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Full Length Research Paper

The effects of soil density on the vegetation of the Umfolozi catchment in South Africa

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The effects of soil compaction on plant productivity were studied in the dry season of September 2008 in Umfolozi catchment, South Africa. This study used 10 paired plots each measuring 20 x 20 m and 1 x 1 m quadrats randomly located within the study plots in both degraded and undegraded sites. Soil samples were collected on the outer edge of the quadrats within the study plots. Soil moisture (%) in the soil samples collected from the degraded and undegraded sites was 8.94 and 13.48%, respectively. Organic matter (%) was 3.17 and 5.46% on degraded and undegraded sites, respectively. Average soil bulk density (g/cm^{-3}) was 0.99 g/cm^{-3} (CV=1.81 %) and 0.83 g/cm^{-3} (CV=5.02 %) on degraded and undegraded sites, respectively. Porosity was greater on undegraded sites (36.2%) than on degraded sites (34.2%). Seedling density (no/pot) was 18 seedlings per pot in soil samples collected on degraded and 10 seedlings per pot on undegraded sites. Seedling mortality (no/pot) was 17 seedlings per pot and 9 seedlings per pot in the soil samples collected on degraded and undegraded sites, respectively. Spearman rank correlation showed strong correlation between seedling density and soil compaction (r=-0.481, P<0.05). Seedling emergency density (no/pot) reached highest level on degraded sites compared to undegraded sites. Seedling mortality (no/pot) reached highest level on degraded sites. The study suggests that soil compaction and soil bulk density are critical for an efficient resource management in rangelands.

Key words: Soil density, soil compaction, degraded landscapes, semi-arid areas.

INTRODUCTION

The effects of soil compaction on plant productivity have frequently been studied in the context of agriculture, but less information exists about this relationship in the context of rangeland resources. Several studies (Dougill and Cox, 1995a, b; Wilson et al., 1984; Tafangenyasha and Campbell, 1998) have shown that overgrazing leads to increases in runoff and soil erosion. Runoff and soil erosion processes are the result of physical changes in the soil; and vegetation and specific physical change in the soil is related to soil compaction (Morgan, 1980). Soil compaction has been described as simply the increase of soil bulk density and is usually the result of trampling and root thinning (Engels, 2009). Soil compaction and soil strength are also a function of bulk density and water content (Cyzt, 2004; Tokunaga, 2006). The processes by which water enters, moves through and exits soil are essential for sustaining plants and soil organisms, transporting nutrients and recharging surface and ground water. Compaction by animals or natural processes of top soil removal by overland flow can affect soil water movement by increasing bulk density and decreasing porosity and infiltration. These changes can result in less soil water storage, poor nutrient movement, slowed gas exchange and restricted root growth, all of which can cause a reduction in crop yield (Cyzt, 2004).

Soil functions affected by soil compaction include air

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Figure 1. Present study area situated about 10 km northeast of St Paul Mission near Nqutu in central KwaZulu-Natal (after Botha and Fedoroff, 1995).

capacity and permeability, available water capacity, water conductivity and root length, penetration resistance and dry bulk density (Taylor and Gardner, 1963; Daddow and Warrington, 1983; Tsimba et al., 1999). Soil susceptibility to erosion depends on soil properties and external factors like climate and soil use (Davidson, 1980; Hudson, 1995). Increased runoff may occur as a result of compaction and increased bulk density. Soil physical properties, including texture, structure, bulk density, soil organic matter (SOM) levels and water content control how well soil resists compaction. Compaction is the process of increasing the bulk density of a soil or aggregate by driving out air. Bulk density is dependent on moisture content. At very high moisture contents, the maximum dry density is achieved when the soil is compacted to nearly saturation, where almost all the air is driven out. Available soil water also declines when the void volume is decreased (Rockich et al., 2001). When this occurs, nutrients and water may become limited because the plant's demands exceed the ability of the roots system to access these resources (Froehlich and McNabb, 1984).

One other useful parameter to consider in soil properties is porosity (Schjonning et al., 1998). Porosity is a measure of the void spaces in a material, and is measured as a fraction, between 0 to 1, or as a percentage between 0 to 100%. To effectively identify harmful changes to the soil through loading, soil properties linked to soil compaction should be investigated. The objective of this paper is to investigate and to explain the importance of soil bulk density to plant establishment on the degraded and undegraded sites in the Umfolozi catchment in central midlands of KwaZulu Natal Province, South Africa. The effects of soil density on the vegetation in the semi-arid areas of the central midlands of South Africa have been little studied thereby prompting an investigation on its nature.

