Establishing baseline values for soil quality indicators in the Southern Cape of South Africa

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Abstract. Commercial dairy farming on pasture is commonly practiced in the southern Cape region of South Africa. In terms of its sustainability, quantification of the impact of dairy-pasture management on soil quality is essential. To comprehend the behaviour of soils in terms of quality, indicators should be assessed to screen the general direction of soil quality within a management system. Development of a soil quality assessment framework necessitates establishment of baseline values for soil quality indicators. The aim of this study was to establish baseline values for soil quality indicators for dairy-pasture soils in the southern Cape. Physical, chemical and biological indicators on a no-till kikuyu (*Pennisetum clandestinum*)-ryegrass (*Lolium* spp.) pasture were compared to those of a virgin soil. Stratification ratios, which demonstrated the rate at which the indicator decreased with depth, were assessed for soil organic matter (SOM) related indicators. Biological indicators showed a well-established and well-functioning microbial population in the improved pasture soil. Stratification ratios demonstrated that the soil quality of the improved pasture system was improved relative to the virgin soil. Chemical indicators showed that the impact of nutrient management was favourable to pasture productivity. The association between the chemical and biological indicator were better established in the managed pasture. Physical indicators demonstrated that management practices adversely impacted the ability of the soil to provide physical support and structural functionality. This data were used in developing a first approximation of baseline values. Further research is warranted to validate them on representative commercial dairy farms in the southern Cape.

Keywords: Dairy farming, no-till management, organic matter, soil compaction.

Introduction

Dairy production from improved pasture is one of the main farming practices of the southern Cape region of South Africa. Large areas of natural rangeland were converted to improved pastures to comply with the demand for forage production for dairy farms. The conversions included chemical amendments to increase soil fertility, installation of irrigation systems and establishing various forage grass and legume species by different cultivation techniques. No-tillage systems with kikuyu (*Pennisetum clandestinum*) as a pasture base are the dominant pasture management practice. However, milk production from kikuyu pastures is restricted by the seasonality and low nutritional value of the herbage. This is overcome by incorporating different annual and perennial ryegrass species and varieties (*Lolium* spp.) into the pasture base to improve the seasonal aboveground phytomass production and nutritional value of the pasture (Botha 2003). This management system is well researched and proved to be the most dominant pasture system for the region (Botha 2003; Van der Colf 2010).

Even though it is believed that the benefit from this management technique is mainly as a result of increased soil organic matter (SOM) stocks, research on soil quality and the importance of SOM on sustainability of the systems, have only recently been initiated (Swanepoel *et al*. 2011). It is known that conversion from natural ecosystems to agro-ecosystems may have significant influences on ecological functioning and soil quality (Mills *et al*. 2012), and is often associated with a decline in soil quality (Tornquist *et al*. 2009). The effects of no-tillage systems may improve the otherwise nutrient poor, unproductive rangeland and research to investigate the effects of agro-ecosystems on soil quality is much needed. Soil quality is greatly valued by dairy-pasture farmers because it maintains or increases productivity, maximizes profit and supports food security while simultaneously ensuring sustained soil potential for future generations (Mausbach 1998). Sustainability of pasture demands adequate and correct management practices to be followed which should maintain or enhance soil quality. Quantification of the impact of improved pasture management on soil quality is therefore essential. To comprehend the behaviour of soils in terms of quality, indicators should be assessed to screen the general direction of soil quality within a management system. These indicators provide information on the normality of soil functioning (Nielsen and Winding 2002). Baseline values of indicators do not exist for the southern Cape soils and should be established for accurate interpretation of results. The aim of this study was to establish baseline values for soil quality indicators for improved pasture soils in the southern Cape.

Materials and Methods

Two study sites were selected on the Outeniqua Research Farm (33° 58' 38" S, 22° 25' 16" E) in the southern Cape region of South Africa to represent the comparison of soil quality indicators between different land uses. The first site comprised an established kikuyu based pasture on a no-till regime and permanent sprinkler irrigation which was grazed by dairy cows. The second site remained historically undisturbed in its virgin state. Both sites were located on podzolic soils (spodosols according to the USDA Soil Taxonomy) with similar clay contents. A rising plate meter was used to determine the amount of aboveground phytomass before each grazing. Twenty soil samples, taken aseptically at three depths (0-100mm, 100-200mm and 200-300mm), were composited for each plot. Physical analyses on samples included particle size distribution and wet aggregate stability (Klute 1986). Bulk density and penetration resistance were measured *in situ*. Biological indicators included active C by wet oxidation (Weil *et al*. 2003); soil organic C (C_{org}) by the Walkley-Black technique (Walkley 1935); microbial biomass C (MBC) by microwave irradiation (Islam and Weil; 1998) and microbial quotient by dividing MBC with C_{org} (Nielsen and Winding 2002). Stratification ratios were calculated by dividing soil property values of the 0 – 100 mm sampling by those at 200 – 300 mm (Franzluebbers 2002). Standard nutrient analyses were performed for chemical indicators. Total N was determined by the Kjeldahl method (Bremner 1960), extractable P with the citric acid method, exchangeable Ca, Mg, K and Na and extractable B, Cu, Mn, Zn and S with standard procedures and CEC with the ammonium acetate method (Non-Affiliated Soil Analysis Work Committee 1990). Data were expressed as mean values per depth and analyzed using a two sample Student's t-test for independent samples. The data was acceptably normally distributed, but with heterogeneous treatment variances and a significance level of $P\leq0.01$ was established *a priori*. Data were analyzed using the statistical program GenStat®.

