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Full Length Research

Re-analysis of engineering the stabilization and restoration of supercritical hardpans in the Umfolozi catchment, South Africa

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The hypothesis that lack of vegetation establishment exacerbated degradation of landscapes in the Umfolozi catchment, South Africa was investigated by germinating seed bank in the University of Zululand Greenhouse. Soil samples from 10 degraded plots and ten un-degraded plots were collected. In each 20x20 m plot, three 1x1 m quadrats were randomly located within a plot. Soil core samples were collected on the outer edge of quadrats within the plots. A volume of 400g soil was placed in each pot. Each pot measured 13 cm diameter and a depth of 7 cm. A soil depth of 4 cm and diameter of 13 cm in each pot was used for germination tests. Seedling density was 18 seedlings per 52 cm^3 in soil samples collected on degraded sites and 10 seedlings per pot on un-degraded sites. Spearman rank correlation showed strong negative correlation between seedling density and soil compaction ($r = -0.481$, $P<0.05$). Plant species germinating in nursery pots in the university greenhouse showed a mix of species including woody plants, grasses and weeds in soil samples from both degraded and un-degraded sites. The study leaves gaps on the bearing of soil nutrient supply during the pre-germination and post germination stages of woody plants and a *de-novo* approach is required. The study provides critical understanding relevant to stabilization and restoration of the supercritical degraded Umfolozi catchment soils and other similarly affected areas elsewhere.

Keywords: Soil seed bank, Soil bulk density, Soil stabilization and restoration

INTRODUCTION

The first steps towards improving environmental conditions of sheet eroded soil hardpans include understanding constraints limiting plant germination. The second step includes reworking the conceptual framework to reach desirable rangeland productivity. The final steps include a gamut of measures to achieve stabilization and restoration that can reach full productive capacity of the degraded rangelands. The Umfolozi catchment erosion in central Zululand in South Africa has dramatically reduced livelihood options. Tafangenyasha *et al* (2011a) and Tafangenyasha *et al* (2011b) contributed to the initial understanding of the Umfolozi sheet erosion processes. The absence of adequate plant cover in soil restoration and stabilization on the large tracts of bare soil continue to evoke interest in the attempt to meet one health for ecosystems and humans in the Umfolozi catchment. Plants have been proven efficient eco-engineers in most soil conservation works around the globe (Reubens et al, 2007, Gray and Leiser, 1982) but little is known about the mechanisms of establishment on disturbed soils and bare landscapes of the Umfolozi catchment.

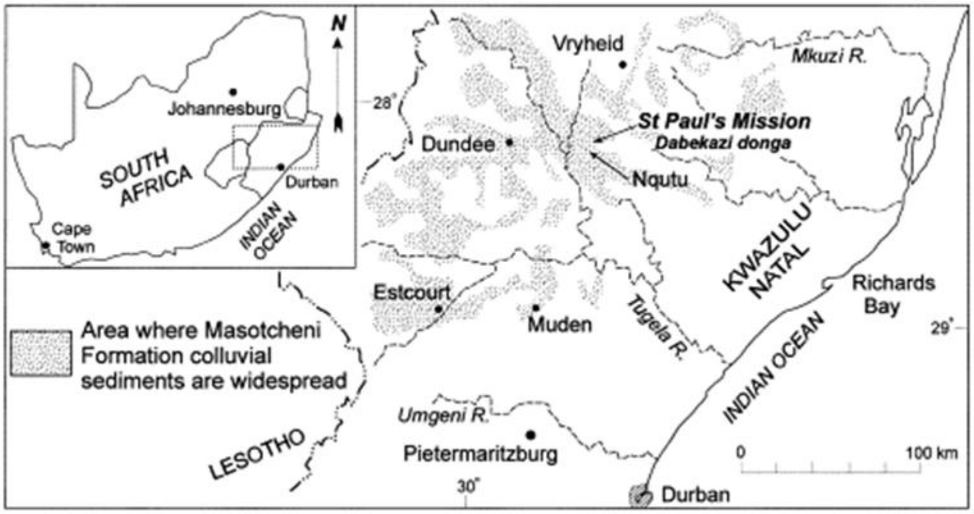

Figure1: Present study area situated about 10 km northeast of St Paul Mission near Nqutu in central KwaZulu-Natal (after Botha and Fedoroff, 1995). The hatched areas on the map indicate Masotcheni Formation collovium sediments where the erosion is widespread.

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A seed bank is the collection of seeds in the soil from a single fertile and viable species or from the species in an area. Seeds from plants forming seed banks should be from a healthy and vigorous plant community. Viable seed storage time in the soil depends on the species but recalcitrant seeds do not retain viability for long. Seed dormancy ensures that viable seeds germinate under optimal light, temperature and moisture. Dormancy imposes a delay between seed shedding and germination depending on the time before stimulation of dormancy release. Dormancy release is regulated by a combination of environmental and endogenous signals with both synergistic and competing effects. Findings from molecular studies attributed alterations in transcriptomes, proteomes, and hormone levels to have a bearing in facilitating endogenous signaling of seed dormancy (Finkelstein et al., 2008). Physical factors such as hard seed coats affect the availability of moisture and gases required for the embryo to leave its quiescent state and mobilize stored nutrients. Soil properties also affect seed dormancy probably on a much wider scale.

