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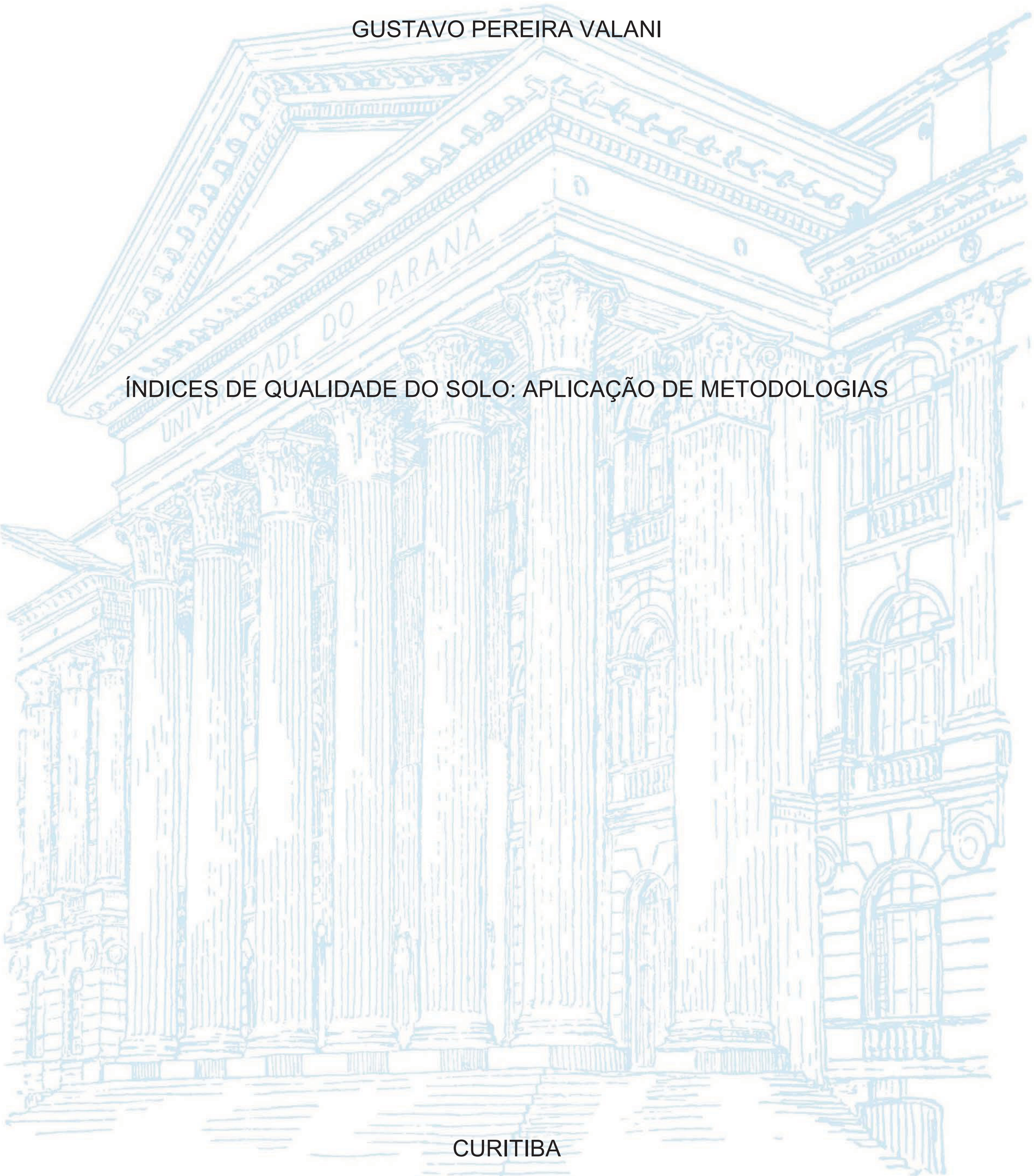

ÍNDICES DE QUALIDADE DO SOLO: APLICAÇÃO DE METODOLOGIAS

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2019

GUSTAVO PEREIRA VALANI

ÍNDICES DE QUALIDADE DO SOLO: APLICAÇÃO DE METODOLOGIAS

Dissertação apresentada ao curso de Pós-Graduação em Ciência do Solo, Setor de Ciências Agrárias, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Ciência do Solo, na linha de pesquisa qualidade, manejo e conservação do solo e da água.

Orientadora: Profa. Dra. Fabiane Machado Vezzani

Coorientadora: Profa. Dra. Karina Maria Vieira Cavalieri Polizeli

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em CIÊNCIAS DO SOLO d Universidade Federal do Paraná foram convocados para realizar a arguição da Dissertação de Mestrado de **GUSTAVO PEREIRA VALANI** intitulada: **Índices de qualidade do solo: Aplicação de metodologias**, após terem inquirido o aluno e realizado avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Curitiba, 29 de Janeiro de 2019.

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RESUMO

Apesar da avaliação da qualidade do solo ser baseada principalmente em métodos laboratoriais, a avaliação da qualidade do solo em campo permite que agricultores, técnicos e pesquisadores analisem solos de forma rápida e econômica. A hipótese desse estudo foi que dois métodos de avaliação da qualidade do solo em campo, o Diagnóstico Rápido da Estrutura do Solo (DRES) e o Guia Prático de Avaliação Participativa da Qualidade do Solo (PGPE) são eficientes em diferir a qualidade de solos em diferentes sistemas de manejo em relação a metodologia laboratorial amplamente utilizada SMAF (*Soil Management Assessment Framework*). Portanto, esse estudo objetivou testar o DRES, PGPE e o SMAF em solos com diferentes sistemas de manejo, assim como determinar a correlação entre os resultados de cada método de campo (DRES e PGPE) com os resultados do SMAF. Cambissolos sob plantio convencional, plantio direto, sistema orgânico, sistemas agroflorestais e em vegetações nativas foram amostrados na camada de 0-25 cm dentre dois municípios do sul do Brasil. A avaliação pelo SMAF foi realizada integrando seis indicadores da qualidade do solo (carbono orgânico total, carbono da biomassa microbiana, estabilidade de macroagregados, densidade do solo, pH e conteúdo de P) em um índice final de qualidade do solo. A análise pelo DRES associou informações obtidas em campo sobre agregados do solo, compactação, resistência à penetração, sistema radicular e atividade biológica em um índice final de qualidade do solo. A avaliação pelo PGPE integrou observações em campo sobre matéria orgânica, sistema radicular, estrutura do solo, compactação, infiltração, erosão, umidade do solo, macrofauna e cobertura do solo em um índice final de qualidade do solo. Os dados foram submetidos ao teste de normalidade e uma análise de variância foi realizada entre cada índice de qualidade do solo em cada local. O coeficiente de correlação de Pearson foi calculado entre cada índice de campo e o índice SMAF. As estratégias de avaliação qualidade do solo em campo DRES e PGPE foram eficientes em distinguir os locais de estudo, assim como também foi o método laboratorial SMAF. O PGPE diferenciou mais amplamente os sistemas de manejo que o DRES, independente do município ou tipo de solo. O PGPE apresentou maior força de correlação com o SMAF que o DRES, especialmente em solos argilosos e franco argilosos. Esses resultados evidenciam a aptidão dos métodos de avaliação da qualidade do solo em campo, que fornecem resultados seguros de forma mais rápida e mais econômica que métodos laboratoriais.

Palavras-chave: SMAF. DRES. Avaliação participativa. Funções do solo. Propriedades do solo.

ABSTRACT

Although soil quality assessments are mostly based on laboratorial approaches, on-farm evaluations help farmers, advisors and researches to analyse soils rapidly and inexpensively. This study's hypothesis was that two on-farm soil quality assessments, the Rapid Diagnosis of Soil Structure (DRES) and the Practical Guide for Participative Evaluation of Soil Quality (PGPE) are efficient to distinguish the quality of soils with different management systems in relation to the widely-used and laboratorial strategy SMAF (Soil Management Assessment Framework). Thus, this study aimed to test DRES, PGPE and SMAF in soils with different management systems, as well as to determine the correlation between the results from each on-farm assessment (DRES and PGPE) and SMAF results. Cambisols of conventional farming, no-till farming, organic farming, agroforestry systems and native vegetations were sampled in the 0-25 cm layer within two municipalities in southern Brazil. SMAF assessment was performed by integrating six soil quality indicators (total organic carbon, microbial biomass carbon, macroaggregate stability, bulk density, pH and soil P) into a final soil quality index. DRES assessment combined on-farm information about soil aggregates, compaction, rupture resistance, root system and biological activity into a final soil quality index. PGPE assessment integrated the on-farm observation of organic matter, root system, soil structure, soil compaction and infiltration, erosion, moisture retention, soil macrofauna and soil cover into a final soil quality index. The data were tested for normality and an Anova analysis was implemented between each soil quality index in each site. Pearson correlation coefficient was calculated between each on-farm index and SMAF. The on-farm strategies to assess soil quality DRES and PGPE were proven to be efficient to distinguish the sites of this study, as well as was the laboratorial method SMAF. The PGPE distinguished a wider range of soils than DRES, regardless the municipality or soil type. The PGPE were more correlated with the SMAF than the DRES, especially in clay and clay loam soils. These results evince the suitability of on-farm soil quality assessments, providing reliable results and being less costly and less time-consuming than laboratorial methods.

Keywords: SMAF. DRES. Participative evaluation. Soil functions. Soil properties.

SUMÁRIO

1 INTRODUCTION

Soil quality is “*the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*” (KARLEN et al., 1997, p. 6). Due to its complexity, soil quality cannot be directly measured neither on-farm nor at laboratories. Nevertheless, it can be construed from soil properties considered as soil quality indicators (CARDOSO et al., 2013; ZORNOZA et al., 2015). Monitoring such properties in different land management systems is crucial to identify strategies to achieve a more sustainable agriculture (CHERUBIN et al., 2015).

Several efforts to address the challenge of assessing soil quality resulted in different approaches to integrate soil quality indicators into a final soil quality index. Such methodologies are developed to guide farmers, advisors and researches to understand soil processes and ecosystem services to manage soils in order to promote sustainability (PALM et al., 2007; BÜNEMANN et al., 2018).

The Soil Management Assessment Framework (SMAF), described by Andrews, Karlen and Cambardella (2004) has been widely used with outstanding sensitivity to distinguish soils with different management systems. It is a laboratorial methodology which integrates soil biological, physical and chemical indicators of soil quality into a soil quality index. The SMAF are turning to a standard method to assess soil quality as it has been successfully used to assess soil quality in different management systems worldwide (GELAW; SINGH; LAL, 2015; KALU et al., 2015; SWANEPOEL et al., 2015; CHERUBIN et al., 2016; APESTEGUÍA et al., 2017; ŞEKER et al., 2017). Despite its efficiency, it is costly and time-consuming, which may decrease it suitability under such circumstances.

Although SMAF and most approaches to assess soil quality are often based primarily on analytical methods (BÜNEMANN et al., 2018), on-farm assessments of soil quality are considered to be important in management programs as well as in yield gaps analysis (MCKENZIE; MONCADA; BALL, 2015). These strategies may help farmers, advisors and researches in a quicker and cheaper analysis of soil quality, with immediate results (EMMET-BOOTH et al., 2016). Among such strategies, the DRES - Rapid Diagnosis of Soil Structure (RALISCH et al., 2017) and the PGPE - Practical Guide for Participative Evaluation of Soil Quality (COMIN et al.,

2016) are examples of practical and rapid assessments of soil quality. These are on-farm approaches which result in a final soil quality index to assess soil quality.

DRES consists of a strategy to assess topsoil structure in relation to visual features (RALISCH et al., 2017). The method was published by the Brazilian Agricultural Research Corporation as a feasible and rapid alternative of soil structural assessment, with minimal intervention in the site and vast sensitivity to detect differences in soil management changes. According to the authors, the DRES is based in other strategies, as the Visual Evaluation of Soil Structure – VESS (GUIMARÃES; BALL; TORMENA, 2011) and the Cultural Profile methodology (TAVARES FILHO et al., 1999). Furthermore, the DRES is easy to perform and totally suitable for tropical and subtropical conditions. As the soil structure assessed in DRES is an important component of soil quality (MUELLER et al., 2013; ASKARI et al., 2015), closely related with soil biological, physical and chemical properties (SILVA et al., 2014; ASKARI et al., 2015; RABOT et al., 2018), it is therefore notable that monitoring soil structure is important to infer about soil quality, especially with DRES, as there is still no published studies of its effectiveness to distinguish soil management systems.

The PGPE - Practical Guide for Participative Evaluation of Soil Quality (COMIN et al., 2016) is another on-farm strategy to assess soil quality. Apart from soil structure, the PGPE also assess organic matter, root system, soil compaction and infiltration, erosion, moisture retention, soil macrofauna and soil cover. Although this strategy requires some training, it is more accessible than laboratorial methods, therefore it can be performed by a wider range of the public, including farmers themselves. The PGPE was proposed as a methodology to assess soil quality under no-tillage vegetables (COMIN et al., 2016), however, it has a potential to be tested in other agricultural or native ecosystems. Furthermore, it includes a wider range of soil quality indicators than DRES, which may permit a greater efficiency to assess soil quality in different management systems, requiring, however, comparative studies.