Results and Discussion

Improved pasture was highly productive and suitable for dairy production. The average aboveground phytomass production of the improved pasture was 18.89 ± 0.54 t/ha/year, which was similar to previous studies (Botha 2003; Van der Colf 2011), and that of natural rangeland was 6.59 ± 0.56 t/ha/year.

Mean pH (KCl) was lower ($P\leq0.01$) in the virgin soil ranging from 4.1 to 5.3, and for kikuyu-ryegrass pastures within the optimal range of 5.0 to 5.5. Total N, extractable P, exchangeable Ca, Mg, K and Na, extractable Cu, Mn and Zn, and CEC of the improved pasture soil were significantly higher than that of the virgin soil with the exception of B and S which were similar in all layers, K in 100-300mm layers and total N and CEC in the 200-300mm layer. Fertility levels in the improved soil were satisfactory for all nutrients.

The improved pasture soil had similar bulk densities to virgin soil ($P>0.01$) in the 0-100mm and 100-200mm layers, but was higher ($P\leq0.01$) at 200-300mm depth of the improved pasture soil. Penetration resistance showed that improved pasture had higher ($P\leq0.01$) physical resistance at all layers. It is evident that the soil of improved pastures was more compacted at 200-300mm depth than virgin soil, despite a similar texture. Conversion of virgin soil to improved pastures adversely affected soil physical resistance, probably caused by tractor traffic and livestock. Water stable aggregate (WSA) percentage did not differ ($P>0.01$) between land uses and pasture improvement practices had therefore no effect on the soil microstructure. The perenniality and growth form of kikuyu should contribute to conservation of aggregate stability. The water holding capacity (WHC) of the surface layer of the improved pasture soil was higher ($P\leq0.01$) than that of the virgin soil, but did not differ ($P>0.01$) in the 100-200mm and 200-300 mm layers. Conversion from virgin soil to improved pasture resulted in a 5% increase in WHC in the 0-100 mm layer and because of similar textures between land uses, it can be deduced that the high SOM content should be the main factor governing the higher WHC.

Distribution patterns of C_{org}, active C and MBC are shown in Figure 1. C_{org} stock in the 0-100mm layer for

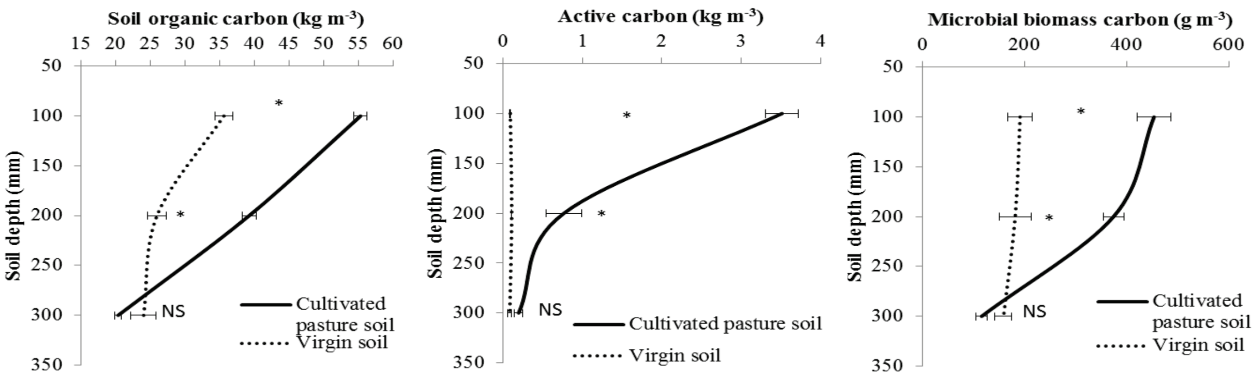

Figure 1. Soil organic C, active C and microbial biomass C stocks of improved pasture soil and virgin soil. Error bars indicate standard error. * indicates P≤0.01 and NS indicates no significant difference (*P*>0.01).

