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ORIGINAL ARTICLE

The nature of soil erosion and possible conservation strategies in Ntabelanga area, Eastern Cape Province, South Africa

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ABSTRACT

Soil erosion is a major land degradation problem in South Africa (SA) that has economic, social and environmental implications due to both on-site and off-site effects. High rates of soil erosion by water are causing rapid sedimentation of water bodies, ultimately leading to water crisis in SA. Lots of financial and human resources are channelled towards controlling of soil erosion but unfortunately with little success. The level of soil erosion in a particular area is governed by the site properties. Therefore, it is inappropriate to generalize data on soil erosion at a large-scale spatial context. The literature on soil erosion in SA classifies Eastern Cape Province as a high-erosion-potential area using data collected at a large-scale spatial context. Collecting soil erosion data at a large spatial scale ignores site-specific properties that could influence soil erosion and has resulted in failure of many traditional soil erosion control measures applied in the province. Moreover, scientific principles underlying the processes and mechanisms of soil erosion in highly erodible soils are missing in SA. This review was to find effective soil erosion control measures by having an insight on what happens during soil erosion and how soil erosion occurs in Ntabelanga. The literature suggested that erosion in Ntabelanga could be influenced by both the erosivity and erodibility factors though the erodibility factors being more influential. Soil permeability contrast between the horizons could be influencing the rate and nature of soil erosion. To mitigate the impact of soil erosion in Ntabelanga, efforts should aim to improve the vertical flow capacity in the B horizon. Clay spreading, clay delving, addition of gypsum, deep ploughing and mulching could aid the water permeability problems of the subsurface horizons. However for effective soil management and control option, detailed studies of specific site properties are needed. The generated information can assist in formulating soil erosion policies and erosion control strategies in the Ntabelanga area and SA at large.

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Water; erosion; processes and mechanism; control; permeability; vertical flow

Introduction

Soil erosion is an important form of land degradation and is among the world's and South Africa's most critical environmental issues (Le Roux et al. 2008). Rates of soil loss are high in South Africa (SA) which are estimated at 300–400 million tonnes, nearly three tonnes for each hectare of land (http://www.botany.uwc.ac.za). Compared to Australia, the average predicted soil loss for SA is three times as much as that estimated (4.1 t/ha.yr) by Lu et al. (2003). The high rates of soil loss in SA are due to the scant vegetation cover caused by overgrazing (Laker 2004) and low soil organic carbon (SOC) (Du Preez et al. 2011). The limited available data show that South African soils are characterized by very low organic matter levels (Scotney & Dijhuis 1990). According to Du Preez et al. (2011), only a small percentage (4%) of the South African soils contains more than 2% organic carbon. SOC concentrations are often cited as major indicators of soil quality. It is agreed that SOC values of 2% SOC (equivalent to 3.4% SOM) is an upper threshold, below which most soils are prone to structural destabilization (Howard & Howard 1990; Janzen et al. 1992).

Garland et al. (2000) indicate that more than 70% of SA is affected by varying intensities of soil erosion. Although the present soil erosion rates in SA are still poorly constrained, Eastern Cape Province is the most severely affected (where the average annual soil loss rates exceeds 12 t/ha.yr) (Le Roux et al. 2007). Soil erosion not only involves the loss of fertile topsoil and reduction of soil productivity but is also coupled with serious off-site impacts related to increased mobilization of sediments and delivery to rivers and dams. Flugel et al. (2003) state that eroded soil material leads to sediment concentrations in streams which affects water use and ecosystem health. For instance,

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in SA, the storage capacity of the Welbedacht Dam near Dewetsdorp in the Free State was rapidly reduced by more than 86% from its original storage capacity within 20 years since its completion in 1973 (DWA 2013). The siltation problem is exacerbated by the inherent erodibility of the parent materials in SA that give rise to erodible soils (Laker 2004). The soil sedimentation problem may get worse in the future due to population and climatic changes (Le Roux et al. 2008). Considering the increasing threat of sedimentation of water bodies, it is important to identify source areas and key processes and nature of erosion in an area.