Study area

Covering ten percent of KwaZulu Natal Province, the Umfolozi is the Province's second largest catchment (Figure 1). The study area lies between 28°00'00" S and 28°10'00" S; 30° 37'00" E and 30°55′00″E), 28 km south-west of Vryheid town in central KwaZulu-Natal province (Figure 1). The study area falls within Mondlo Communal Land. The study area and the adjacent areas (Figure 1) have been described by Rein's et al. (2000). The area is known for extreme temperatures with hot summers and cold winter months. The average summer rainfall of the region is 350 mm per annum with range values between 60 to 129 mm (CV ranges from 63 to 217%). The rainfall is concentrated between the months of October and February. Mean annual temperature ranges from 12 to 23°C. Mean annual minimum temperature ranges from 4 to 7°C. The rainfall over the region varies from 700 mm in the south-east to 900 mm in the west, on the Drakensberg range. Frost is a common feature and appears from April to September. The climate of the study area is maintained by the position of the Southern African position in which it lies and its relation to the major atmospheric circulation of the southern hemisphere. The climate, slope and soil conditions combine to determine the potential of a region or site. The area is known for extensive stock farming with goats, sheeps and cattles. The topography of the area consists of mountains, hilly and undulating veld and flat veld. The vegetation consists of typical Karoo veld (Acocks, 1988). The climate, slope and soil conditions combine to determine the potential of the study area to erosion.

According to the Natal Town and Regional Planning Commission (1984) 54% of it has a high natural erosion hazard potential. Ramakgoba (1966) estimates that 17 and 25% of it is already very severely eroded, respectively. Degraded soils have top soil stripped away by overland flow leading to subsoil compaction. The study area is drained by two major tributaries that include the White Umfolozi and Black Umfolozi Rivers. The White Umfolozi and the Black Umfolozi Rivers rise near the study area at altitudes of 1620 and 1524 m a.s.l., respectively, and traverse over 400 km on their course to the sea (Begg, 1988). The Umfolozi catchment contains a wide diversity of physiographic, geological, soil and vegetation. Due to the soils types, the susceptibility to sheet and gully erosion is variable. In their investigation of the 525 km^2 area surrounding Ulundi, Berjak et al. (1986), Liggitt (1988) and Liggitt and Fincham (1989) found that gully erosion was best represented on Dwyka Tillite and to a lesser extent on Pre-Cambrian Rocks, and on slopes less than 9°. The study by Botha (1992) of the 1 360 km^2 area between Dundee and Nqutu included a substantial portion of the Umfolozi catchment, and revea-led the preferential development of gullies in the partly consolidated, bedded sediments of the Masotcheni Formation underlain by Vryheid and Volksrust Forma-tions, Beaufort Group and dolerite bedrock. He also noted that they mostly occur within terrain characterized by concave/ convex topography, highly variable relief and slopes less than 9°.

MATERIALS AND METHODS

An investigation of the influence of soil bulk densities as influenced by agricultural activities was conducted during the dry season of September 2008. The study sites consisted of 10 paired plots in both degraded and undegraded sites. Each plot measured 20 x 20 m and soil samples were collected on the outer edge of the randomly located 1 x 1 m quadrats within the 20 20 x 20 m plots. The plot size of 20 x 20 m plot was determined by using a builder's tape measure. SBD is the ratio of the mass of dry solids to the bulk volume of the soil occupied by those dry solids (Blake and Hartage, 1986). The bulk volume includes the volume of the solids and the pore space. Bulk density of the soil is an important site characterization parameter since it changes for a given soil. It varies with structural condition of the soil, particularly that related to packing. The SBD contains bulk density of the soil based on dry weight and volume using the core method at 0 to 10 cm depth. Samples were collected at randomly identified 20 locations within the study area during the dry season of 2008. Soil bulk density was analysed using the protocols of Blake and Hartage (1986), Doran and Mielke (1984) and Smith and Atkinson (1975). The methods used by Blake and Hartage (1986), Doran and Mielke (1984) and Smith and Atkinson (1975) were found to be repeatable and offering reliable results for the study area.

A shovel, plastic bags to line the excavated hole, water to pour into the plastic bag, and a graduated cylinder were used to determine the volume of water in the bag. Each sample can was identified by the sample site ID code. After bulk density sampling, the soil samples were put in plastic bags for later weighing to obtain the wet weight. Volumetric sampling of collected soil samples were conducted by inserting a plastic bag into the cavity of the ring. The volume of the sample was determined by lining the hole with a plastic bag and measuring the volume of water needed to fill the bag to the level of the surrounding surface. The bag was again removed, soil excavated to a depth of 10 cm, the bag replaced and refilled, and a measure of the volume of the sample between the 0 cm and 10 cm depths calculated. A laboratory dry combustion procedure (loss on ignition (LOI)) was performed on soil samples taken from all 20 sampling points in order to determine the organic matter content (Smith and Atkinson, 1975). Soil samples were dried at 105ºC for 24 h to remove moisture. The dried samples were placed in a muffle furnace at 375ºC for 16 h to incinerate all organic matter. Upon cooling to room temperature, the percent organic matter was calculated by mass after Smith and Atkinson (1975) as follows:

% soil moisture (SOM) weight= [(wet weight-dry weight)/dry weight] × 100

Bulk densities were calculated in the following manner: any dry gravimetric soil samples collected during the dry season of 2009, which weighed more than 65 grams, were assumed to have been collected with the volumetric sampler (i.e., volume = 92.92 cubic centimeters). The bulk density for each of these samples was calculated according to the following Blake and Hartge (1986) formula:

Bulk Density = (Dry weight of sample in grams) / (volume of the sample in milliliters)

Bulk Density = (Dry weight of sample in grams) / 92.92

A mean of all bulk density determinations at a given site-depth was calculated. The number of determinations and the standard deviation of the mean bulk density are also reported. The bulk densities were then calculated using the following Brady and Weil (1996) formula:

Porosity (%) = (1-Bulk density/Particle density)*100

Where 2.65. The mineral grains in many soils are mainly quartz and feldspar, so 2.65 was an adequate average mineral specific gravity for the sand fraction.