It is interesting to note that the different approaches to assess soil quality may take into consideration similar indicators with different interpretations. Soil aggregates scored with SMAF, for example, interpret the macroaggregates (>250 µm) stability and consider a maximum score whenever the macroaggregate stability is more than about 0.50 (ANDREWS; KARLEN; CAMBARDELLA, 2004). DRES evaluation, in contrast, assess aggregates up to 10 cm and consider aggregates between one to four centimetres as the ideal range of aggregate sizes (RALISCH et al., 2017). Differently from SMAF and DRES, the PGPE assess soil structure as the abundance of visual aggregates and its ease to disruption (COMIN et al., 2016). Despite the individuality of each assessment, most strategies to assess soil quality integrate soil quality indicators in order to distinguish different management systems (BÜNEMANN et al., 2018). Moreover, it is important to test different soil quality strategies to investigate whether their different approaches to the same indicators results in similar outcomes.

This study hypothesised that the on-farm methods DRES (Rapid Diagnosis of Soil Structure) and PGPE (Practical Guide for Participative Evaluation of Soil Quality) are efficient to distinguish soil quality of soils with different management systems in relation to the widely-used strategy SMAF (Soil Management Assessment Framework) for the reason that both DRES and PGPE assess soil quality through soil quality indicators, as SMAF also does. Hence, the on-farm methods may lead to the same results trends as SMAF, though being less costly and less time-consuming. Thus, this study aimed to test DRES, PGPE and SMAF in soils with different management systems, as well as to determine the correlation between the results from each on-farm assessment (DRES and PGPE) and SMAF results.

2 MATERIALS AND METHODS

2.1 STUDY SITES AND SOIL SAMPLING

The study was carried out in the Atlantic Forest biome located on the coast of the Brazilian state of Paraná. Soil samples were taken in sites of two municipalities, Lapa (subtropical Cfb climate) and Morretes (subtropical Cfa climate). Detailed information about each site, its municipality, date of sampling, its coordinates, soil texture and the Brazilian soil classification (SANTOS et al., 2018) is shown in TABLE 1. Details about the crops in each agricultural site and its farming management are listed in TABLE 2. All sites were located in farms owned by smallholder farmers. Soil order according to the World Reference Base (WRB/FAO) was Cambisol for all sites (IUSS WORKING GROUP WRB, 2015).

TABLE 1 – LOCATION OF THE STUDY SITES AND SOIL FEATURES

Site	Municipality	Date of Soil Sampling (dd/mm/yyyy)	Coordinates	Soil Texture	Brazilian Soil Classification
CF	Morretes	07/12/2017	25°28'21"S 48°50'13"W	Clay	CAMBISSOLO HÁPLICO Tb Distrófico típico
NV_{CF}	Morretes	07/12/2017	25°28'20"S 48°50'12"W	Clay	CAMBISSOLO HÁPLICO Tb Distrófico típico
OF	Morretes	16/05/2018	25°29'47"S 48°48'40"W	Clay	CAMBISSOLO HÁPLICO Tb Distrófico típico
NV_{OF}	Morretes	16/05/2018	25°29'48"S 48°48'39"W	Silty Clay	CAMBISSOLO HÁPLICO Ta Eutrófico típico
HB7	Morretes	04/01/2018	25°30'58"S 48°52'07"W	Clay Loam	CAMBISSOLO HÁPLICO Tb Distrófico típico
TR7	Morretes	04/01/2018	25°30'58"S 48°52'07"W	Clay Loam	CAMBISSOLO HÁPLICO Tb Distrófico típico
NV_7	Morretes	04/01/2018	25°30'57"S 48°52'10"W	Clay Loam	CAMBISSOLO HÁPLICO Ta Alumínico típico
HB11	Morretes	04/01/2018	25°30'53"S 48°52'01"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Ta Distrófico típico
TR11	Morretes	04/01/2018	25°30'53"S 48°52'01"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Ta Distrófico típico
NV_{11}	Morretes	04/01/2018	25°30'52"S 48°52'00"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Ta Alumínico típico
NT	Lapa	24/03/2018	25°38'31"S 49°41'57"W	Sandy Clay	CAMBISSOLO HÁPLICO Tb Distrófico típico
OF	Lapa	24/03/2018	25°38'27"S 49°41'57"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Ta Distrófico típico
HB	Lapa	13/03/2018	25°38'26"S 49°41'49"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Tb Distrófico típico
TR	Lapa	13/03/2018	25°38'26"S 49°41'49"W	Sandy Clay Loam	CAMBISSOLO HÁPLICO Tb Distrófico típico
NV_L	Lapa	13/03/2018	25°38'26"S 49°41'44"W	Sandy Loam	CAMBISSOLO HÁPLICO Ta Distrófico típico

CF: conventional farming, NV_{CF}: native vegetation adjoining to CF, OF: organic farming, NV_{OF}: native vegetation adjoining to OF, HB7: horticultural beds in the 7-year-old agroforestry system, TR7: tree rows in the 7-year-old agroforestry system, NV_7: native vegetation adjoining to 7-year-old agroforestry system, HB11: horticultural beds in the 11-year-old agroforestry system, TR11: tree rows in the 11-year-old agroforestry system, NV_{11}: native vegetation adjoining to 11-year-old agroforestry system, NT: no-tillage, HB: horticultural beds in the agroforestry system, TR: tree rows in the agroforestry system. NV_L: native vegetation in the municipality of Lapa. SOURCE: The author (2019).

TABLE 2 – FARMING MANAGEMENT OF EACH AGRICULTURAL SITE

Site	Previous crop	Current Crop	Crops in the crop rotation	Farming Management
		Sites in Morretes		
CF	Sugarcane (until 2007)	Maize	Aubergine, beans, courgette, cucumber, ginger and okra	Intense soil tillage; continual inputs of synthetic chemical fertilisers, pesticides and herbicides are performed; poultry litter is applied sporadically
OF	Vegetables under conventional farming (until 200)	Fallow	Courgette, ginger and lettuce	Intense soil tillage; organic preparations are frequently used and poultry litter is applied sporadically; weeds are removed from crop fields manually
HB7	Sugarcane (until 1950) followed by pasture (until 2007)	Lettuce	Chicory, lettuce, rocket, spinach, spring onion and yams	Intense soil tillage, use of organic preparations, use of grass straw for weed control
TR7		Acerola, banana, cedar, custard apple, eucalyptus, lemon, orange and tangerine	Acerola, banana, cedar, custard apple, eucalyptus, lemon, orange and tangerine	No-tillage, use of organic preparations, fruit trees grown for profit-making and timber trees for biomass purposes
HB_{11}	Sugarcane (until 1950) followed by pasture (until 2007)	Yams	Ginger, lettuce and yams	Intense soil tillage, use of organic preparations, use of grass straw for weed control.
TR11		Banana, cedar, eucalyptus, lemon and orange	Banana, cedar, eucalyptus, lemon and orange	No-tillage, use of organic preparations, fruit trees grown for profit-making and timber trees for biomass purposes
		Sites in Lapa		
NT		Maize	Maize and beans	No-tillage, continual inputs of synthetic chemical fertilisers, pesticides.
OF	Pine and eucalyptus (until 2000)	Lettuce	Carrot, cabbage, courgette and lettuce	Intense soil tillage, organic preparations are frequently used and weeds are removed from crop fields manually
HB		Lettuce	Chicory, lettuce, rocket,	Intense soil tillage, use of organic preparations, use of grass straw for

		spinach, spring onion and yams	weed control.
TR	Cattley guava, cedar, eucalyptus, lemon, loquat and orange.	Cattley guava, cedar, eucalyptus, lemon, loquat and orange.	No-tillage, use of organic preparations, fruit trees grown for profit-making and timber trees for biomass purposes

CF: conventional farming, OF: organic farming, HB7: horticultural beds in the 7-year-old agroforestry system, TR7: tree rows in the 7-year-old agroforestry system, HB11: horticultural beds in the 11-year-old agroforestry system, TR11: tree rows in the 11-year-old agroforestry system, NT: no-tillage, HB: horticultural beds in the agroforestry system, TR: tree rows in the agroforestry system. NV_L: native vegetation in the municipality of Lapa. SOURCE: The author (2019).

The agroforestry systems were consisted of horticultural crops grown in beds in-between tree rows. Soil samples were taken both in the horticultural beds and in the tree rows, wherein each sampling position was considered as a different site in this study.

The agricultural sites sampled in Morretes were located far from each other, thereafter, every agricultural site was contrasted with an adjoining native vegetation. The study sites of Lapa, on the other hand, were located close to each other, wherefor one native vegetation was considered as a reference for all agricultural sites.

All sites of native vegetation in the municipality of Morretes were part of the Serra do Mar coastal forest, which is an ecoregion of the Atlantic Forest biome. The native vegetation of the municipality of Lapa was consisted of the mixed ombrophilous forest, also known as araucaria moist forest, which is a coniferous forest ecoregion of the Atlantic Forest Biome.

Soil samples were taken at the depth of 0-25 cm in four plots in each site. The reasons for sampling the top 25 cm are i) it is the recommended sampling depth for one of the methodologies studied (the Rapid Diagnosis of Soil Structure – DRES), ii) more than 70 % of the soil microbial biomass are in top 30 cm and this portion of microbial biomass is the most active along soil profile (FIERER; SCHIMEL; HOLDEN, 2003; XU; THORNTON; POST, 2013), iii) this depth is highly influenced by tillage operations, which may alter soil structure and total organic carbon content (ZHENG et al., 2018) and iv) it concentrates nutrients strongly cycled by plants, such as P and K (JACKSON; JOBBAGY, 2001).

All samples were taken after two or three days after a rainy day, in order to sample the soil as close to the field capacity as possible. Undisturbed aggregate samples, disturbed soil samples and soil cores were taken at each site. The disturbed samples were sieved through a 2 mm sieve and kept in a refrigerator at 4 ^{o}C prior to microbiological analysis, which commenced within a week after sampling.

2.2 SOIL ANALYSIS

Soil biological, physical and chemical properties were analysed to integrate the minimum data set for the Soil Management Assessment Framework (SMAF) analysis.

Total organic carbon was determined by dry combustion on a Vario EL III CHNOS elemental analyser. Microbial biomass carbon was determined by the fumigation-extraction method (VANCE; BROOKES; JENKINSON, 1987) and calculated as the difference between the carbon in fumigated and non-fumigated replicates, with a *k*-factor of 0.40, as indicated to be more appropriated for Brazilian soils (ROSCOE et al., 2006; KASCHUK; ALBERTON; HUNGRIA, 2010).

The soil bulk density was determined as the relation between the dry mass of soil and the bulk volume of the core used for sampling (BLAKE; HARTGE, 1986), which was approximately 60 cm^2. Wet macroaggregate stability was determined using an apparatus for vertical oscillation (YODER, 1936) with three sieve sizes (2000, 250 and 53 μm) operating at 42 oscillations per minute for 15 minutes. The macroaggregate stability was calculated as the ratio between the mass of aggregated larger than 250 μm and the total soil mass.

Chemical analysis included the soil pH, which was determined in a 1:2.5 soil:water solution and soil P, extracted using Mehlich-I and measured in an ultraviolet-visible spectrophotometer after adding ammonium molybdate and ascorbic acid.

2.3 SOIL MANAGEMENT ASSESSMENT FRAMEWORK (SMAF)

The Soil Management Assessment Framework (SMAF) was performed to assess soil quality in the agricultural sites as well as in the soils under native vegetation. Six soil quality indicators were used: total organic carbon, microbial biomass carbon, macroaggregate stability, soil bulk density, soil pH and soil P. These indicators were selected for the reason that they are part of the available soil quality indicators of the SMAF tool and they are related to a range of soil functions and ecosystem services well reviewed in the literature (ANDREWS; KARLEN; CAMBARDELLA, 2004; ZORNOZA et al., 2015). Furthermore, the use of these indicators address the SMAF protocol, which suggests using a minimum of five indicators, including biological, physical and chemical properties or processes (KARLEN et al., 2008).

Each soil quality indicator was interpreted by transforming its mean value into a unitless 0-1 value using non-linear scoring curves (0 being the lower quality and 1 the highest). The scoring curves (either more-is-better, less-is-better or mid-point optima) used were based on site-specific algorithms according to analytical methods, climate, crop, season at the moment of sampling, soil iron oxide class, soil mineralogy, soil organic matter, soil texture, soil weathering class and surface slope. Upper and lower limits or optima values in the curves represented the indicators threshold values outside of which soil functions are impaired (WIENHOLD et al., 2009). The scoring algorithms and the site-specific factor for each indicator used are report by Andrews, Karlen and Mitchell (2002).

