Geoderma Regional 14 (2018) e00176

Contents lists available at ScienceDirect

Geoderma Regional

journal homepage: www.elsevier.com/locate/geodrs

Soil health assessment for coffee farms on andosols in Colombia

Fatma Rekik [a,*], Harold van Es [a], J. Nicolas Hernandez-Aguilera [b], Miguel I. Gómez [b]

[a] Soil and Crop Sciences Section, School of Integrative Plant Science, Cornell University, Bradfield Hall, 306 Tower Rd, Ithaca, NY 14850, United States
[b] Charles H. Dyson School of Applied Economics and Management, Cornell University, Warren Hall, 137 Reservoir Ave, Ithaca, NY 14850, United States

ARTICLE INFO

Article history:
Received 24 March 2018
Received in revised form 8 May 2018
Accepted 9 May 2018
Available online xxxx

Keywords:
Mollic Andosols
Lithosols
Soil health assessment
Soil health benchmarks
Scoring functions
Colombia
Coffee
Smallholder agriculture

ABSTRACT

Developing local soil health (SH) benchmarks for different ecosystems is important for supporting locally appropriate management decisions and correct interpretation of soil health results. This study was conducted to develop SH scoring functions as benchmarks specific to coffee production in Cauca, Colombia. A total of 223 soil samples were collected from coffee farms in six municipalities and were analyzed for 13 SH indicators including wet aggregate stability (WAS), available water capacity (AWC), respiration rate, pH, contents of active carbon (AC), organic matter (OM), protein, phosphorus (P), potassium (K), magnesium (Mg), manganese (Mn), iron (Fe) and zinc (Zn). A scoring function for each indicator was developed using the cumulative normal distribution (CND) function with parameters based on either the average local conditions for a given indicator (physical and biological indicators), or thresholds found in the literature for coffee systems (chemical indicators). Separate scoring functions by textural group (fine, medium) were necessary for AWC, OM, AC, and respiration. A best subsets regression (BSR) using the overall soil health index as the response variable was executed to determine the indicators with highest predictive power of overall soil health. AC was the best single predictor of soil health, and AC combined with protein, P and pH offer additional predictability, suggesting them for a simplified SH test.

1. Introduction

Soil health (SH) is critical to sustainable agricultural production, and its quantitative assessment provides a framework for management. Proper interpretation of SH measurements requires benchmarks to assess where a sample lies on the SH spectrum (Arshad and Martin, 2002). The Comprehensive Assessment of Soil Health (CASH) approach developed at Cornell University measures biological, chemical and physical soil properties that are key indicators of SH, and converts laboratory and field measurements into generally recognized and easily interpretable scores that aid in management decisions (Moebius-Clune et al., 2016). In this framework, scores are derived from functions that were developed following the approach of the Soil Management Assessment Framework by Andrews et al. (2004) which assesses a soil indicator measurement in relation to a set of empirical values and assigns a normalized score. Similarly, scoring in CASH consists of comparing individual measured data to a standardized dataset of soils from regions in the United States (Fine et al., 2017). The scoring of each individual SH indicator comes in one of three forms - "more is better", "optimum range", and "less is better" - and is adjusted for soil texture when it affects the SH indicator.

CASH scoring functions for the physical and biological indicators generally follow a cumulative normal distribution (CND) curve specific to each indicator. Others are based on thresholds determined in the literature, which are outcome-based in terms of crop response to different levels of an indicator, as in the case of P, K, pH, and minor elements (Moebius-Clune et al., 2016). All scoring functions are scaled between 0 and 100, and indicator scores are grouped into three ranges: "low" (0–30), "medium" (30–70) and "high" (70–100). From all indicator scores an overall SH index score is calculated as their unweighted arithmetic mean and is interpreted as "very low" (<40), "low" (40–55), "medium" (55–70), "high" (70–85), and "very high" (>85; Moebius-Clune et al., 2016).

