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The merits of the Visual Evaluation of Soil Structure method (VESS) for assessing soil physical quality in the remote, undeveloped regions of the Amazon basin

Rachel M.L. Guimarães[a,*], Afrânio F. Neves Junior[b], Wellington G. Silva[c], Craig D. Rogers[d], Bruce C. Ball[e], Célia R. Montes[f], Bruno F.F. Pereira[c]

[a] Federal University of Technology-Paraná, Department of Agronomy, Via do Conhecimento, km 1, 85503-390, Pato Branco, PR, Brazil
[b] Universidade Federal do Amazonas, Av. Gen. R. Otávio Jordão Ramos, 3000-Coroado I, Centro de Educação a Distância, 69077-000, Manaus, AM, Brazil
[c] Universidade Federal do Amazonas, Av. Gen. R. Otávio Jordão Ramos, 3000-Coroado I, FCA, DEAS, 69077-000, Manaus, AM, Brazil
[d] Independent Scholar, UK
[e] Scotland's Rural College, Crop and Soil Systems Research Group, West Mains Road, Edinburgh, EH9 3JG, UK
[f] Center for Nuclear Energy in Agriculture, University of São Paulo, Avenida Centenário, 303, 13416-903, Piracicaba, SP, Brazil

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ABSTRACT

The Visual Evaluation of Soil Structure (VESS) is a straightforward and practical method for characterising and scoring soil structural and physical quality, ideally suited to evaluate and monitor soil degradation in remote and undeveloped areas. The research presented here tested for the first time the feasibility of using VESS in the Amazon basin, under the specific land uses and soils (Oxisol and "Terra Preta de Índio") of the region, and its relation with quantitative soil properties commonly used as indicators of soil physical quality. The evaluated areas, which had never been subjected to mechanisation, chemical fertilisation nor tillage, were "Terra Preta de Índio"/Anthropogenic Dark Earth; Regenerating Forest; Slash and Burn; Pasture; and Pristine Forest. The results showed that the quantitative properties were less sensitive at revealing signs of degradation than VESS and that VESS brought to light evidence of historic land use change and limitations to crop productivity. VESS was significantly correlated with soil resistance to penetration. However, VESS had difficulty capturing surface sealing, but the hands on approach to VESS allowed the user to identify these problems, despite not being listed in the reference chart. Overall, VESS was a more integrated soil quality indicator, providing more information about different soil functions than the quantitative properties, it was also a more practical method to perform making it ideal for tracking soil degradation and structural quality in similarly challenging situations. However, more research is required to fully enable VESS to capture structural quality in 'sandified' soils, caused by the slash and burn method widely used in the Amazon region.

1. Introduction

The Amazon forest is one of the largest areas of contiguous forest in the world, with the Amazon basin covering approximately 40% of South America, spread across Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname and Venezuela, with 60% falling within the borders of Brazil. The Amazon forest is estimated to contain 150–200 Pg C in living biomass and soils (Feldpausch et al., 2012) and to account for approximately 25% of Earth's terrestrial species (Malhi et al., 2008).

Even though they exhibit a high level of productivity, tropical rainforest soils, such as those found in the Amazon basin, are nutrient poor (Herrera et al., 1978; Laurance et al., 1999), rely on the recycling of nutrients from soil organic matter to maintain fertility (Tiessen et al., 1994), have a high turnover rate of organic matter and can be subjected to high levels of weathering (Peña-Venega et al., 2016). This results in a fragile soil, vulnerable to anthropogenic disturbance (Reichert et al., 2014), that can result in a loss in soil function and, consequently, damage to the component ecosystems and the services they provide (Foley et al., 2007).

Despite its importance and fragile nature, the Amazon area is subjected to extensive deforestation and has lost almost 20% of its coverage since the 1970s (INPE, 2015). The rate of deforestation has

* Corresponding author.
E-mail address: rachelguimaraes@utfpr.edu.br (R.M.L. Guimarães).

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generally slowed within the Brazilian Amazon since 2004, a 77% fall in annual rates between 2004 and 2011 (Godar et al., 2014), due to a number of socioeconomic factors (Godar et al., 2014; Nepstad et al., 2014). Since then, deforestation rates have stabilised at between 5000 and 7000 $km^2 yr^{-1}$ in Brazil (Godar et al., 2014; INPE, 2015), while deforestation rates in many non-Brazilian regions of the Amazon have increased. Deforestation in the Amazon basin is mainly due to land use change, deforestation for farming, illegal logging and mining as well as natural sources such as fire, drought and flooding.

Soil degradation, the loss of soil potential productivity due to a loss in soil fertility, greatly affects the Amazon region and can be induced by the land use changes listed above, as well as inappropriate cropping systems and management techniques (Lal, 1997). Soil degradation can come in the form of biological (loss of soil micro and macrobiota), chemical (nutrient loss/imbalance, acidification, salinisation, decrease in cation exchange, volatilisation) and physical degradation (crusting, compaction, erosion, leaching and anaerobism) (Guimarães et al., 2015).

These degradation processes result in a soil of poorer quality that is less fertile and, thus, less resistant to further erosion due to exposure, resulting in a downward spiral of degradation. Therefore, it is important to monitor the quality of the soil so as to record degradation, identify inappropriate use and management and to allow practices to be implemented to ameliorate the problem.