The data on the rates of soil erosion in SA were obtained at a large-scale spatial context using geographical information systems (GIS) and remote sensing techniques (Le Roux et al. 2007). Collecting data on soil erosion using such techniques poses challenges on devising soil erosion control options in an area. The techniques used overparameterize and have misleading parameter values in the local context and lack of verification data therefore tend to give a general understanding of soil erosion in the spatial context. Furthermore, these techniques just detect severely eroded bare areas but cannot identify the nature of erosion and intrinsic soil properties influencing the erosion (Pretorius 1998). In terms of soil erosion management intervention, it is especially important to highlight areas that are intrinsically susceptible to erosion.

Le Roux et al. (2007) stressed that erosion data from GIS and remote sensing give a broad overview of the general pattern of the relative differences between soil loss and sediment yield and not accurate absolute erosion rates. Rates of erosion can also be determined by measuring volume of sediments collected in water bodies but this has limitations on soil erosion data. Research findings suggest that soil loss within a catchment can be five times greater than sediment yield due to the reduction in the total eroded volume by deposition. With such understanding it is noteworthy that differences between sediment yield and soil loss can be very high. Laker (2004) noted also that erosion research methodologies have been diversified over the preceding few decades but the methods used and the results produced are not comparable with each other. These problems hinder successful soil erosion risk assessment and development of site and scale-specific control measures to reduce and prevent soil erosion in SA.

Soil erosion is highly variable in time and space, which makes it difficult to base an assessment on data collection methods that generalize soil properties on a very large area. Soil erosion depends on many site properties, such as soil erodibility, topography and rain erosivity, all known to change over short distances. The current literature shows the importance of intrinsic soil and site properties on soil erodibility (Amezketa et al. 2004; Igwe 2005; Yan et al. 2010). However, due to how soil erosion data are obtained in the Eastern Cape Province, a general approach is used when managing and controlling soil erosion. Ignoring of specific site properties when devising soil erosion controlling options results in implementation of ineffective measures against the problem. Soil erosion is highly variable in time and space, which makes it difficult to base an assessment on data collection methods that generalize soil properties on a very large area. Therefore attention is needed at specific sites on what happens during soil erosion and how it occurs for effective controlling of soil erosion.

The government of SA under the Department of Water Affairs (DWA) has proposed to build a multipurpose dam along Tsitsa River in Ntabelanga. Soil erosion data collected at the large spatial context characterized the soils in the area as highly unstable and easily erodible. Efforts to control the rates of soil erosion in the area are failing (Laker 2004), which suggests that they could be more site-specific properties that have to be determined before prescribing effective controlling options. Currently there are limited data if any on the specific soil characteristics and they influence rates and nature of soil erosion. The area is in the sub-escarpment grassland and sub-escarpment Savanna bioregions (Mucina & Rutherford 2006). It is dominated by grasslands and *Acacia* is the most common tree. Surprisingly the sub-humid grasslands suffer from severe gully erosion even with their dense grass cover (Sonneveld et al. 2005), which suggests that soil erodibility is more influential to soil erosion than erosivity.

Ntabelanga is underlain by sedimentary rocks of the Tarkastad subgroup of the Beaufort of the karoo supergroup and post-karoo dolerite intrusives. There are also traces of mud flake conglomerates. The area is characterized by highly unstable soils that are prone to erosion, as evidenced by extensive areas of severe gully erosion on the inter-fluvial areas adjacent to stream channels (Van Tol et al. 2014). The erosional and piping characteristics in Ntabelanga are suggestive of the presence of dispersive soils (DWA 2013). Duplex soils are highly sensitive to erosion. Therefore in an attempt to find effective soil control measures in Ntabelanga, a review on the processes and nature of erosion with a bias towards the duplex soils was done.

Duplex soils

Cox and Pitman (2002) described duplex soils as having a subsoil (B horizon) at least one and a half texture groups finer than the surface soil (A horizon), with a clear boundary between surface and subsoil. Duplex soils are widespread in SA and characterized by strong and abrupt textural differences between A (or E) and B horizons. According to Fey and Gilkes (2010), more than 80% of the country is covered by duplex soils and at least 90% of the soils found in the Eastern Cape Province. The contrast in clay content between A and B horizons can be as high as 1: 10 and can occur over a distance <2 cm (Fey & Gilkes 2010). Often, duplex soils have high ionic strength and pH, impoverished acid clays or bleached infertile subsoil horizons of high bulk densities. The texture contrast in a duplex soil can be the result of clays breaking down at the interface of the A and B horizons with the infill at the top of the B horizon being clays either translocated from the A horizon or synthesized in situ (Cox & Pitman 2002). As a result pores of the subsoils are often blocked with clay (Verboom & Pate 2006) which lowered the hydraulic conductivities (K) of the B horizon.