Many different factors can break the dormancy of seed and this should allow additional time for seed dispersal over distances. Seed coat dormancy may be due to seed coats covering the embryo which are hard and impermeable to moisture and gases. As the seed coats gain permeability to soil moisture and gases they may resist embryo expansion, cell elongation, division and development delaying germination. Availability of moisture and gases may be affected by the soil properties such as bulk density, particle density and porosity. The decline in vegetation cover and increase in bare soil in the Umfolozi catchment has been attributed to a vicious cycle of growing soil erosion problems (Watson, 1996). Water-driven erosion is the most widespread cause of soil degradation in South Africa, affecting 70 % of the land (Department of Environment and Tourism, 2008). In landscapes prone to soil hardpan formation **(Figure1**), gullying, sedimentation, land sliding and bare soil cover, soil pedestals, crusts, exposed roots, and organ pipe erosion are often the major symptoms.

Species whose seeds remain viable in the soil for relatively long periods (> 5 years) form long-term persistent seed banks, in opposition to those species whose seeds generally germinate (or die) earlier (Zabinski and Cole 2000). The contents of the seed bank mostly comprise of viable seeds undergoing a partial metabolic arrest associated with aspect of growth cessation termed seed dormancy. Seed dormancy can go for decades in a cool and dry environment, with little damage to their genetic material and other structures. By contrast, recalcitrant seeds are damaged by dryness and by low (but still above freezing) temperatures, and so may be depleted in the soil. It is not just the DNA that is degraded in seeds, but structures and living tissues. For example, the rapid re-vegetation of burned or abandoned sites is in large part often due to presence of soil seed banks (Mott, 1972, 1974, Mott and Comb, 1974a, 1974b, Gambiza *et al*., 2005). Rapid re-vegetation may follow re-sprouting from underground organs (Mlambo and Mapaure, 2006, Gambiza *et al*., 2005). Burning produces smoke which contains dormancy breaking compounds such as nitrogen oxides and butenolide (Flemmuti et al, 2004). Even under the most ideal conditions, many seeds fail to germinate due to age, disease, over watering, and poor soil conditions (Mott, 1974). Many kinds of seeds in savannas have very thick seed coats. Baskin and Baskin (2004) have defined five classes of dormancy that include morphological (MD), physiological (PD), morpho-physiological (MPD), physical (PY) and combinational (PY + PD. Seeds from deep in the pot may not have received the cues for germination, or seedlings may not have been able to emerge when buried at greater depth. Non-deep PD and PY are the most common kinds of dormancy (Baskin and Baskin, 1998). The seed may be ripe (mature) when it is shed, but the embryo underdeveloped which result in a condition termed rudimentary germination. The combination of MD and PY is not known, rather than that it is impossible.

Fenner (1985) and Thompson *et al*. (2003) cite dormancy as a characteristic of the seed and not of the environment. Many seeds buried in soil are dormant for part or all of the year and thus will germinate when exposed to the right combination of environmental factors, e.g., temperature and light (Thompson *et al*., 2003). When the seed is exposed to the optimum conditions the hormonal levels changes notably the abscisic acid and gibberellins ratio. The ratio is regulated by the balance of synthesis and catabolism due to environmentally regulated expression of specific isozymes. Essentially increased levels of gibberellins stimulate germination by weakening the seed coat and the endosperm through inducing hydrolytic enzymes (Schofer and Plachy. 1984).

The efficiency and success of raising plants in a nursery or by direct seeding depends to a great extent on the physical quality of the seed. Colonizers of degraded landscapes may depend on carryover seed banks. However, for most degraded savanna landscapes plants recruit from soil seed banks. The hypothesis tested was that degraded soils have extensive bare soil cover because the seed bank is poor. Thompson *et al*. (2003)) suggest need to test viability of seeds in controlled environments favoring germination. Roads, homesteads, crop fields and animal pens and even grazing lands are at risk from the scouring action of water in the Umfolozi catchment. Previous surveys in the study area investigated the geology, soils, extent of erosion (spatial data), human factors, soil information and agricultural potential of the area (Acocks, 1988, Berjak *et al*., 1986, Botha *et al*., 1994, Botha *et al*., 1995, Watson, 1993). This paper seeks to throw light on the soil hardpan as a major factor hindering germination and soil stabilization. Soil hardpan is a soil that is under-laid by a rock-hard layer of material close enough to the surface to limit the depth plants can extend their roots and to prevent internal drainage of the soil (ucanr.edu/sites/sacmg/files/163130.pdf).

STUDY AREA

The Umfolozi catchment where the study was undertaken covers ten percent of KwaZulu Natal Province in South Africa. The study area lies between 28^{o}00’00” S and 28^{o}10’00” S; 30^o 37’00” E and 30°55′00″E), 28 km southwest of Vryheid town in central KwaZulu-Natal province. The study area (Figure1) falls within Mondlo Communal Land. The study area and the adjacent areas have been described by Rienks *et al.* (2000). The area is underlain by consolidated, bedded sediments of the Masotcheni Formation and by the Vryheid and Volksrust Formations, Beaufort Group and dolerite bedrock (Botha, 1992). The Masotcheni Formation mostly occurs within terrain characterized by concave/convex topography, highly variable relief and slopes less than three degrees (Botha, 1992). The symptoms of soil erosion are mostly in the form of rills, gullies, organ pipe erosion and bare soil. The area is known for extreme temperatures with hot summers and cold winter months. It is a summer rainfall area and the average rainfall of the region ranges from 63% to 217 %. The rainfall is concentrated between the months October and February. Mean annual temperature ranges from 12^{o}C to 23^{o}C. Mean annual minimum temperature ranges from 4-7^{o}C. Frost is a common feature and appears from April to September.