Organic matter content can be used as a rough estimate of the total organic carbon content. Soils contain a large variety of organic materials ranging from simple sugars and carbohydrates to the more complex proteins, fats, waxes and organic acids. Important characteristics of the organic matter include their ability to: form water-soluble and water insoluble complexes with metal ions and hydrous oxides; interact with clay minerals and bind particles together; sorb and desorb both naturally-occurring and anthropogenically-introduced organic compounds; absorb and release plant nutrients; and hold water in the soil environment. The loss-on-ignition (LOI) method for the determination of organic matter involves the heated destruction of all organic matter in the soil or sediment. A 10 g was placed in a ceramic crucible which was then heated to between 350 and 44°C overnight (Nelson and Sommers, 1996). The sample was then cooled in a desiccator and weighed. Organic matter content was calculated as the difference between

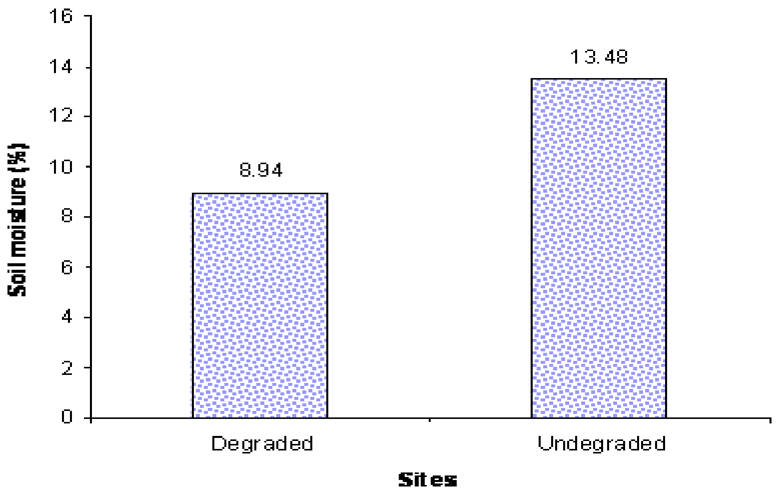

Figure 2. Soil moisture (%) in the soil samples collected from the degraded and undegraded sites.

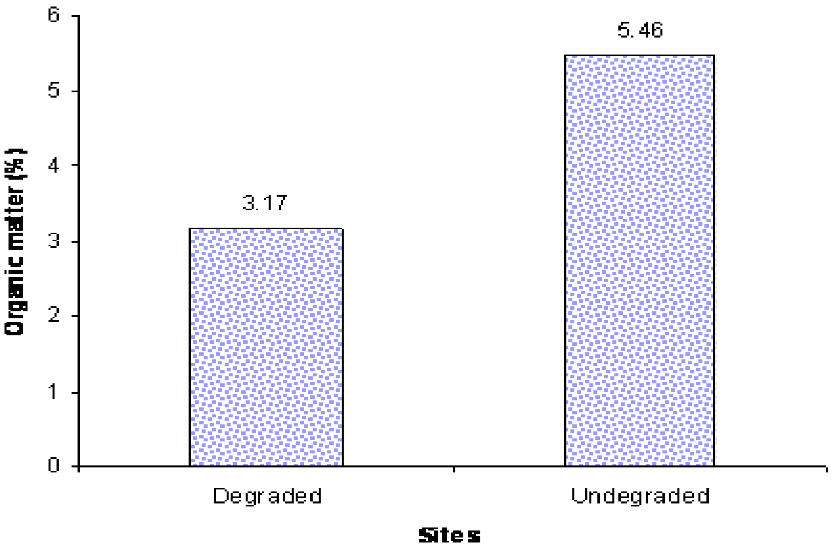

Figure 3. Organic matter (%) in the soil samples collected from the degraded and undegraded sites.

the initial and final sample weights divided by the initial sample weight times 100%. The weight was then corrected for moisture / water content prior to organic matter content calculation.

The factors known to influence seedbank germination included soil compaction, organic matter and soil bulk density. Stepwise multiple regression was carried out using SPSS software (Nie et al., 1975). Stepwise multiple regression identified the order and degree of contribution of the independent variables in terms of prediction of eroded land percentage.