As the soil quality indicators were interpreted according to several factors, the use of SMAF was performed considering the SMAF codes that matched each factor for this study's conditions. The P method code was 1 (P extracted by Mehlich-I); the climate factor was 1 (≥ 170º days and ≥ 550 mm of mean annual precipitation); season code was 2 (summer / mid-growing season); soil iron oxide class was 2 (related to Cambisols); soil mineralogy code was 3 (1:1 clay and Fe and Al oxides); soil organic matter ranged from class 3 to 4, according to the sampling sites; texture factors ranged from 1 to 2 and from 4 to 5, according to each site; soil weathering code was 3 (slightly weathered) and the surface slope factor was 2 for all sites (2-5 % slope). Detailed information about each code can be found in the appendices.

Crop factors were the ones related to the current crop at the moment at sampling and they affected pH and soil P scores. In this study, the factor for native vegetation (Atlantic Forest) was the same as described by Cherubin et al. (2016). New crop factors were added to the SMAF spreadsheet in order to include the crops of this study. These new crop factors were set using regional recommendations (PAULETTI; MOTTA, 2017). Optimum pH and soil P values were considered as the ones that support up to 90 % of crop yield. Maximum values were considered as the ones that support up to 100 % of crop yield, and if increased, it may limit crop production (PAULETTI; MOTTA, 2017). Optimum and maximum pH values for all new crops were set as 5.7 and 6.2. Optimum and maximum soil P (mg dm^{-3}) were 13.0 and 18.0 for the no-till site and 51.0 and 100.0 for the sites where horticultural crops were grown.

As the agroforestry systems were composed of a range of different crop species combined, it was challenging to set a new crop factor for them. Considering that the agroforestry systems were sampled both in the horticultural beds and in the tree rows, the crop factors were established according to each sampling position. The crop factor for the horticultural beds in the agroforestry systems was set as the same for the other sites where horticultural crops where grown. The crop factors for tree rows were set as described for forestry systems by Pauletti and Motta (2017), where optimum and maximum pH values were 5.7 and 6.2 and optimum and maximum soil P were 6.0 and 7.0 mg dm^{-3}.

Each indicator score was thereafter integrated into an overall soil quality index through an arithmetic mean. Whenever the overall soil quality index was not efficient to clearly distinguish the management systems in each site, the index was parted into its biological, physical and chemical components and a cluster analysis from the soil quality indicators was performed using Euclidian distances and the unweighted pair group method with arithmetic mean (UPGMA).

2.4 ON-FARM EVALUATIONS OF SOIL QUALITY

Soil quality was evaluated on-farm by two methods: the Rapid Diagnosis of Soil Structure, known as DRES (RALISCH et al., 2017) and by the Practical Guide for Participative Evaluation of Soil Quality - PGPE (COMIN et al., 2016). All on-farm evaluations were performed with a group from three to four people.

2.4.1 Rapid Diagnosis of Soil Structure (DRES)

Undisturbed soil samples of 10 x 20 x 25 cm (length x width x height) were placed in plastic trays and disintegrated into smaller aggregates. Structural quality was graded according to the scoring table ranging from 1 (lowest quality) to 6 (highest quality) provided by Ralisch et al. (2017). The criteria for structural assessment in DRES was as follow: size and shape of soil aggregates, presence or absence of compaction or other soil degradation related process, rupture resistance, distribution and appearance of the root system, as well as evidence of biological activity. Whenever the soil had different layers in the 25 cm depth, a score was given for each of them. The final soil structural index was calculated as a weighted average between the score and the depth of each layer.

As soil structure is an integration of biological, physical and chemical properties, the structural index DRES was deemed as a soil quality index for assessing changes in the different sites of this study.

2.4.2 Practical Guide for Participative Evaluation (PGPE)

On-farm assessment of soil quality was also performed by the Practical Guide for Participative Evaluation (PGPE) of Soil Quality, proposed by Comin et al. (2016). The soil was dug up to 25 cm to maintain the same assessment depth of the others methodologies used in this study.

Scores from 1 to 10 were given to the following indicators of soil quality: i) organic matter, ii) root system, iii) soil structure, iv) soil compaction and infiltration, v) erosion, vi) moisture retention, vii) soil macrofauna and viii) soil cover. Higher scores indicated higher soil quality for each assessment. The final soil quality index for the Practical Guide for Participative Evaluation of Soil Quality was calculated as the mean average of all indicators.

2.5 DATA ANALYSIS

The normality of the data for each soil quality index in each site was tested with the Shapiro-Wilk test ($p>0.05$) and no data transformation was needed. An analysis of variance (Anova) was performed for each site and each soil quality index determined (SMAF, DRES and PGPE), contrasting the agricultural site(s) with the adjoining native vegetation. Whenever the Anova F statistics was significant ($p<0.05$), the means were compared through the Tukey test.

Pearson correlation coefficient was calculated between the results from each on-farm soil quality index and SMAF, parting the results according to soil texture, for the reason that the correlation between visual observations and standards measurements are type dependent, as well as should be its interpretations (MUELLER et al., 2009; VAN LEEUWEN et al., 2018).

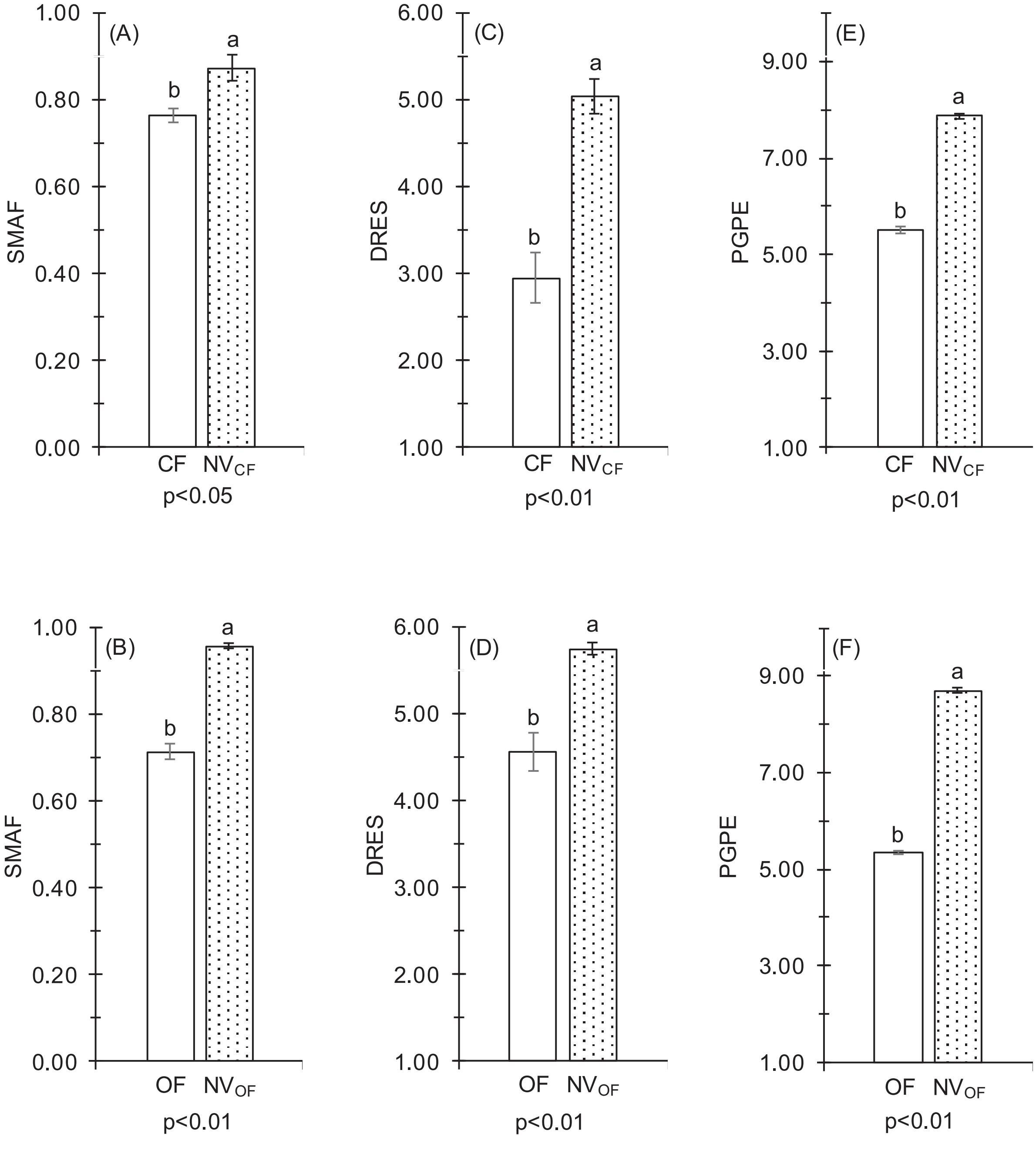
All statistical analysis were performed at the R studio environment version 3.5.0 (R CORE TEAM, 2018).

3 RESULTS AND DISCUSSION

3.1 SOIL QUALITY INDICES IN MORRETES

Soil quality according to SMAF, DRES and PGPE in conventional and organic farming in the municipality of Morretes were lower than each of their adjoining native vegetation, regardless the assessing strategy (FIGURE 1). Tillage operations in both agricultural sites may have lowered soil quality indices, as the structural cracks caused by tillage negatively influence soil biological, physical and chemical properties (BRONICK; LAL, 2005), as well as the visual observations. These results evince the suitability of the different methods to assess soil quality, as both laboratory and on-farm strategies were effective to distinguish different soil management systems in this environmental condition.

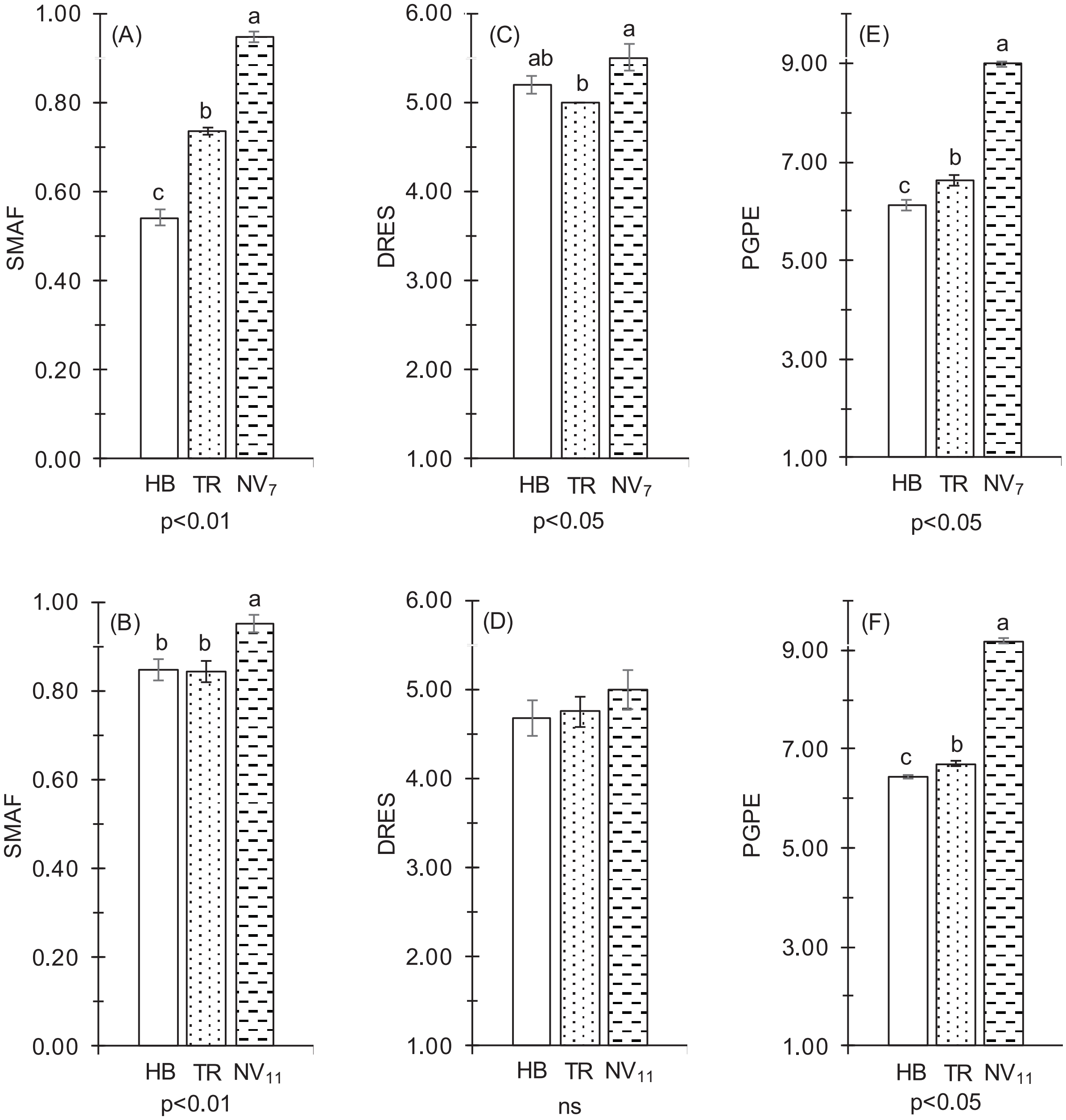
FIGURE 1: SOIL QUALITY INDICES DETERMINED BY THE SOIL MANAGEMENT ASSESSMENT FRAMEWORK - SMAF (A AND B), RAPID DIAGNOSIS OF SOIL STRUCTURE - DRES (C AND D) AND PRACTICAL GUIDE FOR PARTICIPATIVE EVALUATION OF SOIL QUALITY - PGPE (E AND F) IN CONVENTIONAL FARMING (CF), ORGANIC FARMING (OF) AND EACH OF THEIR ADJOINING NATIVE VEGETATION (NV) IN MORRETES - PR.