Regional, climatic and soil differences generally have a significant impact on SH and require adjustment of scoring and interpretation frameworks (Congreves et al., 2015). In addition to regions in the USA, Moebius-Clune (2010) developed scoring functions for SH assessment in western Kenya from a chrono-sequence experiment on recently deforested agricultural land. It is important to further "test the Test" in other ecosystems which may ultimately serve as a step towards a widely-standardized SH assessment and interpretation protocol. The scoring functions used in CASH were developed for regions in the USA that are characterized by a temperate climate with diverse production systems including grain, livestock, vineyards and vegetable production, and their use in SH assessment in tropical climates, including Colombian coffee smallholder farms, is not appropriate (Congreves et al., 2015; Idowu et al., 2008; Moebius-Clune, 2010; Schindelbeck et al., 2008).

* Corresponding author at: 1006 Bradfield Hall, 306 Tower Rd, Ithaca, NY 14850, United States.
E-mail addresses: fr235@cornell.edu (F. Rekik), hmv1@cornell.edu (H. van Es), jnh79@cornell.edu (J.N. Hernandez-Aguilera), mig7@cornell.edu (M.I. Gómez).

https://doi.org/10.1016/j.geodrs.2018.e00176
2352-0094/

The objectives of this study were therefore to (i) develop a set of SH scoring functions specific to coffee production using the CASH approach and soil data retrieved from Cauca, Colombia, and (ii) explore opportunities for a lower-cost and simplified version of this SH assessment framework.

2. Materials and methods

2.1. Site description

The research site was located in a coffee-growing region in the Department of Cauca, Colombia (approx. 2.2°N and −76.4°W; Fig. 1). Farms were situated at elevations ranging between 1269 and 1959 m. Annual rainfall in the study site ranges from 261 to 313 mm y^{-1} and has a bimodal distribution centered around the months of April and November (computed from: Promedios Climatológicos 1981–2010.xlsx).[1] Based on personal communication with a local soil extension agent, the soils in the project area are Andosols derived from volcanic ash (Saul Antonio Agredo, personal communication, March 12, 2015). This was also evidenced by the soil's thixotropic properties. However, the Digital Soil Map of the World (1,5,000,000; FAO and UNESCO, 2007) portrays Lithosols as the dominant soil in one of the two map units. Andosols are a minor component of this map unit, occupying the fertile lower slopes.

Coffee in our sampling site is produced by small-scale subsistence farmers as either monoculture or polyculture, with an average farm size not >5 ha. Crops that accompany coffee trees in polyculture settings typically include a variety of shade tree species to provide canopy cover for the coffee and other ecosystem services (Hernandez-Aguilera et al., 2018). These trees were mainly guamo (or pacay, *Inga edilus*), avocado (*Persea americana*), nogal (or walnut tree, *Juglans* spp.) and orange (*Citrus reticulata*).

Coffee growers in our study were split into two groups. The first consisted of 78 member farmers of a cooperative that operated under an alternative business model denominated Relationship Coffee Model (RCM) that promotes transparency, traceability and active engagement of smallholders throughout the value chain (Raynolds, 2009), and where coffee quality is at the core of the commercial relationship for which farmers adopt more sustainable resource management practices such as shade-grown coffee systems and have better access to credit.

The second group consisted of 67 farmers who were not members of the previous cooperative and mostly sold their coffee to the regular commodity market. Overall, we considered a sample of smallholders participating in a diversified coffee market that includes traditional commodity and specialty coffees.

2.2. Soil sampling and soil health measurements

A total of 223 soil samples were collected in January 2014 from 145 coffee farms across six municipalities (Cajibio, Timbío, Rosas, Piendamò, Morales and Popayán) within Cauca, Colombia (Fig. 1). All samples were collected from the 0–15 cm depth range using a Dutch-style soil auger after surface residue removal. Two representative soil samples were collected from the 78 member farms: One from the farm's most fertile plot and the other from the least fertile as designated by the farmer, yielding a total of 136 soil samples. From the remaining 67 non-member farms, one representative sample was collected. All samples were sent to Cornell University (Ithaca, NY USA) where processing and analysis of physical, chemical and biological soil properties were performed following the CASH protocol (Moebius-Clune et al., 2016). Briefly, this includes:

[1] http://www.ideam.gov.co/web/tiempo-y-clima/clima. Accessed: 2/21/2016.