RESULTS

Soil moisture (%) in the soil samples collected from the degraded sites was 8.94 and 13.48% on undegraded sites (Figure 2). Organic matter (%) was 3.17 and 5.46% on degraded and undegraded sites, respectively (Figure 3). Bulk density (g/cm^3) was 0.9 and 0.83 g/cm^3 on degraded and undegraded sites, respectively (Figure 4). The variation in bulk density across the sampled plots is given in Table 1. Porosity was greater on undegraded sites (36.2%) than on degraded sites (34.2%) (Figure 5). Seedling density (no/pot) was 18 seedlings per pot in soil samples collected on degraded and 10 seedlings per pot on undegraded sites (Figure 6). Seedling mortality (no/pot) was 17 seedlings per pot and 9 seedlings per pot in the soil samples collected on degraded and undegraded

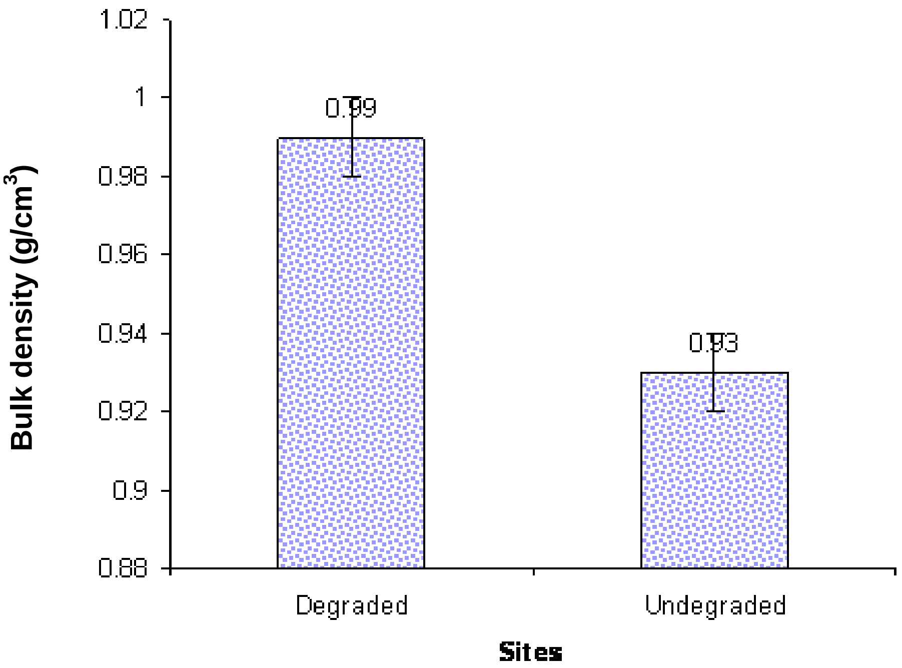

Figure 4. Bulk density (g/cm^3) of the soil samples collected in the degraded and undegraded sites.

Table 1. The variation of bulk density (g/cm^3) across the soil samples collected in the degraded and undegraded sites.

Site no.	Degraded site (g/cm^3)	Undegraded site (g/cm^3)
1	0.96	0.93
2	0.96	0.89
3	0.99	0.97
4	0.96	0.93
5	0.99	0.96
6	1.00	0.95
7	1.00	0.84
8	0.99	0.96
9	1.00	0.88
10	1.00	0.99
11	0.985	0.93
Mean	0.985	0.93
SD	0.0169	0.044
CV (%)	1.81	5.02

sites (Figure 7). Spearman rank correlation showed strong correlation between seedling density and soil compaction (r=-0.481, p<0.05) (Table 2). Soil moisture and soil organic matter showed significant differences between degraded and undegraded sites (Table 3). Seedling emergency density (no/pot) reached highest level on degraded sites compared to undegraded sites. Seedling mortality (no/pot) reached highest level on degraded sites (Figure 7).

The results of the regression analysis are summarized in Tables 4 to 6. Values of simple r (r values for each variable separately) are given for all the regressor variables, allowing for the fact that these factors do not act in isolation. Given the data set (n=75), correlations were evident for Ivy's erosion class and slope angle, that is the two physical factors. Distance to water, distance to hill and distance to road appeared to play no role in the erosion process in stepwise multiple regression. Stepwise multiple regression identified the order and degree of contribution of the five independent variables in terms of prediction of eroded land percentage. Ivy's erosion class proved to be the most important factor influencing erosion, with a large and highly significant F-value and an r square of 0.142 (Table 4). Slope angle was the second variable to enter the equation, increasing the r square to 0.216 (with a very large F-value associated with the r^2 change).