Sites with different lowercase letter significantly differ from each other according to Tukey test with its p-value shown below each graph. SOURCE: The author (2019).

SMAF and PGPE were efficient to assess soil quality in the agroforestry systems, with higher soil quality indices for each of their native vegetation (FIGURE 2). Although SMAF efficiency, it did not distinguish the sampling positions in the 11-year-old agroforestry system. DRES, in its turn, could not statistically differ soil quality changes in the 11-year-old agroforestry system. Moreover, DRES results for the 7-year-old agroforestry system show lower soil quality indices in the tree rows than in the horticultural beds or in the native vegetation, discordantly from SMAF and PGPE.

FIGURE 2: SOIL QUALITY INDICES DETERMINED BY THE SOIL MANAGEMENT ASSESSMENT FRAMEWORK - SMAF (A AND B), RAPID DIAGNOSIS OF SOIL STRUCTURE - DRES (C AND D) AND PRACTICAL GUIDE FOR PARTICIPATIVE EVALUATION OF SOIL QUALITY - PGPE (E AND F) IN AGROFORESTRY SYSTEMS OF 7 (A, C AND E) AND 11 (B, D AND F) YEARS OLD SAMPLED IN THE HORTICULTURAL BEDS (HB) AND IN TREE ROWS (TR) CONTRASTED WITH EACH ADJOINING NATIVE VEGETATION (NV) IN MORRETES – PR.



Sites with different lowercase letter significantly differ from each other according to Tukey test with its p-value shown below each graph. Ns: not significant in Anova. SOURCE: The author (2019).

PGPE indices in the agroforestry systems seemed to show a clearer and more understandable results than both SMAF and DRES (FIGURE 2). The greater fitness of PGPE to distinguish the sites with different management systems might be related with a wider range of soil quality indicators taken in consideration in PGPE analysis than in SMAF and DRES. Hence, the PGPE was deemed more efficient than SMAF and DRES to distinguish the sampling position in the agroforestry systems of the municipality of Morretes.

Considering SMAF, DRES and PGPE results for the agroforestry systems, soil quality seems to be different according to the sampling position, being higher in tree rows than in the horticultural beds. These results are probably related with no-tillage in the tree rows along with the variety of tree species that remain in the soil for a longer period of time. This management of constant crops in combination with no-tillage promotes greater aggregate stability, adds more carbon in the soil and enhance microbial activity, which reflect as greater capacity of the soil to execute its ecosystem functions (VEZZANI et al., 2018).

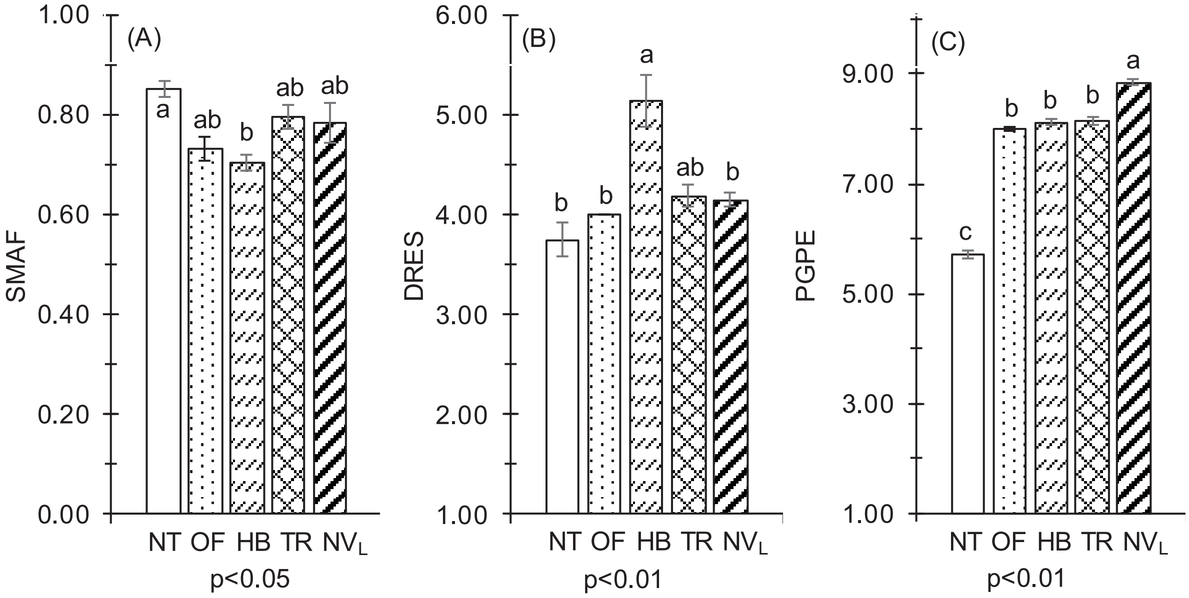
Discordance between on-farm and laboratorial results can be seen amongst DRES and SMAF indices for the 7-year-old agroforestry system (FIGURE 2). This difference might lead to the assumption that the methodology of each assessment results in unconnected information between indices, as discussed for other methodologies by Emmet-Both et al. (2016). Under such circumstances, both on-farm and laboratorial analysis should be taken into consideration in soil quality assessment frameworks (PULIDO MONCADA; GABRIELS; CORNELIS, 2014).

An overall analysis of the soil quality indices tested in the municipality of Morretes showed that both on-farm methods (DRES and PGPE) were efficient to distinguish management systems, with generally the same trends to SMAF. In such environmental condition, the PGPE were more sensitive than DRES to distinguish different management systems in relation to SMAF results and to this study hypothesis.

3.2 SOIL QUALITY INDICES IN LAPA

Distinctively from the results in the municipality of Morretes, most results from Lapa did not show the same trend for the different soil quality indices tested. According to SMAF, for example, soil quality in the horticultural beds of the agroforestry was lower than in the no-till farming (FIGURE 3). DRES results, contrarily, indicates a higher soil quality in the horticultural beds than in the no-till.

FIGURE 3: SOIL QUALITY INDICES DETERMINED BY THE SOIL MANAGEMENT ASSESSMENT FRAMEWORK - SMAF (A), RAPID DIAGNOSIS OF SOIL STRUCTURE - DRES (B) AND PRACTICAL GUIDE FOR PARTICIPATIVE EVALUATION OF SOIL QUALITY - PGPE (C) IN NO-TILL FARMING (NT), ORGANIC FARMING (OF), HORTICULTURAL BEDS OF THE AGROFORESTRY SYSTEM (HB), TREE ROWS OF THE AGROFORESTRY SYSTEM (TR) AND IN THE NATIVE VEGETATION (NV_L) IN LAPA -PR.



Sites with different lowercase letter significantly differ from each other according to Tukey test with its p-value shown below each graph. SOURCE: The author (2019).

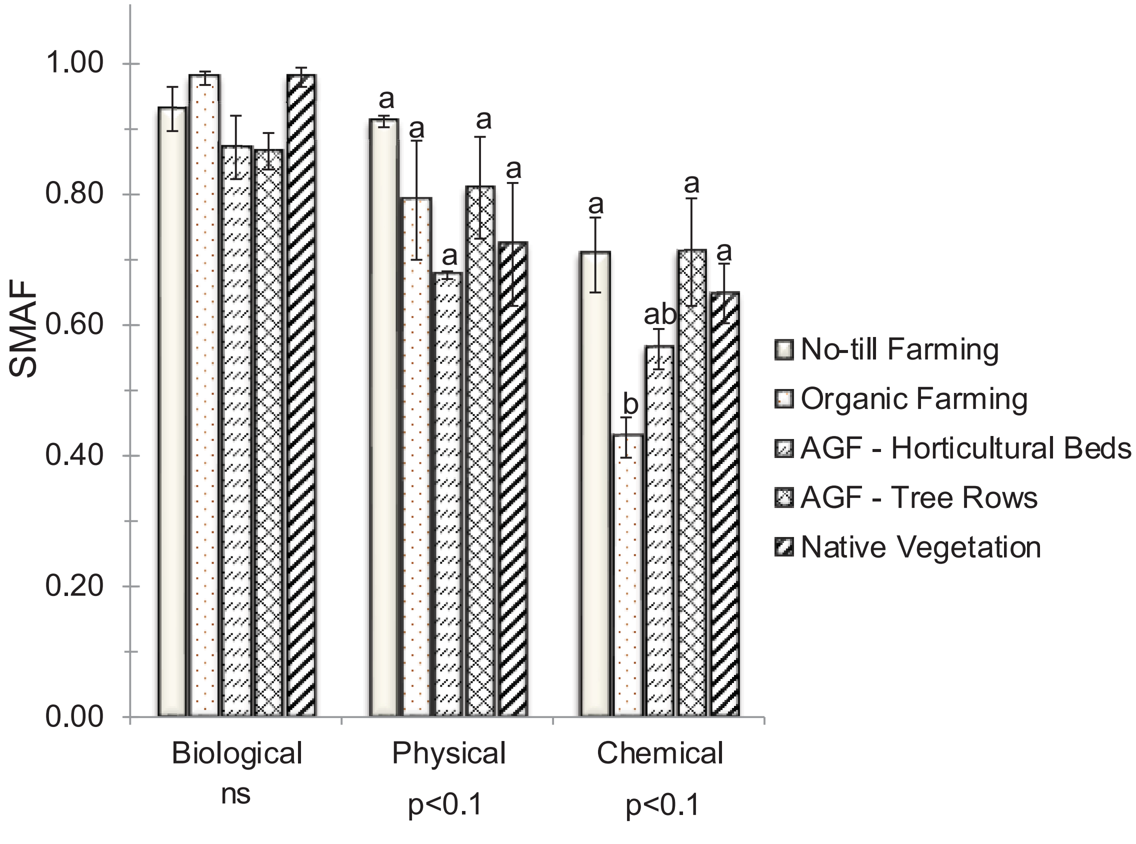
Diverging from both SMAF and DRES, soil quality according to PGPE results was higher in the native vegetation, lower in the no-till farming and intermediate in the organic farming and in the agroforestry system (FIGURE 3). Higher results in the agroforestry system and in the organic farming system confirm the importance of such agroecosystems in Brazil, as they promote soil quality, support agricultural production and contribute to agricultural sustainability (COSTA et al., 2017).

Soil quality indices from on-farm and laboratory assessments in the no-till farming displayed conflicting results (FIGURE 3). Considering DRES results, for example, soil quality in the no-till farming was lower than in the horticultural beds of the agroforestry system. SMAF results, in contrast, suggest higher soil quality in the no-till farming than in the horticultural beds.

The scores in the DRES methodology range from 1 to 6, with the following classes suggested by the DRES authors: scores from 1 to 3 as a group of soil with evidences of soil degradation and scores from 4 to 6 as a group of evidence of soil conservation (or recovery). As the average DRES result in the no-till was 3.75, it is possible that the visual difference in soil structure assessed in DRES was not yet in an extend that could jeopardize soil quality, as soil functionality may be maintained even when a slight degree of compaction is found under no-tillage, as stated by Cavalieri et al. (2009).

In order to further discuss the effectiveness of SMAF to distinguish the sites of Lapa, its final results were disintegrated into its biological, physical and chemical components (FIGURE 4). Although there were no differences within sites for the biological and physical components, the chemical component of the organic farming was lower than most sites (FIGURE 4).

FIGURE 4: SOIL MANAGEMENT ASSESSMENT FRAMEWORK (SMAF) RESULTS FROM ITS BIOLOGICAL, PHYSICAL AND CHEMICAL COMPONENTS IN LAPA - PR.