High levels of exchangeable sodium and sometimes magnesium are also common especially in the prismacutanic forms and in those families of pedocutanic forms that are macropedal (Fey & Gilkes 2010). Salinity may be evident in the more arid duplex soils, especially within or immediately below the B horizon. While data on the chemical properties of these soils are limited, significant datasets on the physical properties of duplex soils are available from several studies of catchment hydrology (Cox & Pitman 2002). Duplex soils are notorious for their limitations, including salinity/sodicity hazards, crusting and poor infiltration rates (Seitlheko 2003). The duplex soils also have slow internal drainage, waterlogging and poor aeration at depth (Cox & Pitman 2002). Hardsetting behaviour (Fey & Gilkes 2010) is commonly displayed by the duplex soils. Often the duplex soils are low in organic matter and sesquioxides and high in dispersive clay (Hardie et al. 2012). Upon drying, duplex soils have a tendency of becoming hard, structureless and slump on wetting (Seitlheko 2003). Significant quantities of water can travel as throughflow on top of the B horizon on sloping duplex soils (Hardie et al. 2012). This increases the risk of waterlogging and salinity in the lower parts of the landscape (Seitlheko 2003). Waterlogging of the duplex soils has been shown by Cox and Pitman (2002) to be because of lack of vertical flow capacity in the B horizon, causing ponding above the boundary between the A and B horizons. Duplex soils can then be typified by ponding of water above the ground appearing as swamps especially during the rainy season (Seitlheko 2003).

Many researchers agree that duplex soils are associated with a range of management problems, including waterlogging, crusting, desiccation, wind erosion, water erosion, tunnel erosion and salinity (Tennant et al. 1992; Edwards 1992; Cotching et al. 2001). Duplex soils are particularly susceptible to land degradation when cleared (Cox & Pitman 2002). Degradation on duplex soils is exacerbated by the development of fluctuating perched water table on slowly permeable subsoil horizon (Cox & Pitman 2002).

The literature suggests that many management strategies of duplex soils were developed mainly from Australian soils (Cotching et al. 2001; Cox & Pitman 2002) and may not be applicable to South African situations. Henceforth much is yet to be done to develop management strategies in Southern African soils (Seitlheko 2003). The physical properties of duplex soils suggest that structures resulting to retention of large amounts of water could increase the risk of erosion, since more water would be fed into the internal drainage system of the soil (Cox & Pitman 2002). This will be a major threat to the proposed Ntabelanga dam. More information to understand the nature and mechanisms of erosion Ntabelanga is required. The failure of some mechanical soil erosion control options in the Eastern Cape Province (Laker 2004; Machado et al. 2010) means that different approaches to control the soil erosion are required.

Mechanisms of soil erosion and water movement in duplex soils

Water movement and soil erosion in duplex soils

Seitlheko (2003) demonstrated that subsurface flow occurred as a two-component system consisting of both rapid macropore flow and slow matrix flow between the A–B horizons. Macropore flow via vertical cracks resulted in rapid saturation of the profile base ahead of a slower moving wetting front in the soil matrix. Cox and Pitman (2002) showed that the development of perched water-table was short lived due to the presence of interconnected pipes at the soil–bedrock interface. In another research by Hardie et al (2012), subsurface lateral flow resulted from vertical transport of rainfall from the soil surface to the B horizon interface by preferential flow.

Duplex soils have a limitation of uneven wetting front and limited water infiltration through the profile due to the presence of non-wetting sands (Hardie et al. 2012). Because of the hydrophobic properties of these sands, water infiltrates the soil profile through particular paths known as finger flows. Finger flows do not depend on soil structure but rather on the hydrophobic behaviour of the sand (Hardie et al. 2012). As a result of this process, water usually bypasses a large area of the profile, leaving areas with dry soil. The limitation caused by non-wetting sand on water infiltration is often the cause of soil erosion due to run-off (Cox & Pitman 2002). If compared to soils with gradational profiles, in duplex soils the sharp boundary between the two horizons separates areas of the profile with extremely different physical properties. Seitlheko (2003) identifies the low permeability of the B horizon as a property which has a major impact on the behaviour of duplex soils. Cotching et al. (2001) described the problem with duplex soils as 'permeability contrast' dependent rather than 'texture contrast' dependent. In effect, most of the concerns within duplex soils appear to be consequences of their peculiar hydraulic properties (Hardie et al. 2012).