Significant correlations were evident for plot erosion and soil compaction and bare soil cover. Soil water infiltration, grass cover and litter cover appeared to play no role in erosion process in stepwise multiple regression. Stepwise multiple regression identified the order and degree of contribution of the five independent variables in terms of prediction of eroded land percentage. Soil compaction proved to be the most important factor influencing erosion, with a large and highly significant F-value and an r square of 0.606 (Table 5). Bare soil cover

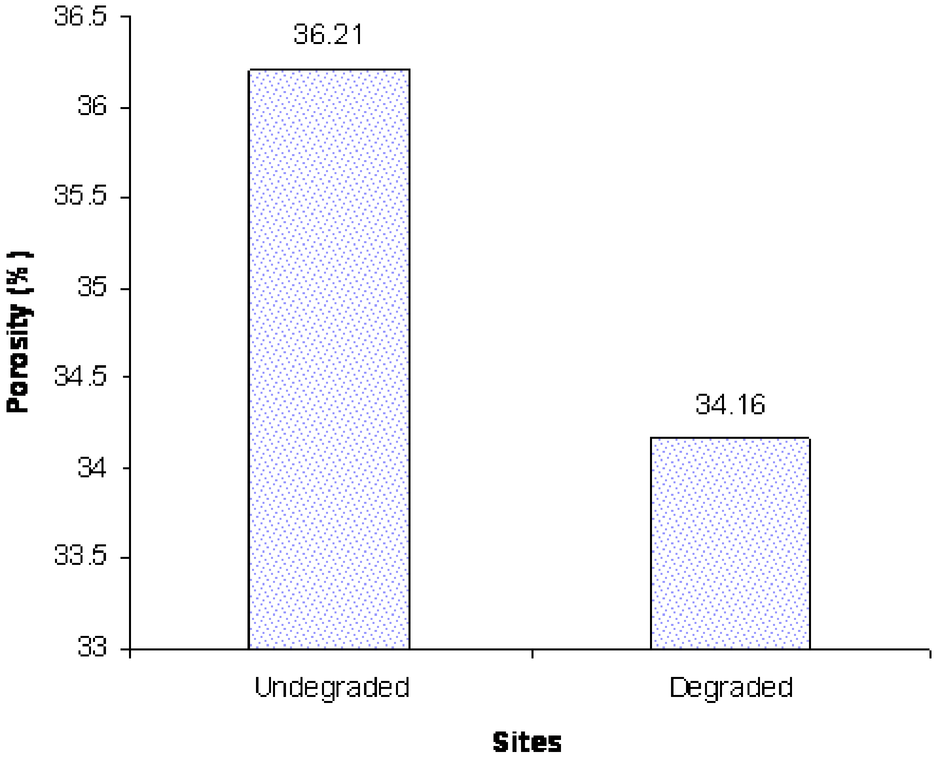

Figure 5. Porosity (%) of the soil samples collected in the degraded and undegraded sites.

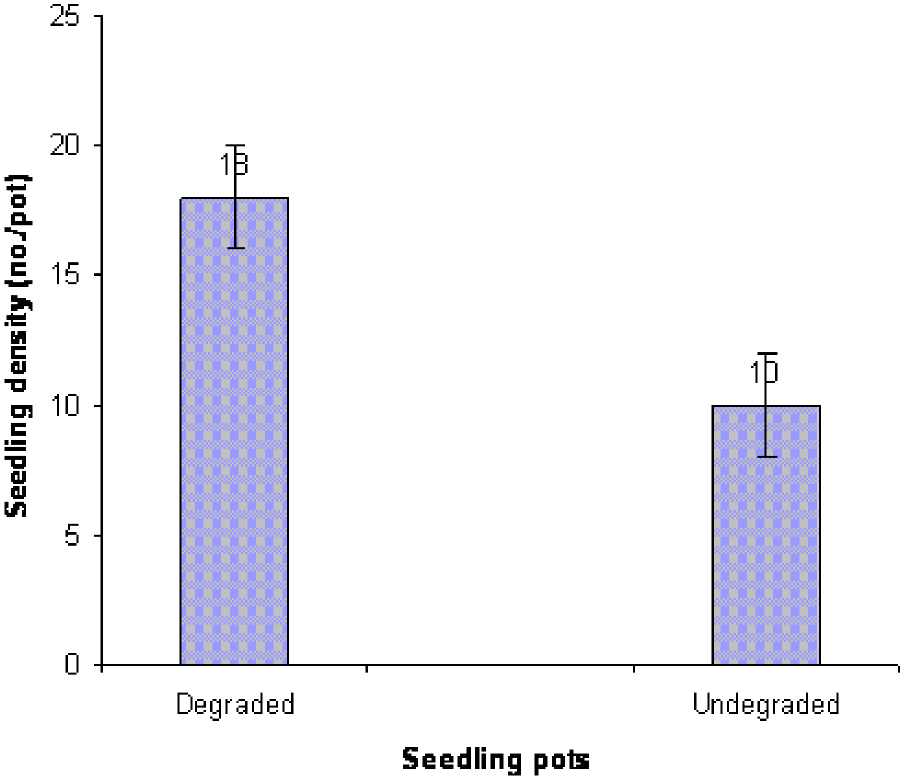

Figure 6. Seedling density (no/pot) in the soil samples collected in the degraded and undegraded sites.