The study area falls within a semi-arid climate (Tyson, 2004). Since the mid 1980’s rainfall patterns have been increasingly variable, when compared with the period 1951-1980 (Dube and Jury 2000, Dube and Jury, 2003, Washington and Preston, 2006). The climate, slope and soil conditions combine to determine the potential of a region or site. Extensive stock farming is an important economic activity in the area. The local farmers rear goats, sheep and cattle. The Umfolozi catchment extends over 10, 075 km^2 (Pitman *et al.,* 1981), the Umfolozi is the second largest drainage basin in the province of KwaZulu Natal. The White and Black Mfolozi rivers rise at altitudes of 1620 and 1524 m a.s.l. respectively in the northwest portion of the catchment and flow over nearly 400 km on their course to the Indian Ocean (Begg, 1988).

The Umfolozi basin contains 11 physiographic, 14 geological, 11 soil, 10 vegetation and eight bioclimatic type categories as identified by Phillips (1973); Kent (1980); Fitzpatrick(1978) and Acocks (1988), respectively. Sheet erosion is variable but is concentrated on the shallow colluvium soils found on outcrops of Dwyka and Ecca Beds of the Karoo Basin. The study area has been previously described by Acocks (1988) Berjak *et al*., (1986), Botha *et al*. (1994), Botha *et al*. (1995), Watson (1993). The vegetation consists of typical Karroo veld (Acocks, 1988). Karoo veld consists of shrub-land with a sparse canopy of small trees of *Euclea, Schotia* and *Boscia* species.

Most grasses have been grazed almost to exclusion and less palatable species such as *Aristida* species (Acocks, 1988) moderate to severe limitations due to soil, slope, temperature or rainfall.

MATERIALS AND METHODS

Soil samples from 10 degraded plots and ten under-graded plots were collected. In each 20x20 m plot, three 1x1 m quadrats were randomly located within a plot. Soil seed bank samples were collected on the outer edge of quadrats within the plots. A volume of 400g soil was placed in each pot. Each pot measured 13 cm diameter and a depth of 7 cm. A soil depth of 4 cm and diameter of 13 cm in each pot was used for seed bank germination tests. Most seeds are known to have some kind of seed-coat dormancy or embryo dormancy or both when they are exposed or buried in the ground until a when time they experience optimal germination (Mott, 1974). The collected seed bank soil **(Figure2)** was subjected to germination tests. Samples were kept in labeled nursery germination pots each with height 7.0 cm, diameter 13 cm and placed in a greenhouse measuring 7 m by 3 m and 2.5 m and managed by the University Of Zululand Department Of Agriculture. This may be deep for such studies. Seeds present in lower levels of the pot may not perceive cues needed for germination (light, or heat), and even if they germinate, they may not have enough reserves to emerge to the soil surface.

The University of Zululand freestanding greenhouse is a Gothic frame structure with a plastic (utility grade Polythene) roof and polythene walls on rigid metal frames; it heats up because incoming solar radiation from the sun warms plants, soil, and other things inside the building faster than heat can escape the structure. Air warmed by the heat from hot interior surfaces is retained in the building by the roof and walls. The greenhouse is located where it gets maximum light with a south west orientation. The site has good drainage. A workplace for potting plants is available. Ventilation is achieved by rolling-up polythene side to allow exchange of air. The temperature range experienced within the greenhouse over the course of study ranged from $15^{o}C$ to $29.4^{o}C$. Carbon dioxide and light are essential for plant growth. The structure is approximately one hectare in size. The greenhouse facility protects plants from too much heat or cold, shield plants from dust storms and strong winds, and help to keep out pests.

The plastic greenhouse regulates temperature. Water was regularly supplied by watering the germination pots to below field capacity. The germination of most tropical plant species tends to be favored by temperatures in the range of 25^{o}-$35^{o}C$. There were two treatments and ten replications. The number of germinated plants in each pot was counted weekly and each seedling was classified as monocotyledon or dicotyledon. Observations lasted 14 weeks and were concluded as soon as the number in the pots began stabilizing or decreasing. Contamination in the nursery was prevented by periodically monitoring three control pots containing sterilized soil distributed among the samples.

The control comprised areas identified as having negligible soil erosion as seen on orthophoto map and an absence of rills and gullies on the ground. The test sites exhibited poor plant cover, pronounced bare soil cover, rills and gullies on orthophoto map and the ground. Depending on the kind of dormancy, the greenhouse ensured that conditions of light, temperature, moisture, etc. were available to germinate seeds from their initial phase of dormancy. The usual factors that affect germination in non-dormant seeds include temperature (constant and fluctuating), light (quantity and quality), substrate moisture, and soil chemical environment (O2, CO2, NO–3, salinity, organic compounds) (Baskin and Baskin, 2004). The ecological role of light quality (including the low fluence, the very low fluence, and the high irradiance responses) and of fluctuating temperatures in germination may have a bearing on recruitment of plants (Baskin and Baskin, 2004). Baskin and Baskin (2004) suggest that the effect of smoke on germination in fire prone sites may be locally important since some plant species flush after a fire event. It is uncertain to what extent climatic warming will have much of an effect on germination, dormancy, or soil seed banks.