Duplex soils are common in SA landmass and occupy at least 90% of soils in the Eastern Cape Province (Fey & Gilkes 2010). Nevertheless, little is known of their hydrology. Conventional understanding of the mechanisms by which infiltration and soil water movement occurs assumes uniform soil structure and equilibrium flow conditions (Hardie et al. 2012). In duplex soils, development of perched water-tables and subsurface lateral flow is generally believed to result from rainfall and infiltration through the A horizon rate which exceeds the hydraulic conductivity of clay subsoil (Brooksbank et al. 2011). Subsurface lateral flow is a common feature in duplex soils. Hardie et al. (2012) defined the subsurface lateral flow as soil water processes in which infiltration water accumulates and moves laterally downslope along the upper surface of a less permeable layer in the soil. The subsurface lateral flow in hillslopes may occur as saturated, unsaturated or macropores (Brooksbank et al. 2011).

The macropores and soil water status are important to the development of subsurface lateral flow and solute movement. Macropores prevent formation of perched water tables and subsurface lateral flows in duplex soils. Hardie et al. (2012) found that soil macroporosity and bypass flow were responsible for preventing subsurface lateral flow at the A–B horizon boundary. Traditional concepts of soil water movement ignore the existence of preferential flows in which infiltration bypasses the majority of the soil matrix resulting in deeper and more rapid soil water movement than would otherwise be expected (Cotching et al. 2001). In some cases, the distinct textural boundary within the profile would not act as a control to vertical infiltration, instead resulted to subsurface lateral flow lower in the profile. The subsurface lateral flow occurred along the soil–rock interface rather than the boundary of the A and B horizons (Cox & Pitman 2002; Hardie et al. 2012).

Researches have demonstrated that infiltration into the duplex soils is more complex than any other soil reported in the literature (Hardie et al. 2012). When dry, infiltration resulted from up to five different forms of preferential flow, including finger flow in the A1 horizon due to water repellence in dry soil conditions, funnel flow in the A2 horizon and sand infills, rivulet flow down the side of the clay columns or within shrinkage cracks in the B2 horizons, and macropore flow through biopores in the A and B2 horizons (Cox & Pitman 2002; Seitlheko 2003). However, when soil moisture was near field capacity, wetting front instability and lateral flow developed in the A1 horizon due to difficulty displacing existing soil moisture further down the soil profile following swelling of subsoil clays (Seitlheko 2003).

Mechanisms of erosion by water in duplex soils

In duplex soils, the subsurface horizons usually have less permeability than the overlaying horizons (Hardie et al. 2012). The differences in permeability between the two layers are often cited as one of the main reasons why gullying is so common in duplex soils (Van Zijl et al. 2013). Gully erosion in duplex soils has shown to occur either through surface flow, which cuts into the soil, or by piping, where the subsoil is dispersed and removed by free water under the soil surface (Van Zijl et al. 2013). With surface run-off gullies, the amount of overland run-off plays the most important role. Such gullies will follow topographical drainage lines, where run-off accumulates and the gully is formed at the confluence of two incipient drainage lines (Seitlheko 2003). For piping to occur, there has to be accumulation of free water in the B horizon, a dispersive soil and an outlet for this free water (Hardie et al. 2012). Gullies formed from piping will not follow the topographic drainage lines, but rather the system of cracks in which the pipes formed. Although such explanations for gully formation in duplex soils exist, it is important to note that initiation of gullies is a complex, cyclic phenomenon, governed by localized thresholds influenced by intrinsic and extrinsic variables (Van Zijl et al. 2013). Therefore it is difficult to identify the cause of gully formation, however, one can define the first-order controls of gully formation by analysing the spatial variability of erosion features and controlling factors (Seitlheko 2003).