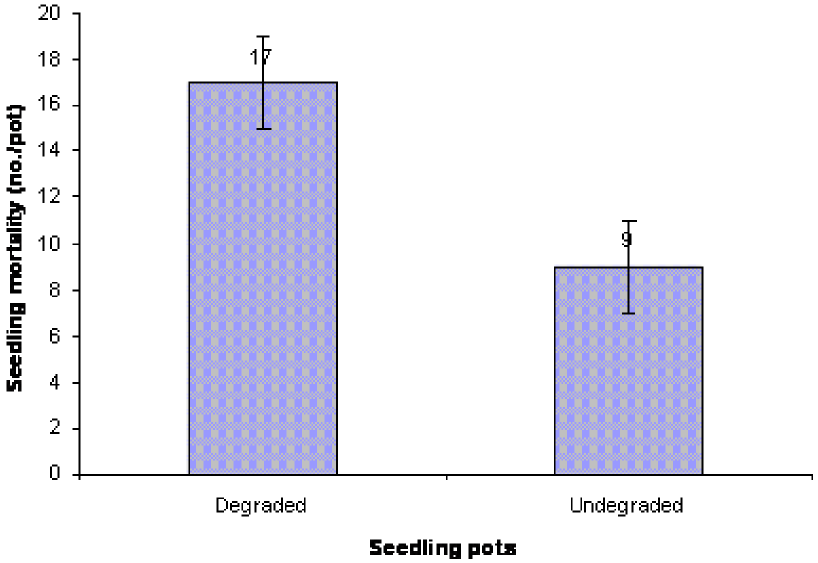

Figure 7. Seedling mortality (no/pot) in the soil samples collected in the degraded and undegraded sites.

Table 2. Spearman rank correlation between seedling density and soil physical properties.

	Soil compaction	TOC	Bulk density
	-0.481	0.192	0.137
Seedling density	0.043	0.446	0.587
	*	ns	ns

ns: not significant; *: significant at 0.05%.

Table 3. Summary of t-test results of SOM and TOC obtained from the degraded and undegraded plots of the Umfolozi catchment area.

Variables (g)	Mean degraded	Undegraded	t-value	Sig.
Soil moisture	8.99	14.22	3.466	*
Soil organic matter	2.91	4.77	1.834	*

*: significant at 0.05%

Table 4. Results of multiple regression with stepwise variable selection using plot level percent of erosion as the dependent variable and Ivy's erosion class, distance to water, distance to hill, distance to road and slope angle as predictor variables.

Predictor variable	Simple r	R square	F-value	Sig.
Ivy's erosion class	0.376	0.142	13.53	**
Distance to water			0.348	ns
Distance to hill			0.009	ns
Distance to road			0.068	ns
Slope angle	0.465	0.216	6.817	*

ns: not significant; *, ** : significant at 0.05 and 0.001%, respectively.

Table 5. Results of multiple regression with stepwise variable selection using plot level percent of erosion as the dependent variable and soil infiltration, soil compaction, grass cover, bare soil cover and litter cover as predictor variables.

Predictor variable	Simple r	r square	F-value	Sig.
Soil infiltration			1.371	ns
Soil compaction	0.779	0.606	4.105	*
Grass cover			0.072	ns
Bare soil cover	0.719	0.517	20.850	**
Litter cover			0.058	ns

ns: not significant; *, ** : significant at 0.05 and 0.001%, respectively.

Table 6. Results of multiple regression with stepwise variable selection using plot seedling density as the dependent variable and soil bulk density, total organic carbon and soil compaction as predictor variable.

Predictor variable	Simple r	r square	F-value	Sig.
Seedling density	0.636	0.404	13.042	**
Bulk density	0.808	0.652	12.924	**
Total organic carbon	0.847	0.718	3.236	*
Compaction			0.027	ns

was the second variable to enter the equation, increasing the r square to 0.517 (with a very large F-value associated with the r^2 change).

Distance to water, distance to hill and distance to road appeared to have no role in the erosion process in stepwise multiple regression. Consequently, with increase in rangeland usage, so the erosion becomes more widespread. Stepwise multiple regression identified the order and degree of contribution of the four independent variables in terms of prediction of seedling density. Seedling density, soil bulk density and total organic carbon were identified by their F-value for their degree of contribution in the stepwise multiple regression. Seedling density proved to be the most important factor influencing erosion, with a large and highly significant F-value and an r square of 0.404. Soil bulk density was the second variable to enter the equation, increasing the r square to 0.652 (with a very large F-value associated with the r^2 change) (Table 6). Total organic carbon was the last variable to enter the equation, increasing the r square to 0.718 (Table 6). Soil compaction appeared to play no role in the establishment of seedlings, possibly due to the importance of water that reduces the stress exerted by compaction on the growing roots. Clearly, the human factors and physical factors stand out as being a greater influence on erosion in this analysis.

DISCUSSION

Human activities in the study area include cultivation, grazing, burning and fuel wood collection. The common tillage treatment used include conventional ploughing (inversion) using a tractor and a single-furrow ox-drawn mould board plough. Using a modified Durham Geo's Pocket soil penetrometer in this study, soil penetration resistance increases to a peak between 20 and 30 cm soil depth. Smith and Dickson (1990) suggested that root penetration was inhibited at soil strength values between 2000 and 3000 kPa and this limits crop emergence and root penetration. The consequence of increased soil compaction is formation of a hardpan near the soil surface. High sheet erosion, rapid breakdown of organic matter and structure are the major factors which contribute to a rapid soil depletion which cannot be sustainably compensated for with inorganic fertilizers. Patches of bare ground are common in the landscape and these changes and fluctuate depending on soil moisture. Bare ground patches are characterized by internal variables such as number of trees, number of tree species, height of trees, percentage soil cover and percentage grass cover. Disturbance through clearing, cultivation, burning and overstocking may be altering the structure of soils through formation of a hardpan.