2.2.1. Physical indicators

Available Water Capacity (AWC) between field capacity and permanent wilting point was assessed gravimetrically by equilibrating soil to −10 kPa and − 1500 kPa, respectively on ceramic plates in high pressure chambers (Topp et al., 1997). The soil water content difference was considered the AWC (Moebius-Clune et al., 2016).

Wet Aggregate Stability (WAS) was assessed using a rainfall simulator adapted from Ogden et al. (1997) that allows aggregates of air-dried soil (0.25–2 mm size) placed on a 0.25 mm mesh sieve to slake under 2.5 J of rainfall energy for 300 s, based on a total of 2.5 cm of rainfall. Wet Aggregate Stability was determined by subtracting the weight of slaked soil plus the remaining stones on the sieve (>0.25 mm) from total soil weight measured before rainfall (Moebius-Clune et al., 2016).

Soil texture was determined using a rapid quantitative method developed by Kettler et al. (2001) where soil samples were fractionated after slaking with 3% sodium hexametaphosphate ($(NaPO_3)_n$). A series of sieving and sedimentation steps were used to separate the different particle size classes (sand, silt, clay).

2.2.2. Biological indicators

Organic Matter content (OM) was analyzed by mass loss on ignition in a muffle furnace at 500 °C for two hours, with values corrected by multiplying percent loss on ignition by 0.7 and subtracting 0.23 (Moebius-Clune et al., 2016). Active Carbon (AC) was measured by adding a dilute potassium permanganate solution ($KMnO_4$) to soil, which acts as an oxidant to AC, and measuring the solution's absorbance at 550 nm using a hand-held colorimeter (Hach, Loveland, CO; Weil et al., 2003).

Autoclaved Citrate Extractable Soil Protein Index (Protein) was measured by extracting proteins from the soil following a series of centrifugation and autoclaving steps using 0.02 M sodium citrate at pH 7 (Hurisso et al., 2018). Soil protein concentration was determined by measuring bicinchoninic acid assay against bovine serum albumin standard curve for soil protein concentration (Walker, 1994; Wright and Upadhyaya, 1996).

Soil Respiration was assessed by trapping and measuring CO_2 emitted by soil microorganisms over a 4-day room temperature incubation in a sealed chamber with a KOH trap (Haney and Haney, 2010). The dissolved CO_2 in the trap was measured using a calibrated electrical conductivity meter.

2.2.3. Chemical indicators

Soil pH was measured in a 1:1 water dispersed slurry determined using an electrode probe (SM802 Smart Combined Meter, Milwaukee Industries, Rocky Mount, NC). Soil nutrients, including P, K, Mg, Fe, Mn and Zn were extracted with a Modified Morgan solution (ammonium acetate - buffered at pH 4.8), and quantified by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP–OES, Varian 730-ES, Mulgrave, Victoria, Australia).

2.3. Soil health scoring

We developed a soil health scoring approach for the Colombian coffee production environment from our dataset (n = 223), adapted from the CASH protocol. Depending on the indicator, scoring functions followed one of three types: “more is better”, “less is better” and “optimum range”. These functions were used to translate each SH indicator measurement into a score. They were texture adjusted for indicators that exhibited significantly different mean measured values between fine and medium textural groups (AWC, OM, AC and Respiration; Table 2; Dexter, a R, 2004; Moebius et al., 2007). Coarse texture scoring was not possible due to an absence of this soil type in our sample data.

Scoring functions were based on the Normal distribution function whose integral yields the Cumulative Normal Distribution function -CND (m, s)- which gives the probability ($0 < x < 1$) that a member of the distribution is less or equal to the SH indicator measurement (x;