The germination pots were watered to below field capacity the first day and thereafter watering was maintained at a level which prevented waterlogging. The soils in the germination pots were irregularly mixed with a trowel to expose bottom soils to light. Depending on the kind of dormancy, light may or may not be an important cue. Heat is more important for some species. Some soils in the pots upon watering developed severe crumbs and compaction after a few days and the crumbs were broken by agitation. Germination was recorded by looking for seedling emergence above ground at weekly intervals. The radicle would go downward into the soil and wouldn't be visible. The part of the seedling that is visible above ground is the cotyledons, the epicotyl; or both. Although radicle emergence is a relatively lax measure of germination, it appears possible to relate it to other measures such as radicle plus shoot growth and viability. The germination of seeds is known to be dependent on both internal and external factors that include temperature, water, oxygen and light (Mott, 1974, Fenner, 2004). Seedling mortality was determined by observing the number of above ground shoots that were killed by unknown factors. Seedling mortality was observed over three months, a period long enough to have competition play a role.

RESULTS

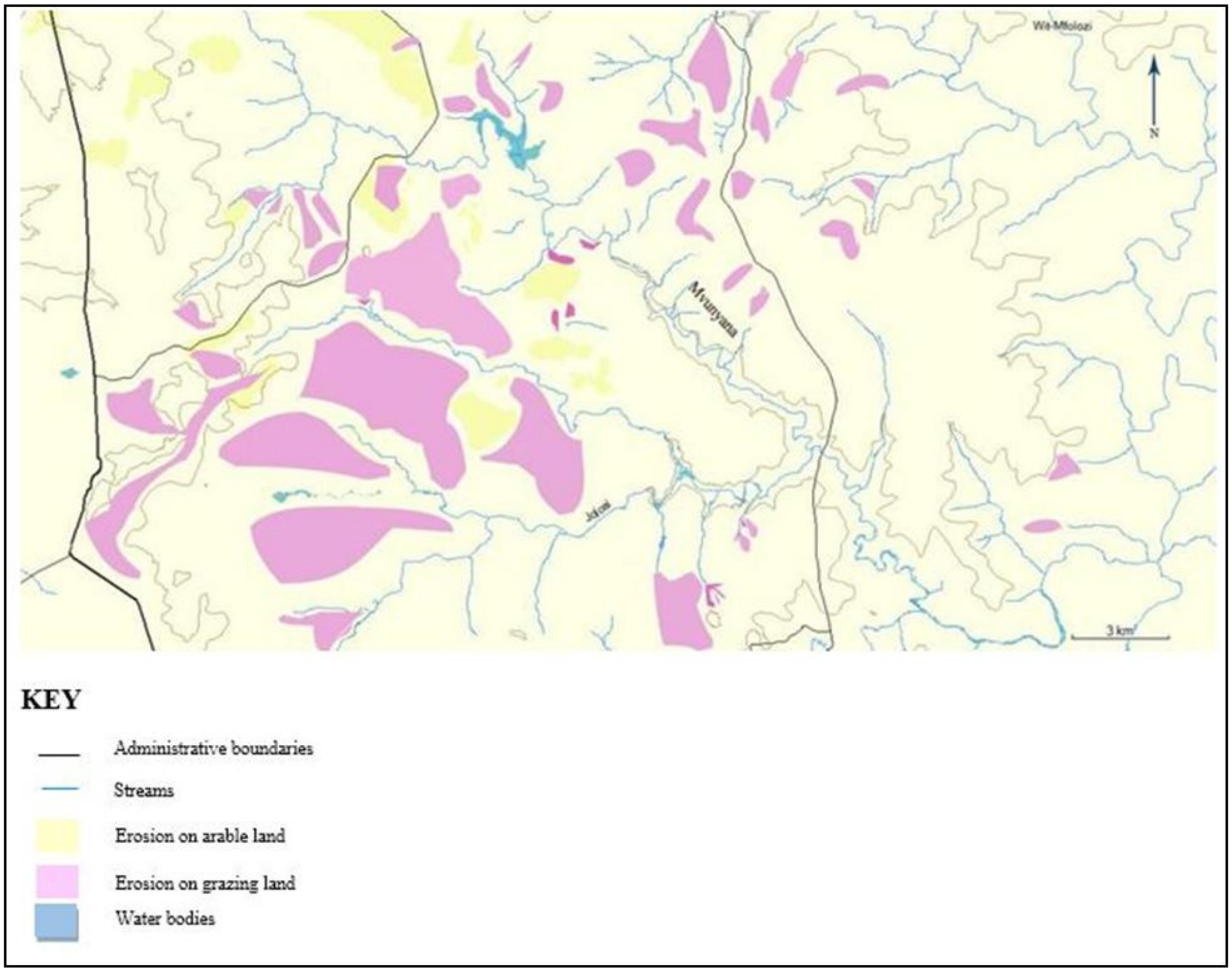

Figure 2: Extent of sheet eroded land in the study area. The yellow hatched eroded lands are encroaching on arable lands whereas the other eroded lands occur in grazing lands

