no sudoeste de Goiás - Brasil. Engenharia Agrícola 35, 689-698. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v35n4p689-698/2015.

Souza, S.F.; Araújo, M.S.B.; Braga, R.A.P.; Silva, C.E.M., 2008. Caracterização fisiográfica da sub-bacia do rio Natuba-PE. Revista Brasileira de Geografia Física 1, 1-14. DOI: https://doi.org/10.26848/rbgf.v1i2.232630.

That, M.M.; Alananbeh, K.M.; Othman, Y.A.; Leskovar, D.I., 2020. Soil health and sustainable agriculture. Sustainability 12, 48-59. DOI: https://doi.org/10.3390/su12124859.

Tschiedel, M.; Ferreira, M.F., 2020. Introdução à agricultura de precisão: conceitos e vantagens. Ciência Rural 32, 159-163. DOI: https://doi.org/10.1590/S0103-84782002000100027.

Were, K.; Singh, B.R.; Dick, O.B., 2016. Spatially distributed modelling and mapping of soil organic carbon and total nitrogen stocks in the Eastern Mau Forest Reserve, Kenya. Journal of Geographic Science 26, 102-124. DOI: https://doi.org/10.1007/s11442-016-1257-4.