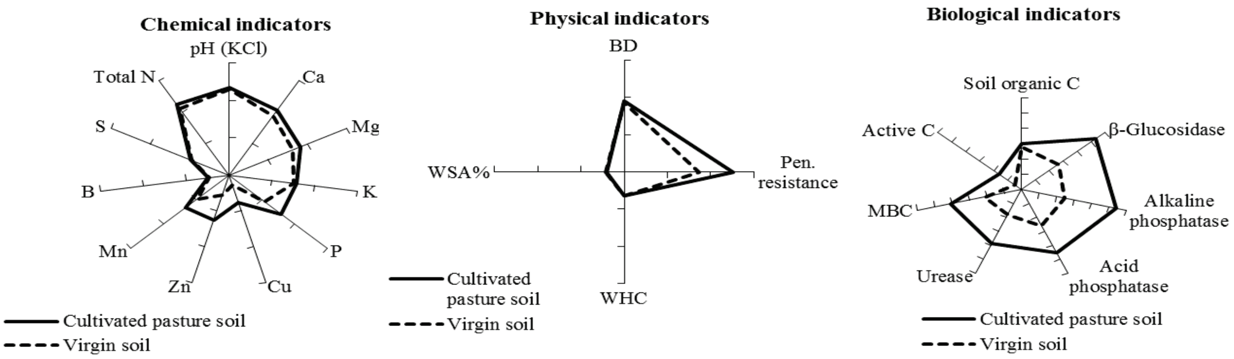

Figure 2. Star plots of the measured chemical, physical and biological parameters of virgin soil and improved pasture soil.

improved pasture soil was 64.4% higher ($P \leq 0.01$) than that of virgin soil. Active C stock in the improved pasture soil was ca. 40 times higher than in that of the virgin soil in the 0-100mm layer. Mean MBC in improved pasture soil was 8.4% higher ($P \leq 0.01$) in the 0-100mm layer. The higher MBC and active C contents in the improved pasture soil could be ascribed to the vigorous and large mass root systems of the kikuyu-ryegrass pasture within improved external environmental conditions such as water supply by irrigation, nutrient supply by fertilization, liming and manure (Carter 1986). It also highlights the importance of the soil surface as a biologically active interface and entry point for additions of readily available organic material. The degree of ecosystem functionality of the two land uses was indicated by stratification ratios. The stratification ratio of C_{org}, was 3.56 ± 0.36 in the improved pasture soil and 1.52 ± 0.07 in the virgin soil ($P \leq 0.01$). Active C content was uniformly distributed within top 300 mm of virgin soil (stratification ratio = 1.96 ± 0.76), but highly stratified (26.36 ± 2.02) in the improved pasture soil. Similarly, MBC in the virgin soil had a stratification ratio of 1.22 ± 0.15 and that of the improved pasture soil was 6.21 ± 1.52. All stratification ratios of SOM related indicators of virgin soil remained below two, but those of MBC, C_{org} and active C of improved pasture soil surpassed two and it can therefore be reasoned that the ecosystem quality and functionality is improved when soil was converted to improved pastures (Franzleubbers 2002).

The microbial quotient did not differ ($P > 0.01$) between sites on any soil depth and the microbial community substrate-use efficiency in the two systems were therefore similar and indicated that the improved soil is also under steady-state conditions. Sudden deviations from this level would indicate that the system is changing and C is being released or accumulated. It is therefore a valuable tool to predict C sequestration actions. Conversion of virgin soil to improved pasture soil improved conditions supporting the build-up of SOM levels and may lead to an enhanced microbial component and soil biological health.

The enzymatic activity of β-Glucosidase, alkaline phosphatase and urease activity were higher ($P \leq 0.01$) in the improved pasture soil in all layers. The enzymatic activities rapidly declined with soil depth and are concomitant with the decline in SOM related indicators observed, which was also noted by Verhulst *et al*. (2010). Acid phosphatase had a different distribution pattern than the other soil enzymes and was similar between sites ($P > 0.01$). Soil pH (KCl) of the virgin soil was significantly lower at all soil depths than that of the improved pasture soil which rendered the efficiency of acid phosphatase higher.

Figure 2 represents star plots of the virgin soil and improved pasture soil. The area of the stars may be interpreted as the soil chemical, physical or biological quality. It is clear that the improved pasture soil had higher nutrient levels, and biological activity (vigour) than the virgin soil. Physical indicators between the two land uses were similar, except for physical resistance visible from physical star plot.

Conclusion

Soil quality needs to be protected in order to maintain sustainability of pasture systems. Chemical indicators were within the recommended thresholds for an improved pasture and supported the kikuyu-ryegrass system. Conversion of virgin soil to no-till pastures enhanced or maintained physical condition of soil, except for physical resistance and bulk density (only at 200-300 mm). The importance of SOM to maintain soil health and a balance between environmental sustainability and agricultural production was reflected by the distribution patterns, stratification and degree of SOM accumulation and enzymatic activity. The indicator values reported may serve as baseline values, since such reference values for the southern Cape region of South Africa are not available. Initial data of this soil quality study should offer the best reference value which can be refined with future research.

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