Figure 2 shows the spatial extent of the sheet erosion in the study area. The sheet eroded sites are characterized by low cover of the sward that is associated with reduced resistive and protective forces. **Figure 3** shows extent of sheet eroded land in the study area; the yellow hatched eroded lands on map represent erosion encroaching on arable lands. Much of the erosion is occurring on grazing lands. Soil moisture (%) in the soil samples collected from the degraded sites was 8.94% and 13.48% on un-degraded sites **(Figure 4).** Organic matter content (%) was 3.17% and 5.46% on degraded and un-degraded sites, respectively **(Figure 5).** Bulk density (g/cm^3) was 0.99 g/cm^3 and 0.83 g/cm^3 on degraded and un-degraded sites, respectively **(Figure 6).** Seedling density was 18 seedlings per 52 cm^3 in soil samples collected on degraded sites and 10 seedlings per pot on un-degraded sites. Seeds from deep in the pot may not have received the cues for germination, or seedlings may not have been able to emerge when buried at greater depth. Seedling mortality (no/pot) was 17 seedlings per pot and nine seedlings per pot in the soil samples collected on degraded and un-degraded sites, respectively. Seedling mortality was observed over three months, a period long enough to have competition play a role. Seedling density was almost twice as high in the pots from degraded soils in germination pots, and this could make a difference on survival between sites in poor and good condition.

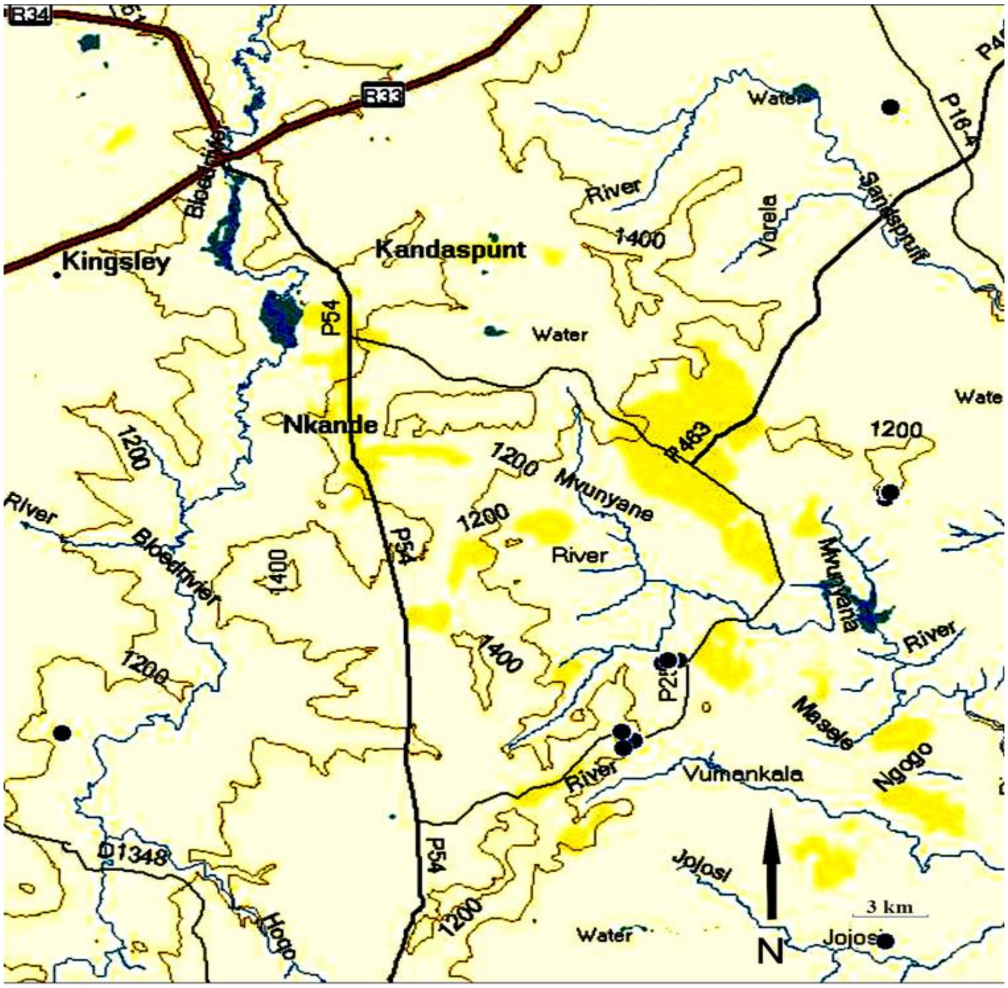

Figure 3: Location of sheet eroded land and sampling sites in the study area

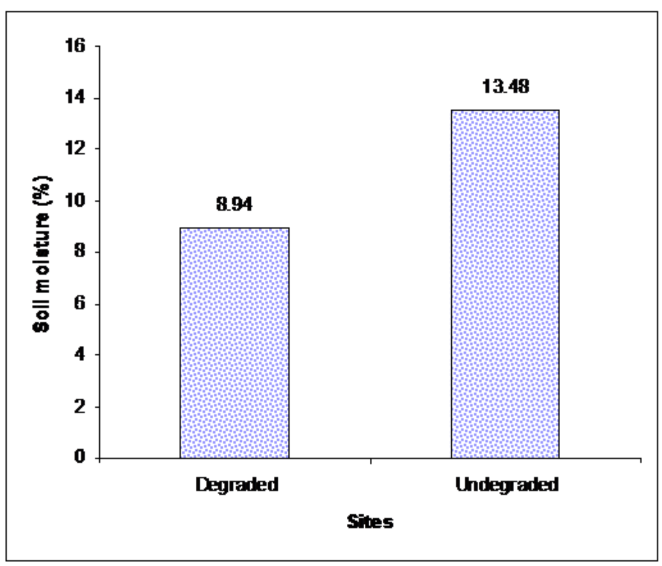

Figure 4: Soil moisture (%) in the soil samples collected from the degraded and under graded sites

