Applied Soil Ecology 113 (2017) 29–35

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Soil quality assessment of different *Camellia oleifera* stands in mid-subtropical China

Jie Liu[a], Lichao Wu[a,*], Dong Chen[a], Ming Li[b], Changjiang Wei[b]

[a] *Key Laboratory of Cultivation and Protection for Non-Wood Forest Trees of National Ministry of Education, College of Forestry, Central South University of Forestry and Technology, Shaoshan South Road, No. 498, Changsha, 410004, China*
[b] *Sanmenjiang State-Owned Forest Farm, Liuzhou, 545006, China*

ARTICLE INFO

Article history:
Received 3 October 2016
Accepted 17 January 2017
Available online 1 February 2017

Keywords:
Soil biological indicators
Soil quality evaluation
Soil quality index
Association degree
Yield
Camellia oleifera

ABSTRACT

Camellia oleifera is a woody oil plant, which suffers from low yields in mid-subtropical areas of China. While increasing yields plays an important role in the development and security of the national edible oil industry, scientific evaluation of soil quality, which is essential for improving yields, has not yet been conducted for *C. oleifera*. To study soil quality and determine the factors limiting yields, 60 soil samples were collected from plantation stands producing different oil yields in mid-subtropical China. Thirty-two physical, chemical, and biological properties of soil were examined based on a one-way analysis of variance, canonical correspondence analysis (CCA) and principal component analysis (PCA). In addition, soil quality was assessed by the soil quality index (SQI) and grey relational analysis (GRA). Significantly high values were found for most properties in the high oil yield soil (HYS) samples, including soil organic matter (SOM), total nitrogen (TN), available calcium (ACa), available boron (AB), microbial biomass carbon (MBC), microbial biomass phosphorus (MBP), bacteria, actinomycetes, total phosphatase (TOP), and urease. Conversely, available P (AP), available potassium (AK), and AB were depleted in the low oil yield soil (LYS) samples. Five soil indicators, namely SOM, AP, ACa, MBC, and catalase, were selected to establish a minimum data set. From this, soil quality was ranked as HYS > medium oil yield soil (MYS) > LYS, with SQI values of 0.65, 0.46, and 0.38, respectively. A similar trend was observed for the GRA results. A significant correlation (coefficient value of 0.699) was found between the SQI and oil yield. With higher SQI scores and a higher association degree, HYS had a greater nutrient supply and microbiological activity than MYS and LYS. SOM appeared to be the limiting factor for low oil yield, with deficiencies in AP found to be major constraints of yield in mid-subtropical China. Measures to improve the AB and AK content should also be considered in the study areas.

1. Introduction

Camellia oleifera is one of the world's four major woody oil plants and is widely cultivated in subtropical acid soils for oil production. The oil has an unsaturated fatty acid content as high as 90%, and large quantities of vitamin E, squalene, and flavonoid substances, which can be easily absorbed, and are reported to prevent hypertension, cardiovascular disease, and aging, as well as improve body immunity (Chen et al., 2001). The health benefits of *C. oleifera* have encouraged its production, with current areas of cultivation in China expected to increase from 3.67 to 4.67 million ha by 2020 (State Forestry Bureau, 2009).

Unfortunately, improper farming and management during cultivation results in low yields per unit area, which threatens national oil security. Currently, 60% of total edible oil is imported, and areas with low-yield *C. oleifera* forest cover 2.68 million ha, accounting for 73% the crop's total area of cultivation in China (Shi et al., 2011). Improper management mainly results from a lack of knowledge regarding the soil quality of *C. oleifera* plantations, which is essential for guiding fertilization and scientific nutrient management to achieve high yields. Based on soil quality assessments, soil can be managed in a reasonable manner, with appropriate soil conservation measures and crop yield improvements (Marzaioli et al., 2010). Therefore, it is important to evaluate soil quality of *C. oleifera* plantations to improve the yields, and ease the disparity between supply and demand.

There has been little research conducted regarding soil quality assessment and significance for *C. oleifera*, although the plant has

* Corresponding author at: College of Forestry, Central South University of Forestry and Technology, Changsha, China.
E-mail address: wulichao@sina.com (L. Wu).

http://dx.doi.org/10.1016/j.apsoil.2017.01.010
0929-1393/

been studied for many years. Soil quality assessment can be assessed by determining soil properties, establishing a minimum data set (MDS) and calculating the soil quality index (SQI). Previous studies have examined the soil properties in *C. oleifera* plantations (Ding et al., 2013; Fu et al., 2013) and established an MDS for evaluating soil quality (Xiang et al., 2013). However, they were primarily focused on the physical and chemical properties of soil, with biological properties, which are important factors in soil quality assessment (Islam et al., 2011), rarely described or selected to establish an MDS. Furthermore, only a few studies have attempted to establish an SQI. The accuracy of evaluation results can be impacted when soil parameters are not comprehensively monitored and the SQI is ignored. This can lead to inappropriate management decisions and poor practical applications when attempting to plant high-yield *C. oleifera*.