Degraded sites in the study area have low soil moisture suggesting a more xeric nature that is likely to impede establishment of plants. Organic matter is lower on degraded sites than on undegraded sites because plant cover is sparse. Woody plants are deliberately removed from the landscape to create space for more grass cover that can benefit grazing domestic livestock. The woody cover in the study area is less than 1%. The removal of trees removes the critical protective forces from raindrop impacts and this leaves the soils crusting and with hardpans. Degraded sites exert pressure on the roots of the few available plants. The study shows a high negative correlation between seedling density and soil compaction. Water supplied to the nursery pots in a seed store experiment (Tafangenyasha et al., in press) was critical in reducing the pressure applied to the roots since seedlings germinated. Gifford et al. (1977) suggests that soil compaction has important hydrologic implications in terms of its contribution to reduced infiltration rates, and increased runoff potentials. In the Mondlo Communal rangeland, soil compaction may occur when weight of livestock or heavy machinery compress soil, causing it to lose pore space. Affected soils absorb less rainfall, thus increasing runoff and erosion. Plants have difficulty in establishing on compacted soil because the mineral grains are pressed together, leaving little space for air and water, which are essential for root growth. The phenomenon of soil-water-compaction has been observed by Engels (2009). Degraded sites in this study have low organic content because plant cover is low due to lack of establishment. The high mortalities among the seedlings in degraded soils in this study may be attributed to poor water holding capacities, compaction and topsoil erosion caused by soil erosion which in turn reduces the water infiltration rate. There were more cotyledons than dicotyledons germinating in the soils in the pots.

The rangeland that is part of the study area is subjected to continuous grazing pressure, there are no partitions that allow seasonal grazing rotations. The increasing and continuous use of degrading landscapes lead to need long time to recover while some degraded landscapes deteriorate to worse conditions. Seedbanks of degraded landscapes in the Umfolozi catchment are viable but once germinated the seedlings are challenged by physical conditions such as compaction and elevated bulk density causing significant (t-test, $p<0.05$) seedling diebacks. The negative emergence and growth conditions of seedlings may be ameliorated by improving the land preparation of the degraded landscapes. Moriuchi et al. (2000) suggest the need for a very long-term data set on plant population dynamics in fragile environments to capture unusual extreme events and explain patterns influenced by weather and edaphic conditions.

Bulk density was 0.99 and 0.83 g/cm^3 on degraded and undegraded sites, respectively. Soil bulk density ranged from 0.84 to 1.00 g/cm^3. The data (Table 1) suggest that degraded sites have higher soil bulk density than undegraded sites. Variation in soil bulk density may be attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil (Blake and Hartage, 1986). In this study, porosity was greater on undegraded sites (36.2%) than on degraded sites (34.2%). Soils formed in organic rich materials might have particle densities of 0.9 to 1.4 g/cm^3 while mineral soils have bulk densities between 1.0 and 2.0 g/cm^3 (Blake and Hartage, 1986). Colluvial soils, reaching thicknesses of more than 10 m, mantle the pediment slopes at about 2 to 3° towards the valley bottoms in the study area. In the majority of cases, the percentage composition of the colluvium in the study area comprises sand ranging in proportion from 45 to 65%, silt from 15 to 25% and clay from 10 to 35% (Watson et al., 1984). The hillslopes in the study area are stripped by sheet-wash and the sediment chokes stream channels and in some cases the sheet-wash produces gullies or dongas reported by Botha et al. (1994) and Botha and Fedoroff (1995). Most mineral soils have bulk densities between 1.0 and 2.0 g/cm^3 (Blake and Hartage, 1986).

Blake and Hartage (1986) suggest that root densities are severely impacted at densities greater than 1.6 g/cm^3. If poorly-sorted particles are loosely packed, smaller particles will fill the voids created by the larger particles and again, bulk densities increase. As density increases, pore space decreases and the amount of air and water held in the soil also decrease. Figure 5 shows that Porosity was greater on undegraded sites (36.2%) than on degraded sites (34.2%). Lower soil bulk densities are desirable for plant growth whether the plants are agricultural crops, trees or grasses (Dudley et al. 2002). Low bulk density soils have greater water infiltration rates which minimize runoff, improve water quality and reduce stormwater flow. Soil bulk density measured in this study ranged from 0.84 to 1.00 g/cm^3 and this is close to the 0.88 and 0.92 g/cm^{-3} measured on moderately grazed pastures by Engels (2009). The average bulk density from the extremely grazed pastures is between 1.07 and 1.13 g/cm^3 (Engels, 2009). Soil bulk density ranged from 0.84 to 1.00 g/cm^3. Soil moisture (%) in the soil samples collected from the degraded sites was 8.9 and 13.48% on undegraded sites (Figure 2). Organic matter (%) was 3.17 and 5.46% on degraded and undegraded sites, respectively (Figure 3).