Piping and erosion in duplex soils

The layer below the B horizon (C horizon) contains lower amount of clay and organic matter than the B horizon in a typical duplex soil profile (Cox & Pitman 2002). As a result there is a formation of less stable aggregates in the C horizon than the B horizon. The C horizon is therefore more erodible than the B horizon (Seitlheko 2003). As downcutting of the gully occurs the running water eventually reaches the C horizon and begins to undercut the more resistant layer (the B horizon) above, leading to the formation of an overhang (Van Zijl et al. 2013). The continued undercutting eventually leads to the collapse of the overhang, thus expanding the gully.

It is important to know the mechanism of gully formation in duplex soils, as it will determine which steps could be taken to ameliorate the problem. When surface run-off causes gully erosion, one would like to decrease the amount of run-off. Check dams and contour walls will be good measures (Morgan 2009). However, if piping through subsurface flow caused gullying, then one must avoid the concentration of free water in the subsurface layers of the soil (Seitlheko 2003). In this case, check dams and contour walls will exacerbate the problem rather than curbing. What will be the fate of the proposed Ntabelanga dam in this regard? Since a considerable percentage of soils in Ntabelanga are duplex (DWA 2013).

Salinity and sodicity effects on water movement in duplex soils

Sodicity is considered to be an intrinsic property of the clay fraction of an affected profile. Its full impact may be revealed through interactions with hydrological processes, resulting in various forms of both on-site and off-site environmental degradation (Qadir & Noble 2006). Salinity in duplex soils is attributed to rising groundwater from excess water accumulation in the less permeable B horizon (Hardie et al. 2012). The surface horizons of duplex soils are often waterlogging due to perching of soil water within the B-horizon and it is likely that interpedal cracks and old tree root holds act as preferred paths for water to flow through the first restricting layer (Van der Merwe et al. 2001). A second fresh-perched water table can occur on top of the pallid zone and the permanent saline water table occurs on top of bedrock and causes salting problems where it comes too close to the soil surface (Bann & Field 2010). Salting problems at the bottom of a slope were observed to be more severe where fresh-perched water tables increase waterlogging. Studies and insurgent management activities suggest that increased soil salinization is a symptom attributed to localized surface water problems and soil and vegetation degradation (Qadir & Noble 2006; Bann & Field 2010). Sodicity often coincides with the distribution of duplex soil profiles. At higher elevations lateral seepage resulted in a decrease in the electrolyte concentration of the soil solution while exchangeable sodium percentage (ESP), an inherent constituent of duplex soils accumulates to a greater extent (ESP > 15%) than calcium or magnesium (Bann & Field 2010). The development of sodicity led to clay swelling and dispersion, contributing to the degradation in both top and subsoils of an inherently weak structure (Hardie et al. 2012).

Strategies to enhancing water movement in the subsurface horizons to control in duplex soils

The major challenge with the duplex soils is the development of perched water-tables and subsurface lateral flows due to the textural or hydraulic conductivity discontinuity between the A and B horizons (Hardie et al. 2012). Some studies have also indicated the preferential flow and spatial and temporal variations in hydraulic conductivity of the upper B horizon. This may influence whether infiltration water accumulates at the A–B horizon boundary or is distributed further down the soil profile (Van der Merwe et al. 2001). Therefore any strategy to enhance water movement within the duplex soil profiles must aim to improve the infiltration between the A–B horizon boundaries.

The most common approach for correcting water repellent sands in duplex soils is through addition of clay to the sandy top soils (Cann 2000). Two different approaches are usually used: clay spreading or clay delving (Davenport et al. 2011). Clay spreading is where clay from a different area of the field is transported and spread over the soil surface. The clay spreading technique was the first successful large-scale method for the treatment of water repellent sands in Australia (Cann 2000). Duplex soils are characterized by poorly structured soils in the A horizon so clay spreading improved the structure. However clay spreading could be expensive especially if the source is located far from the area to be treated (DEFRA 2005).

Clay delving is a technique of improving non-wetting soils by ripping clay from depth and incorporating it in the top layers (Cann 2000). For successful delving operations, growers need to know the precise location and depth of clay layers (Simeoni 2009). Clay delving has additional advantages in the amelioration of sandy top soils with poor properties. In clay delving, it is possible to achieve deeper mixing of clay through the soil profile and the breaking of hardpans usually present at the top of the B horizon in duplex soils (Simeoni 2009). Clay delving causes a drastic modification of duplex soils and produces soil profiles morphologically very distinct from their original ones. Clay delving strongly modifies the soil profile, disrupting the interface between A and B horizons and mixing clay subsoil in the top soil. Cann (2000), Simeoni (2009), noted an increase in the infiltration rate by 11% + on the B horizons of delved than on undelved duplex soils.