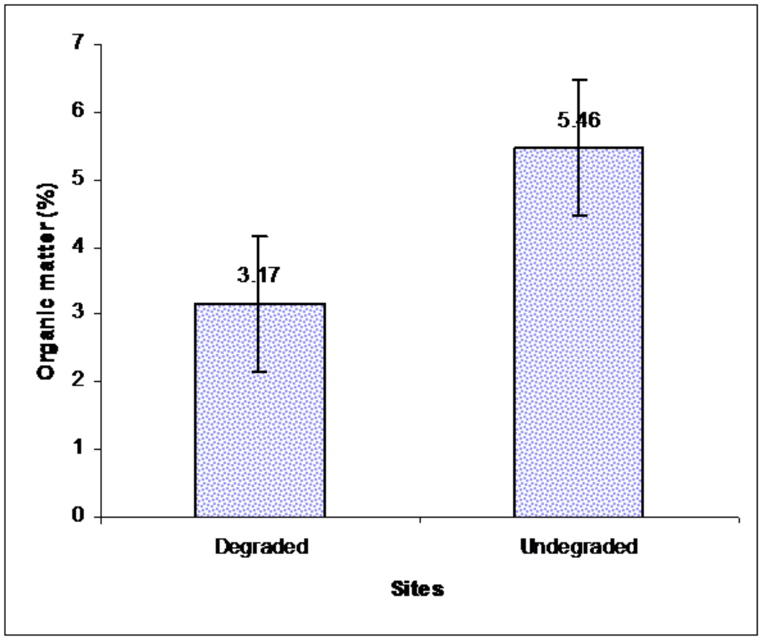

Figure 5: Organic matter (%) in the soil samples collected from the degraded and under graded sites

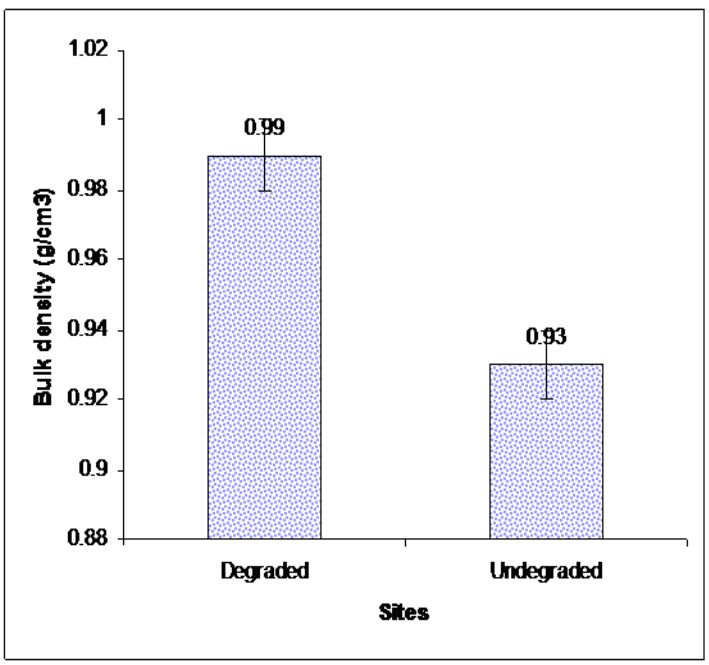

Figure 6: Bulk density (g/cm3) of the soil samples collected in the degraded and under graded sites (Student T Test, $p<0.05$, df=8)

Seedling density was the mean total number of seedlings per pot that appeared over the course of the trials. Seedling mortality was the fate of seedlings that germinated. The 18 seedlings per pot that appeared in degraded sites, 17 of them died **(Figure8).** The 10 seedlings per pot that appeared on un-degraded sites, 9 of them died **(Figure8)**.

It appears that the density of viable seeds was higher in degraded than in un-degraded sites. Soil moisture (g) and soil organic matter content were

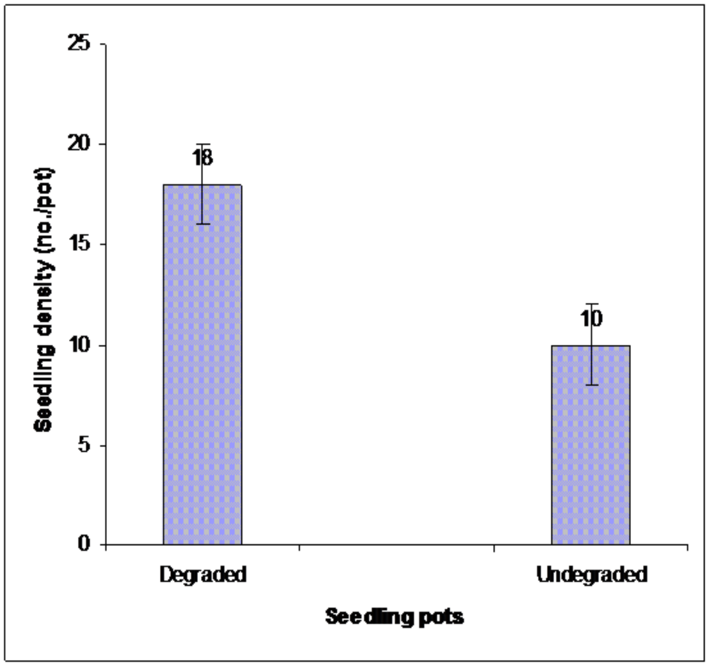

Figure 7: Seedling density (no/pot) in the soil samples collected in the degraded and under graded sites (Student T Test, p<0.05, df=8)