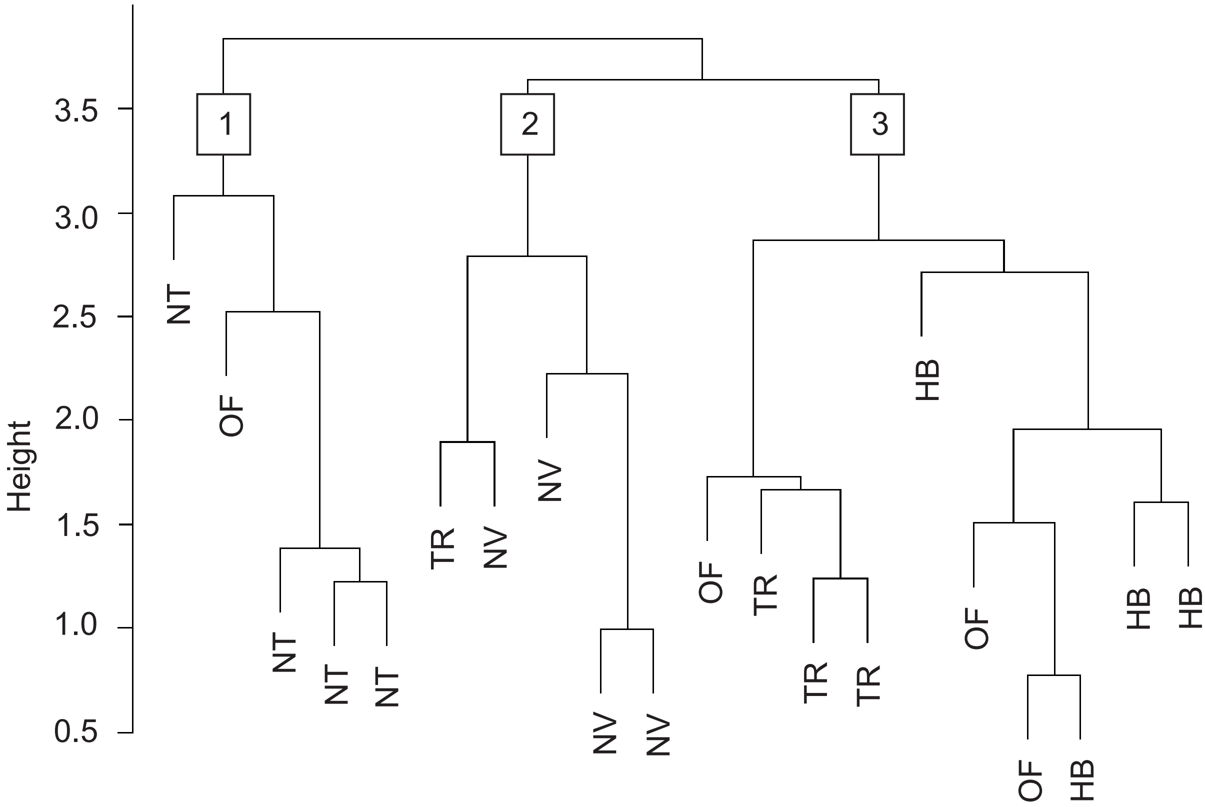
AGF: agroforestry system. Sites with different lowercase letter significantly differ from each other according to Tukey test with its p-value shown below each graph. Ns: not significant in Anova.
SOURCE: The author (2019).

The chemical component of SMAF is an integration of pH and soil P interpretations. Lower soil chemical quality indices in SMAF in the organic farming are related with higher pH in the system, with values beyond the mid-point optima in the scoring curve of this soil quality indicator. Furthermore, the P content may also have influenced the lower result in the organic farming due to its crop factor, as the P content required for horticultural crops were the highest for all sites studied. An example of the P interpretation can be seen between the organic and no-till farming, where despite higher quantities of P were found in the organic farming than in the no-till farming, the P index for the organic farming were lower than the no-till farming, due its crop factors. Detailed information about this can be found in the appendices.

Regarding the physical component of SMAF, the macroaggregates stability in the soils sampled in Lapa ranged from 0.79 to 0.98, which led to the maximum interpretation score (1.00) for all sites. The SMAF scoring curve for this soil quality indicator was thereafter deemed not sensitive in the environmental conditions of this study. The scoring curve was previously considered not sensitive in Brazilian soils by Cherubim et al. (2016) in tropical soils. Higher macroaggregate stability in Brazilian soils might be related with the dominance of Fe and Al oxides as well as 1:1 minerals (SIX; ELLIOTT; PAUSTIAN, 2000). It is important to note that the macroaggregate stability scoring curve in SMAF takes into consideration the soil organic matter, soil texture and the Fe oxide content (ANDREWS; KARLEN; CAMBARDELLA, 2004). However, it was not efficient to detect different management systems in the subtropical conditions of this study.

As the overall SMAF was not fairly efficient to distinguish different soil management systems in Lapa and neither were its biological, physical and chemical components, the soil quality indicators chosen might be questioned. The minimum data set of this study comprises six soil quality indicators: total organic carbon, microbial biomass carbon, macroaggregate stability, bulk density, soil pH and P content. These indicators are well reviewed in the literature (ANDREWS; KARLEN; CAMBARDELLA, 2004; ZORNOZA et al., 2015) and comprise six out of the 13 soil quality indicators with scoring curves or interpretations available in SMAF (ANDREWS; KARLEN; CAMBARDELLA, 2004; WIENHOLD et al., 2009; STOTT et al., 2010). Considering the fitness of such soil properties as soil quality indicators and the low performance of this indicators when interpreted with SMAF, a cluster analysis of the indicators was performed (FIGURE 5). It suggests a distinction of groups according to the sites sampled, confirming the strength of such soil quality indicators to distinguish management systems.

FIGURE 5: CLUSTER ANALYSIS OF ALL SITES IN THE MUNICIPALITY OF LAPA - PR USING EUCLIDIAN DISTANCES AND THE UNWEIGHTED PAIR METHOD WITH ARITHMETIC MEAN (UPGMA).



Cophenetic correlation coefficient = 0.69. Soil quality indicators used: total organic carbon, microbial biomass carbon, macroaggregate stability, soil bulk density, soil pH and soil P. NT: no-till farming. OF: organic farming. HB: horticultural beds of agroforestry system. TR: tree rows of agroforestry system. NV: native vegetation. SOURCE: The author (2019).

Considering a cut-off point of 3.2 in the dendrogram, the groups are formed as follow: group 1: all samples from no-till farming and one sample from the organic farming, group 2: all samples from the native vegetation and one sample from the tree rows in the agroforestry system; group 3: all samples from the horticultural beds in the agroforestry system, most samples from the organic farming and most samples from the tree rows in the agroforestry system.

It is interesting to note that the group 2 and 3 are closer related to each other than to group 1, which suggests that soil quality in the organic farming and in the agroforestry system is generally closer to the native vegetation than to the no-till farming. These results strength the capability of the soil quality indicators chosen to integrate the SMAF minimum data set, as they were sensitive to detect different management systems.

An overall analysis of the soil quality indices tested in the municipality of Lapa showed that none of the methods were efficient to distinguish management systems at all time. Most results from Lapa did not show the same trend for the different soil quality indices tested. Moreover, within the on-farm assessments, the PGPE distinguished a wider range of soils than DRES.

3.3 CORRELATION BETWEEN SOIL QUALITY INDICES IN RELATION TO SOIL TEXTURE

Considering that interpretations of soil quality indices are site depended and that soil texture in particular is crucial for a meaningful soil quality assessment (KARLEN et al., 2017), correlations between soil quality indices in relation to the most common soil textural classes of this study (clay, clay loam and sandy clay loam) in both municipality are presented in TABLE 3. DRES was not significantly ($p<0.05$) correlated with SMAF, regardless soil texture.

TABLE 3 – CORRELATIONS BETWEEN SOIL QUALITY INDICES IN RELATION TO SOIL TEXTURE.

	Pearson's Correlation	p-value
Clay (n=13)		
DRES x SMAF	0.5416	0.0559
PGPE x SMAF	0.8414	0.0003
Clay Loam (n=11)		
DRES x SMAF	0.2365	0.4838
PGPE x SMAF	0.9089	0.0001
Sandy Clay Loam (n=21)		
DRES x SMAF	0.1681	0.4664
PGPE x SMAF	0.1125	0.6275

SMAF: Soil Management Assessment Framework, DRES: Rapid Diagnosis of Soil Structure, PGPE: Practical Guide for Participative Evaluation of Soil Quality. SOURCE: The author (2019).

Higher correlations were found between SMAF and PGPE in clay loam ($r = 0.91$) and clay ($r = 0.84$) soils (TABLE 3). This results strength the capability of the on-farm method PGPE to perform similar results to SMAF, enabling a quicker and cheaper analysis. Their correlation is important in such conditions as described by Batey (2000), where specific tests to assess soil quality cannot be performed or the number of soil samples make it impracticable to tackle spatial and temporal variability appropriately.

It is interesting to note that the DRES methodology stress the importance of texture in relation to soil structure and states that it should be taken into consideration while assessing the soil (RALISCH et al., 2017). The SMAF methodology also emphasises the importance of the soil texture in the indicator's interpretation, as it is one of the factors related to the indicator's interpretation (ANDREWS; KARLEN; CAMBARDELLA, 2004). Despite such assumptions, the results of this study testify the influence of texture in the correlation between the results of the indices tested in this study, despite the efforts of the assessments strategies to dwindle such effects.

Considering the database for correlation, PGPE was more suitable to assess soil quality in order to predict SMAF results than DRES, especially in clay and clay lam soils. This result is possibly related with the wider range of soil quality indicators taken into consideration in the PGPE, which permitted a greater efficiency to assess soil quality in the different management systems.

4 CONCLUSIONS

The on-farm strategies to assess soil quality studied, the Rapid Diagnosis of Soil Structure (DRES) and the Practical Guide of Participative Evaluation (PGPE) were efficient to distinguish soil quality of soils with different management systems, as well as was the Soil Management Assessment Framework (SMAF). The PGPE distinguished a wider range of soils than DRES, regardless the municipality or soil type.

Considering both on-farm strategies to assess soil quality studied, the Practical Guide of Participative Evaluation (PGPE) was more correlated with the Soil Management Assessment Framework (SMAF) than the Rapid Diagnosis of Soil Structure (DRES), especially in clay and clay loam soils.

This study’s results evince the suitability of on-farm soil quality assessments, providing reliable results and being less costly and less time-consuming than laboratorial methods. They are valuable alternatives for teaching and serving purposes, especially for the reason that it can be performed by a wider range of the public, including farmers themselves. However, it is important to note that such on-farm strategies may require previous training in order to be performed accordingly.

REFERENCES

ANDREWS, S. S.; KARLEN, D. L.; CAMBARDELLA, C. A. The Soil Management Assessment Framework: A Quantitative Soil Quality Evaluation Method. **Soil Science Society of America Journal**, v. 68, n. 6, p. 1945–1962, 2004.

ANDREWS, S. S.; KARLEN, D. L.; MITCHELL, J. P. A comparison of soil quality indexing methods for vegetable production systems in Northern California. **Agriculture, Ecosystems and Environment**, v. 90, n. 1, p. 25–45, 2002.

APESTEGUÍA, M. et al. Tillage effects on soil quality after three years of irrigation in Northern Spain. **Sustainability**, v. 9, n. 8, p. 1476, 2017.

ASKARI, M. S. et al. Evaluation of soil structural quality using VIS–NIR spectra. **Soil and Tillage Research**, v. 146, p. 108–117, 2015.

BATEY, T. Soil Profile Description and Evaluation. In: KEITH A SMITH; CHIRS E MULLINS (Ed.). **Soil and Environmental Analysis: Physical Methods**. 2. ed. New York: Marcel Dekker Inc., 2000.

BLAKE, G. R.; HARTGE, K. H. Bulk Density. In: DINAUER, R. C.; BUXTON, D. R.; MORTVEDT, J. J. (Ed.). **Methods of Soil Analysis, Part 1 - Physical and Mineralogical Methods**. 2. ed. Madison: Soil Science Society of America Inc., 1986. p. 363–375.

BRONICK, C. J.; LAL, R. Soil structure and management: A review. **Geoderma**, v. 124, n. 1–2, p. 3–22, 2005.

BÜNEMANN, E. K. et al. Soil quality – A critical review. **Soil Biology and Biochemistry**, v. 120, p. 105–125, 2018.

CARDOSO, E. J. B. N. et al. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? **Scientia Agricola**, v. 70, n. 4, p. 274–289, 2013.

CAVALIERI, K. M. V. et al. Long-term effects of no-tillage on dynamic soil physical properties in a Rhodic Ferrasol in Paraná, Brazil. **Soil and Tillage Research**, v. 103, n. 1, p. 158–164, 2009.

CHERUBIN, M. R. et al. Physical, chemical, and biological quality in an oxisol under different tillage and fertilizer sources. **Revista Brasileira de Ciencia do Solo**, v. 39, n. 2, p. 615–625, 2015.

CHERUBIN, M. R. et al. A Soil Management Assessment Framework (SMAF) Evaluation of Brazilian Sugarcane Expansion on Soil Quality. **Soil Science Society of America Journal**, v. 80, n. 1, p. 215–226, 2016.