The aim of this study was to ascertain the soil characteristics of high-yield *C. oleifera* plantations and provide a reference for reforming and improving low-yield *C. oleifera* plantations by evaluating soil quality. The objectives of this study were to: (i) establish an MDS with proper indicators for assessing soil quality, (ii) assess the soil quality of different plantation stands using SQI and GRA, and (iii) determine the limiting factors leading to low oil yields and the soil constraints of *C. oleifera* plantations in the soils of mid-subtropical China.

2. Materials and methods

2.1. Study area

The sampling site was located in Shaoyang County, Shaoyang City, southwest Hunan Province in China (26°54′–28°37′N and 111°19′–111°8′E). This region is characterized by a subtropical monsoon climate, with annual average sunshine of 1610 h, annual average temperature of 18.3 °C, frost-free period of 286 d, and annual average rainfall of 1255 mm. The mean monthly maximum and minimum temperatures are 28.3 °C (August) and 4.9 °C (January). Forestland is located on hilly areas with a mean slope of $<15°$ and altitude of <300 m above sea level. The variety planted is *C. oleifera*, with fruit maturation from October 3 to 8 and tree ages of 15 to 25 a. The soil in the stand is ferralsol, which is derived from quaternary red clay or slate, with a thickness >80 cm.

2.2. Plot design and soil sampling

Sample plots (20 × 30 m) were established with similar natural conditions, and were classified into three groups: high oil yield (>300 kg ha^{-1}), medium oil yield (150–300 kg ha^{-1}) and low oil yield (<150 kg ha^{-1}) according to the mean annual oil yield in recent years. Eight core soil samples were collected from each plot using a soil corer (5 cm in diameter and 40 cm in length), and then mixed to form a composite soil sample, which was placed into a clean cloth bag. Overall, 60 composite soil samples were collected and then immediately transported to the laboratory. Some soil samples were air-dried at room temperature for one week for physical and chemical analysis, the remaining soil samples were stored at 4 °C for biological analysis.

2.3. Soil physical and chemical characteristics

Soil texture was determined by a Bouyoucos hydrometer, while bulk density (BD) and field capacity (FC) were determined by the core method (Gonzalez-Delgado et al., 2015).

The chemical components of soil quality were assessed. Specifically, pH was determined by potentiometry (Kader et al., 2015), total nitrogen (TN) was determined by the Kjeldahl method (Tsiknia et al., 2014), available phosphorus (AP) was determined by the Mehlich 3 method and Smartchem Discrete Auto Analyzer (Westco, Italy) (Daniels et al., 2001), and available potassium (AK) was determined by the Mehlich 3 method and flame photometry (Bond et al., 2006). Soil organic matter (SOM) was measured by dichromate wet combustion and visible spectrophotometry (Van Gaans et al., 1995), and cation exchange capacity (CEC) was measured by sodium saturation (Lu, 1999). Soil available calcium (ACa), available magnesium (AMg), available iron (AFe), available manganese (AMn), available copper (ACu), and available zinc (AZn) were measured by the Mehlich 3 method and atomic absorption spectrophotometry (Bond et al., 2006). Available boron (AB) and available sulfur (AS) were measured by hot water extraction and the calcium phosphate solution method, respectively.

2.4. Analyses of soil biological properties

Soil biological indicators, including the activities of urease, acid phosphatase (ACP), neutral phosphatase (NEP), alkaline phosphatase (ALP), total phosphatase (TOP), catalase, and sucrase, were measured according to Alef and Nannipieri (1995). Microbial biomass carbon (MBC), nitrogen (MBN), and phosphatase (MBP) were determined by chloroform fumigation. Soil microbial quantity was measured according to Lin (2010).

2.5. Canonical correspondence analysis (CCA)

CCA is a nonlinear multiple direct gradient analysis, which combines correspondence analysis with multiple regression rather than direct gradient analysis. Results intuitively reflect the relationship between sample plots and the environment due to the large amount of information and multiple environmental factors (Ter Braak, 1986). It is an important tool for analyzing the internal relationships of soil factors.

In the resulting CCA biplots, arrows represent the biological indicators, triangles represent the chemical indicators and crosses represent physical indicators. The length of the arrows indicates the degree of correlation between soil factors, the linear distance of an arrow to a triangle or cross indicates the influence of the biological indicators on chemical and physical indicators, and the angle between two arrows represents their correlation.

2.6. Soil quality assessment

2.6.1. Indicator selection

Principal component analysis (PCA) was used to reduce redundant information of the original data set and group-related soil properties into a small set of independent factors (Yao et al., 2013). Only principle components (PCs) with eigenvalues ≥ 1 were selected and those with absolute values within 10% of the highest weighting of the loading factor were retained. The higher the factor loading of a variable in each PC was, the greater its contribution to the PC would be. When more than one variable was retained in a PC, correlation analysis was applied. Both variables were considered in the MDS if they were uncorrelated ($r < 0.60$), otherwise the variable with the strongest correlation was selected for the MDS (Andrews and Carroll, 2001).

2.6.2. Indicators scores

Soil indicator scores were determined by linear scoring function, which normalized values to between 0 and 1.0. According to Idowu et al. (2008), there were three types of scoring functions: more is better, less is better, and optimum. The equations of the score curves were then used to calculate the scores of soil indicators (Chen et al., 2013). The critical values of the scoring curves were determined based on past research and the 25th and 75th percentiles suggested by Idowu et al. (2008).