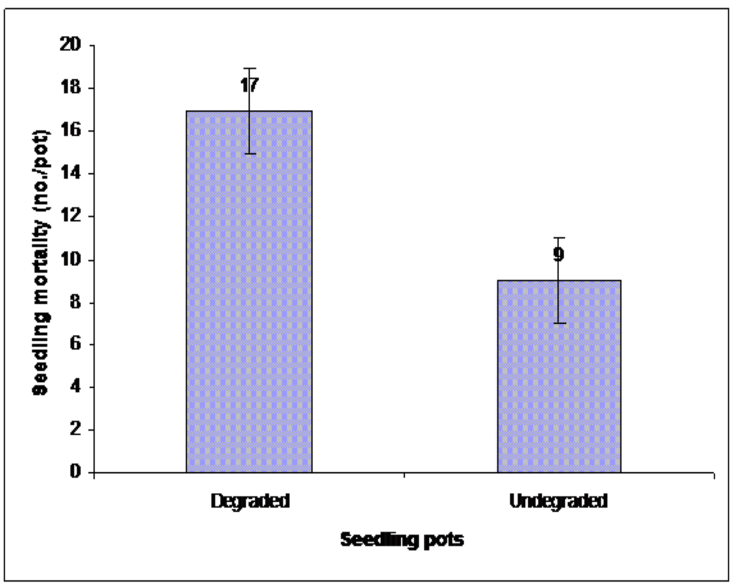

Figure 8: Seedling mortality (no/pot) in the soil samples collected in the degraded and under graded sites (Student T Test, p<0.05, df=8)

significantly different between degraded and un-degraded sites **(Table 1).** Spearman rank correlation showed strong positive correlation between successful seedling density and soil compaction ($r = -0.481$, $p<0.05$) **(Table 2).** Soil bulk density was significantly higher on degraded sites than un-degraded sites ($p<0.05$). Plant species germinating in nursery pots in the university greenhouse showed a mix of species including woody plants, grasses and forbs **(Table 3).**

Density of emerged seedlings (no/pot) reached higher levels on degraded sites than on un-degraded sites **(Figure 6).** Seedling mortality (no/pot) reached highest level on degraded sites **(Figure 7)** but in percentage terms this does not appear to be true**.** In five pots, including soil samples from both degraded and un-degraded sites, no seedlings germinated in pot numbers 5, 6, 5, 27 and 30.

Table 1: Summary of t-test results of Soil moisture (g) and soil organic matter obtained from the degraded and under graded plots of the Umfolozi catchment (*=P<0.05)

	Mean		t-value	Sig.
Variables	Degraded	Under graded		
Soil moisture, g	8.99	14.22	3.466	*
Soil organic matter, g	2.91	4.77	1.834	*

Table 2: Spearman rank correlation between seedling density and soil physical properties (*=P<0.05; NS=Not significant)

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

Table 3: Plant species germinating in nursery pots in the University Greenhouse facility (n.r=not recorded).

Degraded	site	Under graded	site
Pot	Plant	Pot	Plant
1	weed	2	weed
3	woody	4	Grass
6	n.r.	5	n.r.
10	grass	11	Grass
16	grass	15	Grass
18	woody	17	Woody
19	grass	21	Woody
20	weed	28	Grass
27	n.r.	30	n.r.
29	weed		

DISCUSSION

The hypothesis that the **"lack of plant establishment on degraded sites was due to the poor and sterile nature of the soil seed bank"** is not supported. Soils from the degraded sites appear to have had higher densities of viable seeds than soils in the un-degraded site. There are differences between sites in the number of seedlings (and of seeds), and the sites also differ in soil compaction. The proportion of seeds that germinated successfully was affected by soil compaction that probably constricted the young roots. The study shows a high negative correlation between seedling density and soil compaction. Degraded sites recorded higher seedling mortality compared to un-degraded sites in germination pots. Soil compaction has important hydrologic implications in terms of its contribution to reduced infiltration rates, and increased runoff potentials (Gifford *et al.*, 1977). Soil compaction occurs when weight of livestock or heavy machinery compresses soil, causing it to lose pore space. Soils with high levels of compaction become less able to absorb rainfall, thus increasing runoff and erosion. In essence soils with reduced organic matter easily get compacted due to reduced microbial activities and cation exchange capacity (CEC) exchange capacity responsible loosening up soils. Semi-arid regions have low inherent nutrient reserves and rapid acidification. In organic-matter depleted soils, these nutrients would be lost from the system through leaching and runoff (Sombrero and de Bento, 2010). Organic matter retains plant nutrients and prevents them leaching to deeper soil layers. Microorganisms are responsible for the mineralization and immobilization of N, P and S through the decomposition of organic matter (Sombrero and de Bento, 2010). With an increase in organic matter, the soil recovers its natural buffer capacity. CEC is linked closely to the organic matter content of the soil. It increases gradually with time where organic residues are retained, first in the topsoil and later also at greater depth.