COMIN, J. J. et al. **Guia prático de avaliação participativa da qualidade do solo em Sistema de Plantio Direto de Hortaliças (SPDH).** Florianópolis: Universidade Federal de Santa Catarina, 2016. .

COSTA, M. B. B. et al. Agroecology development in Brazil between 1970 and 2015. **Agroecology and Sustainable Food Systems**, v. 41, n. 3–4, p. 276–295, 2017.

EMMET-BOOTH, J. P. et al. A review of visual soil evaluation techniques for soil structure. **Soil Use and Management**, v. 32, n. 4, p. 623–634, 2016.

FIERER, N.; SCHIMEL, J. P.; HOLDEN, P. A. Variations in microbial community composition through two soil depth profiles. **Soil Biology and Biochemistry**, v. 35, n. 1, p. 167–176, 2003.

GELAW, A.; SINGH, B.; LAL, R. Soil Quality Indices for Evaluating Smallholder Agricultural Land Uses in Northern Ethiopia. **Sustainability**, v. 7, n. 3, p. 2322–2337, 2015.

GUIMARÃES, R. M. L.; BALL, B. C.; TORMENA, C. A. Improvements in the visual evaluation of soil structure. **Soil Use and Management**, v. 27, n. 3, p. 395–403, 2011.

IUSS WORKING GROUP WRB. **World Reference Base for Soil Resources: International soil classification system for naming soils and creating legends for soil maps**. Rome: FAO, 2015.

JACKSON, R. B.; JOBBAGY, E. G. The distribution of soil nutrients with depth : Global patterns and the imprint of plants. **Biogeochemistry**, v. 53, n. 1, p. 51–77, 2001.

KALU, S. et al. Soil Quality Assessment for Different Land Use in the Panchase Area of Western Nepal. **International Journal of Environmental Protection**, v. 5, n. 1, p. 38–43, 2015.

KARLEN, D. L. et al. Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). **Soil Science Society of America Journal**, v. 61, n. 1, p. 4–10, 1997.

KARLEN, D. L. et al. Soil Quality Assessment : Past, Present and Future. **Journal of Integrative Bioscience**, v. 6, n. 1, p. 3–14, 2008.

KARLEN, D. L. et al. On-farm soil health evaluations: Challenges and opportunities. **Journal of Soil and Water Conservation**, v. 72, n. 2, p. 26A–31A, 2017.

KASCHUK, G.; ALBERTON, O.; HUNGRIA, M. Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. **Soil Biology and Biochemistry**, v. 42, n. 1,

p. 1–13, 2010.

MCKENZIE, D. C.; MONCADA, M. A. P.; BALL, B. **Visual soil evaluation: realising potential crop production with minimum environmental impact**. Wallingford: CABI, 2015.

MUELLER, L. et al. Visual assessment of soil structure: Evaluation of methodologies on sites in Canada, China and Germany. Part I: Comparing visual methods and linking them with soil physical data and grain yield of cereals. **Soil and Tillage Research**, v. 103, n. 1, p. 178–187, 2009.

MUELLER, L. et al. Evaluation of soil structure in the framework of an overall soil quality rating. **Soil and Tillage Research**, v. 127, p. 74–84, 2013.

PALM, C. et al. Soils: A Contemporary Perspective. **Annual Review of Environment and Resources**, v. 32, n. 1, p. 99–129, 2007.

PAULETTI, V.; MOTTA, A. C. V. **Manual de adubação e calagem para o estado do Paraná**. 1. ed. Curitiba: SBCS/NEPAR, 2017.

PULIDO MONCADA, M.; GABRIELS, D.; CORNELIS, W. M. Data-driven analysis of soil quality indicators using limited data. **Geoderma**, v. 235–236, p. 271–278, 2014.

R CORE TEAM. **R: A language and environment for statistical computing.** Vienna: R Foundation for Statistical Computing, 2018.

RABOT, E. et al. Soil structure as an indicator of soil functions: A review. **Geoderma**, v. 1, n. 314, p. 122–137, 2018.

RALISCH, R. et al. **Diagnóstico Rápido da Estrutura do Solo - DRES.** Londrina: Embrapa Soja, 2017.

ROSCOE, R. et al. Biomassa Microbiana do Solo: Fração mais Ativa da Matéria Orgânica. In: ROSCOE, R.; MERCANTE, F. M.; SALTON, J. C. (Ed.). **Dinâmica da matéria orgânica do solo em sistemas conservacionistas: modelagem matemática e métodos auxiliares**. 1. ed. Courados: Embrapa Agropecuária Oeste, 2006. p. 304.

SANTOS, H. G. et al. **Brazilian Soil Classification System**. 5th ed. Brasília: Embrapa, 2018.

ŞEKER, C. et al. Assessment of soil quality index for wheat and sugar beet cropping systems on an entisol in Central Anatolia. **Environmental Monitoring and Assessment**, v. 189, n. 4, p. 135, 2017.

SILVA, A. P. da et al. Soil structure and its influence on microbial biomass in different soil and crop management systems. **Soil and Tillage Research**, v. 142, p. 42–53, 2014.

SIX, J.; ELLIOTT, E. T.; PAUSTIAN, K. Soil Structure and Soil Organic Matter. **Soil Science Society of America Journal**, v. 64, n. 3, p. 1042, 2000.

STOTT, D. E. et al. Evaluation of β-Glucosidase Activity as a Soil Quality Indicator for the Soil Management Assessment Framework. **Soil Science Society of America Journal**, v. 74, n. 1, p. 107, 2010.

SWANEPOEL, P. A. et al. Assessment of tillage effects on soil quality of pastures in South Africa with indexing methods. **Soil Research**, v. 53, n. 3, p. 274–285, 2015.

TAVARES FILHO, J. et al. Cultural profile methodology for soil physical evaluation under tropical conditions. **Revista Brasileira de Ciência do Solo**, v. 23, n. 2, p. 393–399, 1999.

VAN LEEUWEN, M. M. W. J. et al. Visual soil evaluation: reproducibility and correlation with standard measurements. **Soil and Tillage Research**, v. 178, p. 167–178, 2018.

VANCE, E. D.; BROOKES, P. C.; JENKINSON, D. S. An extraction method for measuring soil microbial biomass C. **Soil Biology and Biochemistry**, v. 19, n. 6, p. 703–707, 1987.

VEZZANI, F. M. et al. The importance of plants to development and maintenance of soil structure, microbial communities and ecosystem functions. **Soil and Tillage Research**, v. 175, p. 139–149, 2018.

WIENHOLD, B. J. et al. Protocol for indicator scoring in the soil management assessment framework (SMAF). **Renewable Agriculture and Food Systems**, v. 24, n. 4, p. 260–266, 2009.

XU, X.; THORNTON, P. E.; POST, W. M. A global analysis of soil microbial biomass carbon, nitrogen and phosphorus in terrestrial ecosystems. **Global Ecology and Biogeography**, v. 22, n. 6, p. 737–749, 2013.

YODER, R. E. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. **Journal of the American Society of Agronomy**, v. 28, n. 5, p. 337–351, 1936.

ZHENG, H. et al. Effect of long-term tillage on soil aggregates and aggregate-associated carbon in black soil of northeast China. **PLoS ONE**, v. 13, n. 6, p. e0199523, 2018.

ZORNOZA, R. et al. Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health. **Soil**,

v. 1, n. 1, p. 173–185, 2015.

APPENDICES

APPENDIX 1 – Sand, silt and clay content and soil texture of the study sites

Municipality	Site	Replicate	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Texture
Morretes	Conventional Farming	1	137.44	325.02	537.54	Clay
		2	137.52	324.99	537.49	Clay
		3	150.06	324.98	524.96	Clay
		4	112.54	337.48	549.97	Clay
	Native Vegetation	1	162.48	325.01	512.51	Clay
		2	237.50	287.50	475.00	Clay
		3	187.60	299.96	512.44	Clay
		4	187.44	325.02	487.54	Clay
	Organic Farming	1	87.66	399.93	512.41	Clay
		2	87.59	399.96	512.45	Clay
		3	100.09	387.46	512.45	Clay
		4	75.05	399.98	524.97	Silty Clay
	Native Vegetation	1	74.86	425.06	500.08	Silty Clay
		2	75.02	412.49	512.49	Silty Clay
		3	87.48	400.01	512.51	Silty Clay
		4	87.61	412.45	499.94	Silty Clay
	7-year-old Agroforestry System - Horticultural Beds	1	425.11	249.95	324.94	Clay Loam
		2	437.36	225.06	337.58	Clay Loam
		3	412.47	200.01	387.52	Clay Loam
		4	437.61	212.46	349.93	Clay Loam
	7-year-old Agroforestry System - Tree Rows	1	450.03	212.49	337.48	Clay Loam
		2	437.47	225.01	337.52	Clay Loam
		3	450.01	212.49	337.49	Clay Loam
		4	424.90	225.04	350.06	Clay Loam
	Native Vegetation	1	350.16	237.44	412.40	Clay
		2	450.03	249.99	299.99	Clay Loam
		3	424.99	237.51	337.51	Clay Loam
		4	387.50	250.00	362.50	Clay Loam
	11-year-old Agroforestry System - Horticultural Beds	1	475.07	187.48	337.46	Sandy Clay Loam
		2	512.61	174.96	312.43	Sandy Clay Loam
		3	512.55	162.48	324.97	Sandy Clay Loam
		4	524.96	137.51	337.53	Sandy Clay Loam
	11-year-old Agroforestry System - Tree Rows	1	512.63	174.95	312.41	Sandy Clay Loam
		2	562.61	162.46	274.93	Sandy Clay Loam
		3	525.00	150.00	325.00	Sandy Clay Loam
		4	462.50	162.50	375.00	Sandy Clay

	Native Vegetation	1	574.97	162.51	262.52	Sandy Clay Loam
		2	537.45	225.02	237.52	Sandy Clay Loam
		3	562.46	162.52	275.03	Sandy Clay Loam
		4	550.06	174.98	274.97	Sandy Clay Loam
Lapa	No-till Farming	1	449.97	137.51	412.52	Clay
		2	462.47	150.01	387.52	Sandy Clay
		3	524.92	112.52	362.56	Sandy Clay
		4	450.12	174.96	374.92	Sandy Clay
	Organic Farming	1	587.49	125.00	287.51	Sandy Clay Loam
		2	525.05	162.48	312.47	Sandy Clay Loam
		3	637.55	87.49	274.97	Sandy Clay Loam
		4	637.45	87.51	275.03	Sandy Clay Loam
	Agroforestry System - Horticultural Beds	1	649.99	50.00	300.01	Sandy Clay Loam
		2	624.95	100.01	275.03	Sandy Clay Loam
		3	562.53	62.50	374.97	Sandy Clay
		4	878.58	14.29	107.14	Loamy Sand
	Agroforestry System - Tree Rows	1	612.57	62.49	324.94	Sandy Clay Loam
		2	687.49	25.00	287.51	Sandy Clay Loam
		3	574.96	112.51	312.53	Sandy Clay Loam
		4	674.98	50.00	275.01	Sandy Clay Loam
	Native Vegetation	1	799.96	50.01	150.03	Sandy Loam
		2	774.98	62.50	162.51	Sandy Loam
		3	737.54	74.99	187.47	Sandy Loam
		4	725.03	87.49	187.48	Sandy Loam

APPENDIX 2 – Soil quality indicators of the study sites

Municipality	Site	Replicate	Total Organic Carbon (g kg^{-1})	Microbial Biomass Carbon (mg kg^{-1})	Macroaggregate Stability	Bulk Density (g cm^{-3})	pH	soil P (mg dm^{-3})
Morretes	Conventional Farming	1	0.14	226.84	0.78	1.18	5.87	27.20
		2	0.12	263.69	0.78	1.22	6.12	16.20
		3	0.14	269.91	0.84	1.27	6.14	24.40
		4	0.14	268.38	0.79	1.28	6.27	45.60
	Native Vegetation	1	0.16	133.70	0.86	1.06	4.54	2.70
		2	0.29	346.62	0.95	0.89	4.42	6.60
		3	0.22	201.38	0.93	1.00	4.43	1.50
		4	0.22	313.86	0.90	0.98	4.33	3.10
	Organic Farming	1	0.20	186.92	0.89	0.99	6.68	73.10
		2	0.20	128.26	0.81	0.92	6.52	57.30
		3	0.21	154.60	0.78	0.82	6.69	104.00
		4	0.20	42.89	0.80	0.82	6.84	55.30
	Native Vegetation	1	0.32	210.65	0.98	1.05	5.57	4.70
		2	0.25	263.12	0.96	0.96	5.32	6.10
		3	0.29	277.69	0.75	0.90	5.63	4.50
		4	0.19	167.80	0.94	1.01	5.77	4.70
	7-year-old Agroforestry System - Horticultural Beds	1	0.19	209.58	0.91	1.31	5.05	3.10
		2	0.15	229.11	0.82	1.51	5.14	3.00
		3	0.14	223.79	0.90	1.48	5.05	2.00
		4	0.16	201.07	0.89	1.39	5.38	3.00
	7-year-old	1	0.16	225.23	0.96	1.29	5.56	3.50

