Geoderma 232–234 (2014) 589–599

Contents lists available at ScienceDirect

Geoderma

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

Soil quality characteristics of kikuyu–ryegrass pastures in South Africa

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ARTICLE INFO

Article history:
Received 19 March 2014
Received in revised form 27 May 2014
Accepted 17 June 2014
Available online 27 June 2014

Keywords:
Biological indicators
Chemical indicators
Minimum data set
Physical indicators
Soil quality index

ABSTRACT

Development of a soil quality index for kikuyu (*Pennisetum clandestinum*)–ryegrasss (*Lolium* spp.) pasture systems in the southern Cape of South Africa is important since there are certain warning signs that their sustainability is being threatened. A total of 142 pastures throughout the region were sampled and several soil physical, chemical and biological indicators were quantified. A minimum data set of the most sensitive indicators was chosen using principal component analyses. Linear scoring functions for these indicators were used to develop a soil quality index. The most sensitive indicators were: extractable P > gravel content > water holding capacity (WHC) > exchangeable acidity (EA) > soil organic matter (SOM) = penetration resistance (PR) > exchangeable Mn. The soil quality index (SQI) was equated as: SQI = 0.13 (PR) + 0.16 (Gravel) + 0.15 (WHC) + 0.14 (EA) + 0.17 (P) + 0.12 (Mn) + 0.13 (SOM). This soil quality index is appropriate for pasture systems in the southern Cape of South Africa, and may be useful for similar pasture systems in other areas.

1. Introduction

Soil is a non-renewable natural resource that provides essential services for human activities and should be managed to sustain or enhance critical functions (Larson and Pierce, 1991). This puts sound soil management practices in a vital position to ensure environmental and economic sustainability of agricultural systems. A total of 27% of world's soil resources were in grasslands in 2007, and in 2011 an estimated 84 million ha in South Africa is permanent meadows and pastures (FAO, 2014). The importance of sound management practices pertaining to soil is therefore also true for the southern Cape of South Africa which depends upon pasture production to support one of the country's most important dairy farming areas. The pasture systems are predominantly based on kikuyu (*Pennisetum clandestinum*), which is annually over-sown with annual or perennial ryegrass (*Lolium multiflorum* and *Lolium perenne*, respectively) (Botha, 2003). The mixed pasture sward is usually achieved using no-tillage implements, but shallow- or deep-tillage (conventional) are also used occasionally. When ryegrasses are established in pure swards, herbicides and no-tillage seed drills are used (Swanepoel et al., 2014a).

There are certain warning signs that soil quality within these pasture systems is on the decline and thus threatening sustainability (Swanepoel and Botha, 2012). Soil quality for these pasture systems is defined as "the ability of a specific soil to function within its capacity and within the managed agroecosystem boundaries, to promote cost-effective pasture and milk production, whilst on-site and off-site water quality is maintained" (Swanepoel, 2014). Therefore, the soil quality assessment concept allows quantification of physical, chemical and biological attributes for a specific land-use at a specific temporal scale (Doran and Parkin, 1994). There are reports that chemical soil quality of podzolic soils managed as a no-till kikuyu-based pasture is seriously threatened by elevated levels of Zn and P, originating from excessive fertilisation in the pursuit of higher pasture production (Swanepoel, 2014). Soil pollution by chemicals is often the case in temperate regions, rather than nutrient depletion (Sanchez et al., 2003; Smaling, 1993). Physical soil quality indicators under permanent kikuyu-based pastures have also shown degradation when compared to soil in its native state (Swanepoel et al., 2013). Conversely, biological soil quality and microbial diversity of kikuyu-based pasture soils were generally improved when compared to their natural state (Swanepoel et al., 2014b).

Proper understanding of the services soils provide is required to quantify soil quality. Models or tools that draw connections between certain indicators and actual soil services or functions, are required to assess soil quality (Sojka et al., 2003). Soil quality assessment also supports the decision-making process for management operations by providing a simplified explanation of obscure and complex processes in soil (Andrews et al., 2002). Developing a soil quality assessment model first requires soils from different areas to be surveyed to obtain information on the distribution and levels of various soil quality

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http://dx.doi.org/10.1016/j.geoderma.2014.06.018
0016-7061/

indicators. Subsequently, the most effective minimum data set (MDS) can be constructed from multivariate regression techniques or principal component analyses (Andrews et al., 2002; Sharma et al., 2005; Wander and Bollero, 1999). The MDS should contain only those indicators that infer data on soil functions that has an important role to play in pursuing the management goals (Andrews et al., 2002, 2004; Arshad and Martin, 2002). The list of indicators could be integrated into an index, which should then provide information on soil condition that will affect the management goals. Numerous methods to assess soil quality have been developed (Andrews and Carroll, 2001; Andrews et al., 2004; Chen et al., 2013; Diack and Stott, 2001; Ditzler and Tugel, 2002; Jaenicke and Lengnick, 1999; Karlen et al., 1998; Liebig et al., 1996; Romig et al., 1996; Sarrantonio et al., 1996; Wienhold et al., 2005; Wilson et al., 2008), but is usually site or crop specific and will not necessarily be the most suitable method to quantify soil quality for high input pasture systems (McBratney et al., 2014). Such a model or tool to measure soil quality does not exist for the pasture systems in the southern Cape. The mechanisms in which pasture management affects soil physical, chemical and biological processes could therefore not be assessed. Farm managers could use a soil quality model to evaluate the effectiveness of their management in order to maintain the land management goals of pasture productivity, recycling of waste products and ensuring a sustainable environment (Swanepoel, 2014), and if necessary, they could adapt one or more of their management practices (Doran and Parkin, 1994; Sarrantonio et al., 1996).