Some researches of permeability experiments and drainage trials have showed that duplex soils responded well to gypsum and improved in drainage (Cann 2000; Van der Merwe et al. 2001). In these experiments, attention was paid to both surface and subsurface drainage. Based on these studies, in Swaziland, the gypsum amelioration policy was expanded to include the application of filtercake at plough out recognized the benefits of organic matter (Meyer & Antwerpen 2010). Van der Merwe et al. (2001) also recommended the use of gypsum and organic matter in Mpumalanga duplex soils to reduce sodicity and improve on their water permeability. Meyer and Antwerpen (2010) also showed that deep ploughing improved permeability of the B horizon in sodic duplex soils. Enhancement of permeability on the duplex soil was also successfully achieved through vertical mulching (Meyer & Antwerpen 2010). Vertical mulching was successfully used in improving movement of water and air within heavily compacted soils (Simeoni 2009). Studies in Australia have shown that vertically mulched slots maintained higher air-filled porosity values between irrigations due to faster moisture redistribution (Meyer & Antwerpen 2010).

Deep tillage and vertical mulching (Meyer & Antwerpen 2010) have been successfully demonstrated to improve water permeability in the B horizon of duplex soils. Deep tillage has shown to improve the water movement through faster infiltration and greater depth of wetting in the B horizon. However deep tillage on its own only partly improves permeability of the B horizon because the fragments formed from tillage will still have the hydraulic properties of the original massive clay layer (Cann 2000). That is, they store little water and have a high resistance to water flow. Currently, there are few if any trials where deep tillage and vertical mulching in duplex soils were done to improve water permeability of B horizon at large scales (DEFRA 2005). Deep tillage and vertical mulching might be difficulty to apply to a large lands scenario. Deep tillage can be negatively affected by the nature of the land terrain and can accelerate soil erosion on slopy areas (DEFRA 2005). Clay spreading (Cann 2000) and vertical mulching proved ideal at small-scale areas; however, the availability of the filler materials or distance from the source of filler materials could be limiting (Betti 2013).

Clay delving can achieve deeper mixing of clay through the soil profile and breaking of hardpans usually present at the top of the B horizon of duplex soils. Delvers are ripper-like machines where tines were modified in design in order to bring subsoil clay to the surface (Cox & Pitman 2002). Clay delving has been successfully done in improving water permeability in Australian duplex soils at a very large scale (Betti 2013). Despite being very successful in Australia (Cox & Pitman 2002), clay delving is yet to be applied to South African duplex soils. Clay delving may be a useful strategy in Ntabelanga soils. Clay delving is negatively affected by the slope (DEFRA 2005). Research is needed on the appropriateness of the strategy.

Soil conservation options in duplex soils

The typical B horizon of a duplex soil has less than 12% storage pores of volume; its hydraulic conductivity at 40kP matrix suction is in the order of 10^{-7} m day^{-1}(Verboom & Pate 2006). Therefore the B horizon is the first-order control of gully formation by restricting vertical water movement in the profile (Seitlheko 2003). In any case, conservation practices in duplex soils must aim to improve the permeability of the subsoil horizon. Normally traditional strategies for erosion control are based mainly on measures that: (i) protect the soil from the raindrop impact to decrease detachment (ii) increase surface depression storage and soil roughness to reduce run-off volume and velocity and (iii) alter slope-length gradient and direction of run-off (Morgan 2009).

The traditional strategies have failed to address soil erosion problems as evidenced by water-damaged stone terraces in most parts of the Eastern Cape Province (Laker 2004). Efforts to curb growths of gullies by stone pilling in the gullies and stone terracing on slopy lands were done but with limited success. The failure of the traditional strategies in soil conservation could be due to the nature of soils found in the area, thus a need of an alternative strategy. Modification of some soil properties responsible for susceptibility to erosion (Morgan 2009) could be fundamental in the Eastern Cape Province. Increasing aggregate stability at the soil surface and preventing clay dispersion could control seal formation and increase the infiltration rate of the B horizon of the duplex soils.