	Agroforestry System - Tree Rows	2	0.15	173.46	0.86	1.29	5.65	3.50
		3	0.13	204.17	0.97	1.27	5.81	3.80
		4	0.15	199.19	0.92	1.34	5.84	5.40
	Native Vegetation	1	0.21	201.72	0.97	1.05	4.73	5.20
		2	0.29	248.89	0.88	1.19	4.48	4.80
		3	0.21	320.39	0.90	1.12	4.70	4.50
		4	0.39	409.35	0.91	0.85	4.71	9.40
	11-year-old Agroforestry System - Horticultural Beds	1	0.20	135.12	0.80	1.24	4.96	36.70
		2	0.14	116.97	0.86	1.33	5.48	26.10
		3	0.19	159.06	0.80	1.24	5.43	29.10
		4	0.16	180.39	0.90	1.15	5.37	30.30
	11-year-old Agroforestry System - Tree Rows	1	0.34	172.93	0.89	1.21	5.33	14.90
		2	0.19	138.75	0.84	1.49	5.73	14.90
		3	0.15	162.30	0.81	1.45	6.08	8.00
		4	0.24	127.16	0.92	1.17	6.08	29.50
	Native Vegetation	1	0.19	237.06	0.93	1.30	4.82	3.60
		2	0.29	271.52	0.95	0.87	4.81	8.00
		3	0.21	296.15	0.95	1.26	4.57	6.10
		4	0.23	249.40	0.94	1.07	4.51	4.10
Lapa	No-till Farming	1	0.33	184.67	0.98	1.12	5.13	3.50
		2	0.36	153.40	0.88	1.26	5.25	5.70
		3	0.36	160.38	0.83	1.15	5.28	6.60
		4	0.40	170.08	0.88	1.14	5.33	4.30
	Organic Farming	1	0.29	78.93	0.79	1.37	6.66	18.80
		2	0.38	211.43	0.90	1.12	6.68	16.20
		3	0.30	106.22	0.84	1.30	6.71	15.90
		4	0.31	188.94	0.83	1.32	6.65	11.70

Agroforestry System - Horticultural Beds	1	0.21	118.86	0.81	1.48	6.58	18.00
	2	0.26	109.32	0.85	1.36	6.64	20.30
	3	0.28	143.10	0.85	1.32	6.60	44.90
	4	0.20	99.63	0.84	1.47	6.48	33.80
Agroforestry System - Tree Rows	1	0.32	171.83	0.86	1.50	6.58	15.70
	2	0.24	187.43	0.86	1.39	6.71	8.00
	3	0.23	165.58	0.88	1.45	5.95	6.50
	4	0.18	100.22	0.81	1.41	5.90	3.50
Native Vegetation	1	0.13	122.08	0.81	1.38	4.29	2.80
	2	0.18	157.03	0.86	1.14	4.30	2.80
	3	0.14	164.74	0.85	1.25	4.17	2.20
	4	0.24	212.56	0.81	1.30	4.36	3.80

APPENDIX 3 – SMAF codes related to factors used for the interpretation of each soil quality indicator

Municipality	Site	Replicate	Climate	Season	F_2O_3	Mineralogy	Soil Organic Matter	Weathering	P method	Texture	Slope
Morretes	Conventional Farming	1	1	2	2	3	3	3	1	4	2
		2	1	2	2	3	3	3	1	4	2
		3	1	2	2	3	3	3	1	4	2
		4	1	2	2	3	3	3	1	4	2
	Native Vegetation	1	1	2	2	3	4	3	1	4	2
		2	1	2	2	3	4	3	1	4	2
		3	1	2	2	3	4	3	1	4	2
		4	1	2	2	3	4	3	1	4	2
	Organic Farming	1	1	2	2	3	3	3	1	4	2
		2	1	2	2	3	3	3	1	4	2
		3	1	2	2	3	3	3	1	4	2
		4	1	2	2	3	3	3	1	4	2
	Native Vegetation	1	1	2	2	3	3	3	1	4	2
		2	1	2	2	3	3	3	1	4	2
		3	1	2	2	3	3	3	1	4	2
		4	1	2	2	3	3	3	1	4	2
	7-year-old Agroforestry System - Horticultural Beds	1	1	2	2	3	4	3	1	4	2
		2	1	2	2	3	4	3	1	4	2
		3	1	2	2	3	4	3	1	4	2
		4	1	2	2	3	4	3	1	4	2
	7-year-old Agroforestry	1	1	2	2	3	3	3	1	2	2
		2	1	2	2	3	3	3	1	2	2

	System - Tree Rows	3	1	2	2	3	3	3	1	2	2
		4	1	2	2	3	3	3	1	2	2
	Native Vegetation	1	1	2	2	3	3	3	1	2	2
		2	1	2	2	3	3	3	1	2	2
		3	1	2	2	3	3	3	1	2	2
		4	1	2	2	3	3	3	1	4	2
	11-year-old Agroforestry System - Horticultural Beds	1	1	2	2	3	4	3	1	2	2
		2	1	2	2	3	4	3	1	2	2
		3	1	2	2	3	4	3	1	2	2
		4	1	2	2	3	4	3	1	2	2
	11-year-old Agroforestry System - Tree Rows	1	1	2	2	3	3	3	1	4	2
		2	1	2	2	3	3	3	1	4	2
		3	1	2	2	3	3	3	1	4	2
		4	1	2	2	3	3	3	1	4	2
	Native Vegetation	1	1	2	2	3	4	3	1	4	2
		2	1	2	2	3	4	3	1	4	2
		3	1	2	2	3	4	3	1	4	2
		4	1	2	2	3	4	3	1	4	2
Lapa	No-till Farming	1	1	2	2	3	4	3	1	5	2
		2	1	2	2	3	4	3	1	4	2
		3	1	2	2	3	4	3	1	4	2
		4	1	2	2	3	4	3	1	4	2
	Organic Farming	1	1	2	2	3	3	3	1	2	2
		2	1	2	2	3	3	3	1	2	2
		3	1	2	2	3	3	3	1	2	2
		4	1	2	2	3	3	3	1	2	2
	Agroforestry	1	1	2	2	3	3	3	1	2	2

System - Horticultural Beds	2	1	2	2	3	3	3	1	2	2
	3	1	2	2	3	3	3	1	2	2
	4	1	2	2	3	3	3	1	2	2
Agroforestry System - Tree Rows	1	1	2	2	3	3	3	1	2	2
	2	1	2	2	3	3	3	1	2	2
	3	1	2	2	3	3	3	1	4	2
	4	1	2	2	3	3	3	1	1	2
Native Vegetation	1	1	2	2	3	3	3	1	2	2
	2	1	2	2	3	3	3	1	2	2
	3	1	2	2	3	3	3	1	2	2
	4	1	2	2	3	3	3	1	2	2

APPENDIX 4 – Soil Management Assessment Framework (SMAF) scores of each soil quality indicator followed by SMAF biological, physical, chemical components and the overall SMAF soil quality index (SQI)

Municipality	Site	Replicate	Total Organic Carbon	Microbial Biomass Carbon	Macro Aggregate Stability	Bulk Density	pH	soil P	Biological SQI	Physical SQI	Chemical SQI	Overall SQI
Morretes	Conventional Farming	1	0.42	0.77	1.00	0.86	0.94	0.94	0.59	0.93	0.94	0.82
		2	0.34	0.88	1.00	0.76	0.70	0.75	0.61	0.88	0.73	0.74
		3	0.46	0.89	1.00	0.63	0.68	0.91	0.68	0.81	0.80	0.76
		4	0.42	0.89	1.00	0.61	0.52	1.00	0.65	0.81	0.76	0.74
	Native Vegetation	1	0.97	0.65	1.00	0.99	0.89	0.42	0.81	1.00	0.66	0.82
		2	1.00	1.00	1.00	0.99	0.86	0.92	1.00	1.00	0.89	0.96
		3	1.00	0.94	1.00	0.99	0.87	0.11	0.97	1.00	0.49	0.82
		4	1.00	1.00	1.00	0.99	0.84	0.53	1.00	1.00	0.68	0.89
	Organic Farming	1	0.81	0.58	1.00	0.99	0.15	1.00	0.69	1.00	0.57	0.76
		2	0.80	0.28	1.00	0.99	0.26	1.00	0.54	1.00	0.63	0.72
		3	0.83	0.41	1.00	0.99	0.14	0.99	0.62	1.00	0.57	0.73
		4	0.79	0.06	1.00	0.99	0.07	1.00	0.43	1.00	0.54	0.65
	Native Vegetation	1	1.00	0.96	1.00	0.99	1.00	0.80	0.98	1.00	0.90	0.96
		2	1.00	0.99	1.00	0.99	1.00	0.90	1.00	1.00	0.95	0.98
		3	1.00	0.99	1.00	0.99	1.00	0.77	1.00	1.00	0.89	0.96
		4	0.99	0.85	1.00	0.99	0.99	0.80	0.92	1.00	0.89	0.94
	7-year-old Agroforestry System - Horticultural Beds	1	0.76	0.69	1.00	0.55	0.43	0.02	0.73	0.78	0.22	0.58
		2	0.53	0.78	1.00	0.30	0.53	0.02	0.65	0.65	0.28	0.53
		3	0.41	0.76	1.00	0.32	0.43	0.00	0.58	0.66	0.22	0.49
		4	0.57	0.65	1.00	0.42	0.81	0.02	0.61	0.71	0.42	0.58

	7-year-old Agroforestry System - Tree Rows	1	0.54	0.76	1.00	0.58	0.96	0.66	0.65	0.79	0.81	0.75
		2	0.50	0.51	1.00	0.59	1.00	0.66	0.51	0.79	0.83	0.71
		3	0.39	0.67	1.00	0.65	0.98	0.71	0.53	0.82	0.84	0.73
		4	0.50	0.64	1.00	0.50	0.96	0.88	0.57	0.75	0.92	0.75
	Native Vegetation	1	1.00	0.94	1.00	0.99	0.93	0.84	0.97	1.00	0.89	0.95
		2	1.00	0.99	1.00	0.84	0.88	0.81	0.99	0.92	0.84	0.92
		3	1.00	1.00	1.00	0.95	0.92	0.78	1.00	0.98	0.85	0.94
		4	1.00	1.00	1.00	0.99	0.92	0.97	1.00	1.00	0.95	0.98
	11-year-old Agroforestry System - Horticultural Beds	1	0.92	0.56	1.00	0.99	0.33	0.97	0.74	1.00	0.65	0.80
		2	0.60	0.43	1.00	0.95	0.91	0.93	0.51	0.98	0.92	0.80
		3	0.89	0.72	1.00	0.99	0.86	0.95	0.81	1.00	0.91	0.90
		4	0.77	0.83	1.00	0.99	0.80	0.95	0.80	1.00	0.88	0.89
	11-year-old Agroforestry System - Tree Rows	1	1.00	0.79	1.00	0.99	0.76	1.00	0.90	1.00	0.88	0.92
		2	0.88	0.58	1.00	0.61	1.00	1.00	0.73	0.80	1.00	0.85
		3	0.68	0.74	1.00	0.70	0.75	0.96	0.71	0.85	0.85	0.80
		4	0.91	0.28	1.00	0.87	0.75	1.00	0.59	0.93	0.87	0.80
	Native Vegetation	1	1.00	1.00	1.00	0.97	0.94	0.64	1.00	0.99	0.79	0.93
		2	1.00	1.00	1.00	0.99	0.94	0.95	1.00	1.00	0.95	0.98
		3	1.00	1.00	1.00	0.99	0.90	0.90	1.00	1.00	0.90	0.96
		4	1.00	1.00	1.00	0.99	0.88	0.72	1.00	1.00	0.80	0.93
Lapa	No-till Farming	1	1.00	0.84	1.00	0.95	0.52	0.56	0.92	0.98	0.54	0.81
		2	1.00	0.78	1.00	0.66	0.67	0.85	0.89	0.83	0.76	0.83
		3	1.00	0.82	1.00	0.91	0.70	0.90	0.91	0.95	0.80	0.89
		4	1.00	0.86	1.00	0.92	0.76	0.70	0.93	0.96	0.73	0.87
	Organic Farming	1	0.99	0.20	1.00	0.89	0.16	0.82	0.60	0.95	0.49	0.68
		2	1.00	0.92	1.00	0.99	0.15	0.74	0.96	1.00	0.45	0.80
		3	1.00	0.35	1.00	0.97	0.13	0.73	0.67	0.99	0.43	0.70