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 respiration and other processes which facilitate growth such as mitosis and morphogenesis. Degraded sites have low organic matter content because plant cover is low due to lack of establishment being exacerbated by limited numbers of saprophytes in the soils which mobilize soil nutrients to be readily available for plants. High correlations between the natural regeneration of vegetation and carbon content and soil density have been recorded by Takahashi (1998). The high mortalities among the seedlings in degraded soils may be attributed to poor water holding capacities, compaction and topsoil erosion caused by soil erosion which in turn reduced the water infiltration rate. There were more monocotyledons than di-cotyledons germinating in the soils in the pots. It is not clear in the study to what extent competition played a role in seedling mortality.

The increasing and continuous use of degrading landscapes lead to long time to recover while some degraded landscapes deteriorate to worse conditions (Magro, 2003). Seed banks of degraded landscapes in the Umfolozi catchment are viable but once germinated the seedlings are challenged by physical conditions such as compaction and bulk density causing significant (*t*-test, $p<0.05$) diebacks. Almost all species had at least some seeds which were dormant, consistent with the idea that risk spreading is important in arid zones. Jurado and Westoby (1992) were of a different view to the soil density hypothesis. Faster germination tended to be associated with low germinability, suggesting a spectrum of strategies from species that risk a small number of their seeds in many rainfall events, to those that germinate only in large rainfall events but then risk large numbers of seeds (Jurado and Westoby, 1992). 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 population dynamics in fragile environments to capture unusual extreme events.

The conditions needed for germination are known to vary considerably between different species and even between different populations of the same species. Welbaum *et al*. (1998) suggested that biophysical, physiological and biochemical processes regulate seed germination. Seed dormancy increases the chances that germination will occur at a time and place most advantageous to the seedling. Seed coat dormancy may be caused by thick seed coat, thin coat, insufficient development, inhibitor, Abscisic acid and inhibitor phenolics. Thick seed coat is overcome by scarification, animal gut digestion, fire, pre-chilling and thaw cycles; thin seed coat by light or darkness, insufficient developments by soil fungus association; inhibitor or Abscisic acid by stratification (e.g. temperature weeks at 4^{o}C) and vernalization and, inhibitor phenolics by leaching or repeated rain. Plant hormones in the soil may signal sensitivity changes and responses. When the conditions are right, the seed is imbibed and bursts open for a new seedling to grow out. Soil seed bank persistence invariably stabilizes plant population dynamics.

The timing of germination is closely tied to physiologically determined temperature and water potential thresholds for radicle emergence which vary among individual seeds in a population (Welbaum *et al*, 1998). 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). The assumption is that when water is available plants tolerate compacted soil. Mott and McComb (1974a, 1974b) established that dormancy is lost after high temperature storage an indication that critical temperatures for germination may have not been reached for some seeds in this study.

The ability of a soil to recover from compaction has been attributed to climate, mineralogy and fauna (Lortie and Turkington, 2002). 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. Four pots (6;27 and 5;30) with soil samples collected from the degraded sites and un-degraded sites failed to germinate probably due to degenerated seed embryo DNA or challenges from disease, insect attack, overwatering and poor soil conditions. Some seed bank seeds germinate only after a fire has burnt the surface earth and some seeds germinate after passing through the gut contents of animals (Radford *et al*., 2002). High seed quality and good seedling establishment are of equal importance in protected cropping, amenity horticulture, forestry and forest restoration. Little is known about how dormancy is controlled at the molecular level or how dormancy mechanisms interact with the soil environment to determine patterns of seedling emergence. Physiological seed dormancy is present throughout the higher plants and has profound impact on structure of plant communities in the natural environment.

The low survival of seedlings reported in this study suggests that the physical and chemical properties of the soils are a constraint to the initial growth and establishment of seedlings. Semi-arid regions have low inherent nutrient reserves and rapid acidification. In organic-matter depleted soils, these nutrients would be lost from the system through leaching and runoff

(Sombrero and de Bento, 2010). Organic matter retains plant nutrients and prevents them leaching to deeper soil layers. Microorganisms are responsible for the mineralization and immobilization of N, P and S through the decomposition of organic matter (Sombrero and de Bento, 2010).With an increase in organic matter, the soil recovers its natural buffer capacity. CEC is linked closely to the organic matter content of the soil. It increases gradually with time where organic residues are retained, first in the topsoil and later also at greater depth. This paper seeks to throw light on the soil hardpan as a major factor hindering germination and soil stabilization).

Other physical conditions regulating the growth of seedlings have implicated fire. The role of fire in seed germination has been recorded as the action of heat in breaking hard seed coats (Kenny, 1999). 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 60-120^{o}C with an optimum between 80-100^{o}C. *Colophospermum mopane* (Benth.) Leonard 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., 2002), results which tend to agree with the findings in this study. The data show that water (Rainfall) is an important determinant of seedling recruitment in the savanna rangeland. The addition of soil treatments and protection from herbivore in early growth stages should increase emergency of seeds from the seed bank and proffer soil stabilization and restoration. The study leaves gaps of nutrients and a *de-novo* approach is required. The role of nutrients is poorly understood. This could form the basis for the next step required to be taken in the study area. This paper seeks to throw light on the soil hardpan as a major factor hindering germination and soil stabilization.

CONCLUSION

The sheet eroded soil hardpans of the Masotsheni Formation have limited potential for the establishment potential of plant species due to the severe soil compaction. The study provides critical understanding relevant to stabilization and restoration of the supercritical degraded Umfolozi catchment and other similarly affected areas elsewhere.

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