Soil compaction reduces the overall pore volume of soil and change the size and distribution of the pores within the soil (Anderson and Stormont, 2006). The loss of porosity reduces the ability of the soil to conduct water and air. The resulting pore space changes are expected to change the moisture characteristic of the soil. Reduced infiltration capacity results in surface runoff, leading to erosion and transport of nutrients to open water. Organic matter content tends to reduce soil compactibility and to increase its elasticity. The presence of plant tissues, living or dead may influence to some degree the ability of soils to resist compaction. Compaction causes an overall decline in growth, vigour, quality and persistence (Daddow and Warrington, 1983; Taylor and Gardner, 1963). The conditions needed for germination are known to vary considerably between different species and even between different populations of the same species. Growth of the plants in the nursery pots in the greenhouse in this study was made possible after a sustained and managed water supply. Tokunaga (2006) observed that shoot production increased significantly at high water potential and moderate bulk density. Biomass production was greatest when water was readily available and the negative effects of highly compacted soils were often less severe when water was available (Tokunaga, 2006), a situation observed in this study. It follows that when water is available plants tolerate compacted soil. The stepwise regression in its variable selection did not reveal soil compaction as an important variable suggesting that other factors may play a role. In the rangeland, the ability of a soil to recover from compaction has been attributed to climate, mineralogy and fauna (Lortie and Turkington, 2002). The erosion in the study area is increasing and the causal factors have been identified as climate and soil factors. The soils in the study area are expansive when wet and appear to form cracks on the surface when dry. Soils with high shrink-swell capacity, such as vertisols, recover quickly from compaction where moisture conditions are variable (dry spells shrink the soil, causing it to crack). But clays which do not crack as they dry cannot recover from compaction on their own unless they host subterranean animals such as earthworms.

The low survival of seedlings reported in this study suggests that the physical properties of the soils are a constraint to the growth and establishment of seedlings. Other physical conditions regulating the growth of seedlings have implicated fire. Fire is used in the study area to initiate an early growth of grass so that grazing livestock can benefit. The role of fire in seed germination has been recorded as the action of heat in breaking hard seed coats (Kenny, 2000; Egerton-Warburton, 1998). Keeley et al. (1981) suggest that the heat required to fracture a seed coat within the soil underneath the passage of a fire varies with species but is generally in the range 60 to 120°C with an optimum between 80 to 100°C. *Colophospermum mopane* (Benth.) showed high rates of height growth immediately after fire (Mlambo and Mapaure, 2006). Most studies suggest that seedling mortality is high during the germination period (Keith, 2002, Radford et al., 2001), results which tend to agree with the findings in this study. Results of this study support the suggestion that water (Rainfall) is an important determinant of seedling recruitment in the savanna rangeland. The addition of soil treatments and protection from herbivory in early growth stages should increase emergence of seeds from the seedbank and offer opportunities for effective restoration of the degraded rangeland.

The results of the regression analysis are summarized in Table 4 to 6. Values of simple r (r values for each variable separately) are given for all the regressor variables, allowing for the fact that these factors do not act in isolation. Stepwise multiple regression identified the order and degree of contribution of the independent variables in terms of prediction of eroded land percentage and seedling density. When erosion is used as the dependent variable, erosion class, slope angle, soil compaction and bare soil cover proved to be the most important factors influencing erosion. When seedling density is used as the dependant variable, soil bulk density and total organic carbon proved to be the most important variables influencing plant establishment. Soil compaction appeared to play no role in the establishment of seedlings. Clearly, the human factors and physical factors stand out as being a greater influence on erosion in this analysis.

Reduced infiltration capacity results in surface runoff, leading to erosion and transport of nutrients to open water. Organic matter content tends to reduce soil compactibility and to increase its elasticity. The presence of plant tissues, living or dead may influence to some degree the ability of soils to resist compaction. Compaction causes an overall decline in growth, vigour, quality and persistence (Birkeland, 1984).

The soil erosion taking place in the Mondlo Communal Area represents major environmental changes occurring at the landscape (or larger) spatial scales within the savanna biome. The cause-effects of the soil erosion are similar to others reported elsewhere (Dougill and Cox, 1995a, b; Dudley et al*.,* 2002; Tafangenyasha and Campbell, 1998; Cyzt, 2004; Tokunaga, 2006) and include energy forces, protective forces and social forces, but the erosion in Mondlo Communal area is increasing hence the need to elucidate the erosion problems denovo. As this paper shows, the erosion is being influenced largely by poor soil physical properties. Elevated soil bulk density impedes root penetration and seedling establishment.

Conclusions

Soil bulk density has been suggested as a cause of vegetation change in the Umfolozi catchment in this study. The Masotcheni colluvial sediments blanketing the hillslopes in the Umfolozi catchment are sensitive and fragile to land use and their nature in resource management needs to be understood. Further data collection will continue, making it possible for potential interactions between the effects of grazing history, erosion history and topographic position on bulk density.

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