Attributes of the physical quality of soil can be monitored using both quantitative and semi-quantitative techniques. Quantitative properties such as bulk density, soil resistance to penetration, macro- and micro-porosity and infiltration rate, are useful as they provide information of how the structure of soil is working to supply water, air and support to plants. However, collection of such data often requires large and/or heavy equipment to be transported to the field or soil samples to be brought back to a laboratory for analysis. The lack of transport infrastructure, specialist knowledge, equipment and facilities in many large, less developed regions, such as the Amazon basin, effectively prohibit this type of sampling. Semi-quantitative techniques, such as visual soil evaluation methods, are rapid and simple tests that offer a more integral and holistic numeric assessment of the soil structure and of soil physical quality, as it includes within the assessment a wide range of soil and biological aspects, such as aggregate strength, shape and size, porosity, colour, smell, roots and fauna (Ball et al., 2015, 2016; Batey et al., 2015). The simplest group of visual methods is the spade tests, which are designed for use by scientists, agronomists and land users like farmers (Batey et al., 2015). Spade tests combine a range of soil properties such as aggregate strength, shape and porosity alongside colour and smell to give the soil a score that indicates the structural quality of the soil.

The Visual Evaluation of Soil Structure (VESS) originally proposed by Ball et al. (2007) is a spade method that assesses soil structural quality by comparing features of aggregates and roots with a description chart to attribute a soil quality score (Sq). The most up-to-date and most widely available scoring chart, including the progressive fragmentation of aggregates to confirm the score, was published by Guimarães et al. (2011). The scores produced by this simple and rapid visual test can be subjected to statistical analysis (Batey et al., 2015) and have been correlated with many measured physical qualities including tensile strength, bulk density, resistance to penetration, least limiting water range, hydraulic properties and air permeability (Guimarães et al., 2011, 2013; Giarola et al., 2013; Moncada et al., 2014a, 2014b), demonstrating its reliability for assessing soil structural quality. VESS has proven to be very efficient at distinguishing soil structural qualities under different uses and managements (Batey et al., 2015). The method has had limited testing under tropical soils (Guimarães et al., 2011; Giarola et al., 2013; Moncada et al., 2014b); at the 2014 ISTRO working group F meeting in Brazil, one of the points of discussion was that visual methods developed under temperate conditions need further testing in tropical soils to enable them to be used more widely.

VESS has a very low startup cost, requiring only a spade, the VESS chart and no consumables, and while the test requires training it does not need specialised pedological knowledge. This makes it an ideal tool for characterising and monitoring soil degradation in remote areas with poor infrastructure and limited resources, such as the Amazon basin. However, VESS has not been tested under such conditions nor on the specialised management practices of the region, such as slash and burn agriculture. The Anthropogenic Dark Earth soil, known as *Terra Preta de Índio* (TPI) in Portuguese, that is formed from these indigenous Brazilian agricultural practices (Glaser and Birk, 2012) contains a high level of charcoal and ash as a result of the slash and burn and also available nutrients, due to the incorporation of plant residues and animal waste (Smith, 1980; Kern and Kämpf, 1989; Lima et al., 2002). The addition of the organic matter and charcoal to the soil also affects the physical structure of the soil, improving soil porosity and structural strength (Kern and Kämpf, 1989; Teixeira and Martins, 2003), making the soil an interesting test for the VESS methodology.

The objective of this work was to test, for the first time, the feasibility of using VESS in a difficult to access region of the Amazon basin susceptible to soil degradation; correlate VESS soil quality scores with quantitative soil quality properties; and assess the ability of VESS to evaluate the soil structural quality of an Oxisol, including an area of Terra Preta A horizon, under different land uses.

2. Material and methods

2.1. Experimental area

The study site was located near Santa Isabel do Rio Negro, Amazonas, Brazil, (0° 24′ 40.07″S; 65° 00′ 35.15″W, 49 m a.s.l) in an agricultural area previously occupied and worked by indigenous Brazilians (>1000 years). The region has an average minimum temperature of 22 °C and an average maximum temperature of 31 °C, with an annual rainfall of 3014 mm.

The soil in the area is classified as an Oxisol and has been cultivated and used for foraging and hunting through regional techniques since first settlement. The site was only accessible via a one hour boat ride and had never been subjected to mechanised agricultural practices, tillage, liming nor chemical fertilisation.

The study was performed in five adjacent land uses: (i) Terra Preta (TPI): containing fruit tree and vegetable production in an Anthropogenic Dark Earth (0.3 ha, 40 m a.s.l), with more than 1000 years of use; (ii) Pasture (PA): grassland (*Brachiaria humidicola*) area occupied by cattle and buffalo (~10 ha, 45 m a.s.l) for meat production (stock rate: 1 animal ha^{-1}) with 26 years under this use; (iii) Slash and Burn (SB): area cultivated with cassava and pineapple (~0.5 ha, 46 m a.s.l) under annual burning of weeds and crop residues; with 9 years under this use; iv) Regenerating Forest (RF): area previously cultivated under the slash and burn system, but now abandoned for more than 30 years (~1 ha, 55 m a.s.l); v) Pristine Forest (PF): used for hunting and to extract seeds, fruits and medicines (57 m a.s.l).

For each area a transect line was laid out and ten sampling points (n = 10) were marked out along it. The length of each transect and distance between sampling points was proportional to the size of each area, and were respectively: TPI – 40 m (4 m between sampling points); PA – 300 (30 m between sampling points); SB – 50 m (5 m between sampling points); RF – 100 m