With the understanding of the processes and mechanics of the soil erosion in duplex soils, it follows that strategies for soil conservation in Ntabelanga may need to look at the following:

Reforestation

Agroforestry trees that are sodic and saline tolerant can be planted on the duplex soils. The trees enhance the built-up of organic matter and improve soil structure of the structureless top soil of duplex soils. Vegetation was shown to reduce erosion by water even under extreme torrential simulated rainfall (Bann & Field 2010). Research supports the ability of trees, for example, lucerne to extend its roots to a considerable depth, extract soil water from deep within the profile and reduce deep drainage (Cox & Pitman 2002). Lucerne significantly reduces deep drainage on duplex soils at a small sub-catchment scale, particularly at the upper and mid-slope positions (Cox & Pitman 2002). The main advantage of trees is their ability to extend roots into the subsoil and extract soil water stored deep in the profile, which would otherwise contribute to deep drainage. Bann and Field (2010) showed that individual plants were valuable in interill erosion control at the microscale, and the different plant morphologies and plant components explained the different erosivity. In assessing the great potential of plant covers, it is therefore important to consider its impact on soil protection.

Soil organic management

Soil organic matter (SOM) increases soil porosity, thereby increasing infiltration and water holding capacity of the soil, providing more available for plants and less potentially erosive run-off (Bann & Field 2010). SOM improves stability of soil aggregates in the top soils of duplex soils. Increased soil aggregate stability in the structureless top soil reduces blocking of the micropores within the upper B horizon and avoids horizontal movement of water that initiates gullying. Seitlheko (2003) noted a decrease in horizontal movement of water in the B horizon with an increased organic matter content of the top soil horizon in duplex soils. Beckedahl and De Villiers (2000) also observed that the breakdown of aggregates and dispersion of the finer material in the A horizon block micropores within the upper B horizon, resulting in dominantly horizontal movement of water initiating gullying (Seitlheko 2003). From these studies it can be deduced that addition of organic matter in both the top and sub soils in duplex soils can reduce erosion by water.

Drainage

Excess water in duplex soils can be removed by drains. In soils where drainage is impractical, some success has been obtained by deep ripping and by gypsum amendment (Cox & Pitman 2002). These practices can increase profile storage or drainage. Interceptor drains are suitable for duplex soils with slopes of more than about 1.5% (Cox & Pitman 2002). On more gentle slopes, relief drains are used to remove excess water. Subsurface tube and mole drains were successfully used to drain duplex soils in Victoria, but in Western Australia open drains were preferred because they can carry storm run-off as well as seepage waters (Bann & Field 2010). The greatest cost of open drains is could be the land removed from production. Over 35% of the rain falling during the growing seasons has been successfully removed by draining the duplex soils in Victoria and Western Australia during wet years (Cox & Pitman 2002)

Conclusion and recommendations

The absence of the top horizons in some soils seen in Ntabelanga could be clear evidence of soil mass movement down-slope caused by the restrictive nature of the B horizon to vertical water movement. The presence of deep gullies that do not follow the normal topographic drainage lines could also suggest severe piping of the soils. Moreover, the presence of numerous isolated waterlogged sites around the proposed dam site in Ntabelanga could be a strong evidence of texture contrast soils present in such water-logged areas. Therefore the nature of soil erosion in Ntabelanga could be influenced by the restrictive nature of the subsurface horizons to the vertical flow of water and the piping of the soils.

Soil erosion in Ntabelanga has shown to be highly influenced by the erodibility and less on the erosivity nature of the soils, as gullies are initiating even under thick grass cover and trees in the area. Traditional soil erosion control strategies have failed to curb the erosion, which suggests that there is a need for further understanding of the soil properties found in Ntabelanga.

Though it is difficult to recommend a one-take-all solution to soil erosion in Ntabelanga, the addition of organic matter coupled with clay spreading and delving and deep tillage can be appropriate to enhancing the vertical flow of water capacity in the B horizon of duplex soils. Research is needed on the applicability of these strategies under South African soils and conditions.

In order to improve the management of duplex soils, limited field data and literature review from catchments with bedrocks near the surface indicate that subsurface lateral flow in duplex soils requires further understanding. Furthermore, field studies are required to better understand the mechanisms responsible for the development of perched water-tables and subsurface lateral flow in the duplex soils. Studies need to determine the extent to which the soil properties of the B horizon affect the water movement.

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