Our objective was to develop an index to quantify soil quality of pasture systems in the southern Cape of South Africa. Farmers, extension officers, scientists and policy makers should be able to use this tool constructively in planning of sustainable management strategies.

2. Materials and methods

2.1. Study area

A regional survey was conducted in the southern Cape coastal region extending from Stormsvlei (34° 05′ 05″ S, 20° 05′ 08″ E) in the Western Cape Province to the Van Stadens River (33° 54′ 33″ S, 25° 11′ 50″ E) in the Eastern Cape Province of South Africa and covers a terrestrial area of approximately 6000 km^2 (Fig. 1).

This region is bordered by the Tsitsikamma, Outeniqua and Langeberg mountain ranges to the north, and the Indian Ocean to the south, with an altitude ranging from just above sea level to approximately 300 m above sea level. The long-term mean annual rainfall varies between approximately 700 and 1000 mm, depending on distance from the Indian Ocean and has an inter-annual rainfall pattern. Daily maximum temperatures vary between 18 °C and 25 °C and minimum temperatures between 7 °C and 15 °C in summer and winter, respectively, with no frost days (ARC-ISCW, 2014).

The principal soils of the region are mainly well-sorted sands or sandy-loams in the top 200–300 mm layer (ARC-ISCW, 2006). The dominant soil forms fall within the podzol and duplex soil groups (IUSS Working Group, 2006; Soil Classification Working Group, 1991) otherwise known as Spodosols and Alfisols, respectively (Soil Survey Staff, 2003).

The most important agricultural products of the area are Jersey or Friesland-Holstein dairy production from pastures, and vegetable cropping systems. Sheep production systems are limited to the western parts of the region. This study considered dairy-pasture farms and a total of 142 kikuyu and ryegrass pasture systems were identified throughout the region, which were assessed. Interviews with farmers or farm managers were conducted for each sampling site to collect information on the management procedures of the sites and included past management practices, cultivated pasture species, over-sowing practices, fertiliser types and levels, irrigation and pesticide management and frequency of tillage operations, if any.

2.2. Soil sampling and analyses

Soils from the pastures were collected in a completely randomised design. Representative soil samples of the first 0–100 mm soil layer, consisting of at least 20 subsamples, were taken from pure kikuyu pastures, pure ryegrass pastures, or kikuyu-based pastures over-sown with ryegrass. The data set consisted of 20 pure kikuyu pastures with no soil disturbance or over-sowing practices, 62 kikuyu-based pastures which were mulched once a year during autumn and over-sown with annual ryegrass using a minimum-till seed drill, 29 pure annual ryegrass pastures under minimum-tillage, where the summer crop or self-sown crop was eradicated with herbicides, 16 kikuyu–ryegrass pastures

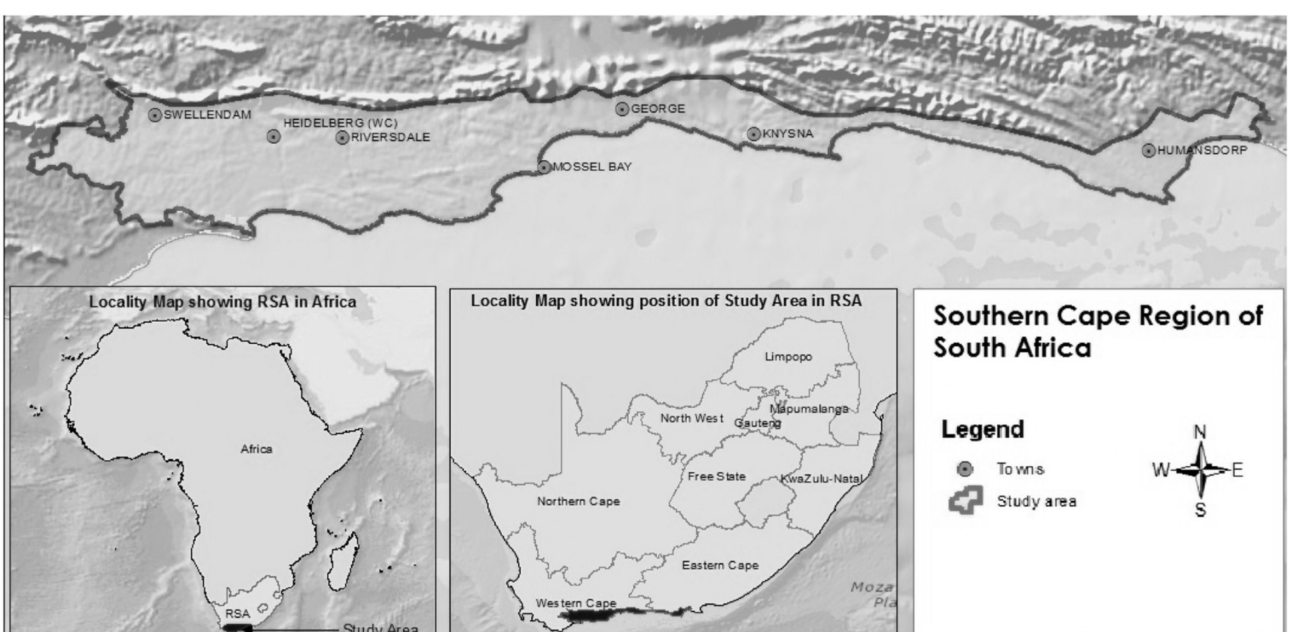

Fig. 1. The southern Cape region of South Africa extends from the Swellendam district in the west to the Humansdorp district in the east. The city of George is the major business centre of the region.