	4	1.00	0.86	1.00	0.96	0.16	0.52	0.93	0.98	0.34	0.75
Agroforestry System - Horticultural Beds	1	0.93	0.44	1.00	0.63	0.21	0.80	0.68	0.81	0.51	0.67
	2	0.99	0.37	1.00	0.91	0.17	0.85	0.68	0.95	0.51	0.72
	3	0.97	0.35	1.00	0.53	0.20	1.00	0.66	0.76	0.60	0.67
	4	0.99	0.38	1.00	0.90	0.30	0.97	0.68	0.95	0.63	0.76
Agroforestry System - Tree Rows	1	1.00	0.79	1.00	0.58	0.21	1.00	0.89	0.79	0.61	0.76
	2	0.97	0.85	1.00	0.84	0.13	0.96	0.91	0.92	0.54	0.79
	3	0.96	0.75	1.00	0.70	0.88	0.93	0.86	0.85	0.90	0.87
	4	0.84	0.31	1.00	0.79	0.92	0.66	0.57	0.89	0.79	0.75
Native Vegetation	1	0.54	0.46	1.00	0.87	0.83	0.45	0.50	0.94	0.64	0.69
	2	0.83	0.71	1.00	0.99	0.84	0.45	0.77	1.00	0.64	0.80
	3	0.60	0.75	1.00	0.99	0.80	0.28	0.67	1.00	0.54	0.74
	4	0.97	0.92	1.00	0.97	0.85	0.67	0.95	0.99	0.76	0.90

APPENDIX 5 – Rapid Diagnosis of Soil Structure (DRES) of the study sites

Municipality	Site	Replicate	DRES
Morretes	Conventional Farming	1	2.00
		2	3.20
		3	3.60
		4	3.00
	Native Vegetation	1	5.36
		2	5.52
		3	4.68
		4	4.60
	Organic Farming	1	5.00
		2	4.28
		3	4.00
		4	5.00
	Native Vegetation	1	6.00
		2	5.68
		3	5.60
		4	5.72
	7-year-old Agroforestry System - Horticultural Beds	1	5.04
		2	5.20
		3	5.52
		4	5.00
	7-year-old Agroforestry System - Tree Rows	1	5.00
		2	5.00
		3	5.00
		4	5.00
	Native Vegetation	1	5.80
		2	5.60
		3	5.00
		4	5.60
	11-year-old Agroforestry System - Horticultural Beds	1	4.72
		2	5.00
		3	5.00
		4	4.00
	11-year-old Agroforestry System - Tree Rows	1	4.20
		2	5.00
		3	4.80
		4	5.00
	Native Vegetation	1	5.00
		2	5.00

		3	5.00
		4	5.00
Lapa	No-till Farming	1	3.20
		2	4.00
		3	3.80
		4	4.00
	Organic Farming	1	4.00
		2	4.00
		3	4.00
		4	4.00
	Agroforestry System - Horticultural Beds	1	5.00
		2	6.00
		3	4.60
		4	5.00
	Agroforestry System - Tree Rows	1	4.56
		2	4.00
		3	4.00
		4	4.20
	Native Vegetation	1	4.00
		2	4.00
		3	4.32
		4	4.28

APPENDIX 6 – Practical Guide for Participative Evaluation of Soil Quality (PGPE) of the study sites

Municipality	Site	Replicate	Organic Matter	Root System	Soil Structure	Compaction	Erosion	Moisture	Macrofauna	Soil Cover	Overall
Morretes	Conventional Farming	1	3.5	3.0	8.0	4.0	10.0	8.0	1.5	5.5	5.4
		2	3.0	3.0	7.0	4.0	10.0	8.0	2.0	5.5	5.3
		3	4.0	4.0	8.0	5.0	10.0	8.0	1.0	5.5	5.7
		4	4.0	3.0	8.0	4.0	10.0	8.0	2.0	5.5	5.6
	Native Vegetation	1	4.5	6.0	9.0	8.0	10.0	9.0	6.0	9.5	7.8
		2	5.0	6.0	9.5	8.0	10.0	9.0	6.0	9.5	7.9
		3	4.0	7.0	8.5	9.0	10.0	9.0	7.0	10.0	8.1
		4	5.0	6.0	9.0	8.0	10.0	9.0	6.0	9.5	7.8
	Organic Farming	1	4.0	3.0	8.0	8.0	10.0	2.5	6.0	1.0	5.3
		2	4.0	3.0	8.0	8.0	10.0	2.0	6.0	1.0	5.3
		3	4.0	4.0	8.0	8.0	10.0	3.0	6.0	1.0	5.5
		4	4.0	3.0	7.0	8.0	10.0	3.0	6.0	1.5	5.3
	Native Vegetation	1	8.0	10.0	9.0	8.0	10.0	6.0	9.0	10.0	8.8
		2	8.0	10.0	9.0	8.0	10.0	6.0	9.0	9.5	8.7
		3	8.0	9.0	8.0	8.0	10.0	6.0	9.0	10.0	8.5
		4	8.0	10.0	9.0	8.0	10.0	7.0	9.0	10.0	8.9
	7-year-old Agroforestry System - Horticultural Beds	1	5.0	6.0	7.0	6.0	9.0	5.0	5.0	7.5	6.3
		2	5.0	6.0	6.0	6.0	9.0	5.0	5.0	7.5	6.2
		3	4.0	6.0	7.0	6.0	9.0	5.0	5.0	7.5	6.2
		4	5.0	5.0	7.0	5.0	9.0	4.0	4.0	7.5	5.8
	7-year-old Agroforestry System -	1	5.0	6.0	7.0	6.0	10.0	5.0	5.0	7.5	6.4
		2	5.0	7.0	8.0	6.0	10.0	5.0	5.0	8.0	6.8
		3	5.0	6.0	7.0	6.0	10.0	5.0	5.0	7.5	6.4

	Tree Rows	4	6.0	6.0	7.0	7.0	10.0	6.0	6.0	7.5	6.9
	Native Vegetation	1	10.0	10.0	8.0	9.0	8.0	8.0	9.0	9.0	8.9
		2	10.0	10.0	8.0	9.0	8.0	8.0	9.0	9.0	8.9
		3	10.0	10.0	8.0	9.0	9.0	9.0	9.0	9.5	9.2
		4	10.0	10.0	9.0	9.0	8.0	8.0	9.0	9.0	9.0
	11-year-old Agroforestry System - Horticultural Beds	1	5.0	6.0	7.0	6.0	9.0	7.0	5.0	7.5	6.6
		2	5.0	6.0	7.0	6.0	9.0	6.0	5.0	7.5	6.4
		3	5.0	5.0	6.0	6.0	9.0	7.0	5.0	7.5	6.3
		4	4.0	6.0	7.0	6.0	9.0	7.0	5.0	7.5	6.4
	11-year-old Agroforestry System - Tree Rows	1	5.0	7.0	7.0	6.0	9.0	7.0	5.0	8.0	6.8
		2	5.0	6.0	7.0	6.0	9.0	7.0	5.0	7.5	6.6
		3	6.0	6.0	8.0	6.0	9.0	7.0	5.0	7.5	6.8
		4	5.0	6.0	7.0	6.0	9.0	8.0	5.0	7.5	6.7
	Native Vegetation	1	10.0	9.0	8.0	9.0	10.0	9.0	9.0	9.5	9.2
		2	10.0	9.0	9.0	9.0	10.0	9.0	9.0	9.5	9.3
		3	10.0	8.0	8.0	9.0	10.0	9.0	9.0	9.5	9.1
		4	10.0	9.0	8.0	9.0	10.0	9.0	9.0	9.5	9.2
Lapa	No-till Farming	1	6.0	6.0	6.0	6.0	10.0	5.0	2.0	5.0	5.8
		2	6.0	5.0	5.0	6.0	10.0	5.0	2.0	5.0	5.5
		3	6.0	6.0	6.0	6.0	10.0	5.0	3.0	5.0	5.9
		4	6.0	6.0	6.0	6.0	10.0	5.0	2.0	5.0	5.8
	Organic Farming	1	7.0	7.0	6.0	9.0	10.0	8.0	8.0	9.0	8.0
		2	7.0	6.0	6.0	9.0	10.0	8.0	8.0	9.0	7.9
		3	8.0	7.0	6.0	9.0	10.0	8.0	8.0	9.0	8.1
		4	7.0	7.0	6.0	9.0	10.0	8.0	8.0	9.0	8.0
	Agroforestry System -	1	6.0	5.0	7.0	10.0	10.0	8.0	9.0	10.0	8.1
		2	6.0	6.0	7.0	10.0	10.0	8.0	9.0	10.0	8.3

Horticultural Beds	3	5.0	5.0	7.0	10.0	10.0	8.0	9.0	10.0	8.0
	4	6.0	5.0	7.0	10.0	10.0	8.0	9.0	10.0	8.1
Agroforestry System - Tree Rows	1	6.0	5.0	7.0	10.0	10.0	8.0	9.0	10.0	8.1
	2	7.0	6.0	7.0	10.0	10.0	8.0	9.0	10.0	8.4
	3	6.0	5.0	6.0	10.0	10.0	8.0	9.0	10.0	8.0
	4	6.0	5.0	7.0	10.0	10.0	8.0	9.0	10.0	8.1
Native Vegetation	1	8.0	10.0	5.0	10.0	10.0	9.0	8.0	10.0	8.8
	2	9.0	10.0	5.0	10.0	10.0	9.0	8.0	10.0	8.9
	3	8.0	10.0	6.0	10.0	10.0	9.0	9.0	10.0	9.0
	4	8.0	10.0	5.0	10.0	10.0	9.0	8.0	10.0	8.8

APPENDIX 7 – Descriptive Statistics of each soil quality index tested in this study

		SMAF					DRES					PGPE				
Municipality	Site	Mean	SD	CV (%)	W test	p (W)	Mean	SD	CV	W test	p (W)	Mean	SD	CV	W test	p (W)
Morretes	CF	0.77	0.04	5.03	0.79	0.09	2.95	0.68	23.07	0.92	0.56	5.50	0.16	2.93	0.95	0.71
Morretes	NV	0.87	0.07	7.84	0.88	0.33	5.04	0.47	9.28	0.85	0.22	7.88	0.14	1.71	0.93	0.61
Morretes	OF	0.71	0.04	6.06	0.92	0.53	4.57	0.51	11.15	0.84	0.18	5.34	0.11	2.03	0.83	0.17
Morretes	NV	0.96	0.02	1.81	0.94	0.68	5.75	0.17	3.03	0.87	0.31	8.70	0.16	1.80	0.98	0.91
Morretes	HB7	0.54	0.04	8.07	0.86	0.27	5.19	0.24	4.55	0.88	0.34	6.13	0.22	3.53	0.80	0.10
Morretes	TR7	0.73	0.02	2.55	0.86	0.27	5.00	0.00	0.00	-	-	6.64	0.25	3.72	0.86	0.25
Morretes	NV	0.95	0.03	2.77	0.98	0.91	5.50	0.35	6.30	0.84	0.19	8.98	0.15	1.64	0.84	0.21
Morretes	HB11	0.85	0.06	6.68	0.77	0.06	4.68	0.47	10.09	0.81	0.11	6.44	0.10	1.59	0.89	0.41
Morretes	HB11	0.84	0.06	6.79	0.85	0.23	4.75	0.38	7.97	0.79	0.09	6.70	0.11	1.59	0.96	0.81
Morretes	NV	0.95	0.03	2.75	0.86	0.26	5.00	0.00	0.00	-	-	9.19	0.10	1.11	0.94	0.68
Lapa	NT	0.85	0.04	4.29	0.95	0.71	3.75	0.38	10.10	0.79	0.09	5.72	0.16	2.75	0.84	0.19
Lapa	OF	0.73	0.06	7.58	0.95	0.72	4.00	0.00	0.00	-	-	8.00	0.10	1.28	0.94	0.68
Lapa	HB	0.70	0.04	5.79	0.86	0.27	5.15	0.60	11.60	0.87	0.28	8.13	0.10	1.26	0.89	0.41
Lapa	TR	0.79	0.05	6.75	0.86	0.27	4.19	0.26	6.30	0.84	0.18	8.16	0.16	1.93	0.90	0.43
Lapa	NV	0.78	0.09	11.46	0.97	0.86	4.15	0.17	4.19	0.78	0.07	8.84	0.12	1.35	0.86	0.27

SMAF: Soil Management Assessment Framework, DRES: Rapid Diagnosis of Soil Structure, PGPE: Practical Guide for Participative Evaluation of Soil Quality. SD: standard deviation, CV(%): coefficient of variation, W test: Shapiro-Wilk's test for normal distribution, p(W): p-value for the W test, CF: conventional farming, NV: native vegetation, OF: organic farming, HB7: horticultural beds of the 7-year-old agroforestry system, TR7: tree rows of the 7-year-old agroforestry system, HB11: horticultural beds of the 11-year-old agroforestry system, TR11: tree rows of the 11-year-old agroforestry system, NT: no-till farming, HB: horticultural beds of agroforestry system, TR: tree rows of agroforestry system, NV: native vegetation.