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Local benefits of retaining natural vegetation for soil retention and hydrological services

P.J. O'Farrell [a,*], J.S. Donaldson [b], M.T Hoffman [a]

[a] *Plant Conservation Unit, Botany Department, University of Cape Town, Rondebosch 7701, South Africa*
[b] *South African National Biodiversity Institute, Private Bag X7, Claremont 7708, South Africa*

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Abstract

Renosterveld is a grassy shrubland with a diverse understory of geophytes. Exceptional plant diversity and endemism, combined with considerable fragmentation due to transformation to cropland, make this vegetation type a conservation priority. The provision of formal reserves is difficult in highly fragmented landscapes. One possible way of motivating for conservation is to demonstrate the ecosystem services derived from the retention of remaining natural fragments, as a motivation for their conservation on private land. This study explored the benefits of retaining renosterveld fragments at the farm-scale based on the hydrological and soil retention services they provide. Rainfall simulations were carried out at paired sites of renosterveld and transformed renosterveld, and renosterveld and managed transformed renosterveld (requiring physical inputs). Infiltration rates, runoff volumes, sediment loads and plant species cover were recorded. This study found that infiltration was linked primarily to vegetation cover, with the highest infiltration rates experienced in renosterveld and managed transformed renosterveld dominated by alien grasses. Similarly aeolian loads and wind speeds among these three vegetation states were explored using suspension traps and hand-held anemometers. Renosterveld remnants were demonstrated to significantly reduce wind speed and aeolian load. Renosterveld provides an important service in reducing runoff, facilitating infiltration and retaining topsoil without expensive management interventions.

Keywords: Ecosystem services; Rainfall simulation; Renosterveld fragments; Transformation; Wind erosion

1. Introduction

Soil erosion is the removal of soil material which includes minerals, nutrients and organic matter, at rates in excess of soil formation and is primarily attributed to human activities (Evans, 1980; Visser et al., 2004). The loss of topsoil through erosion is described as one of the world's greatest environmental and agricultural problems (Skidmore, 1994). It is estimated that as much as 75 billion metric tonnes is lost across the globe every year, with an associated cost of US$400 billion (Myers, 1993; Pimentel et al., 1995). In South Africa three tonnes of topsoil per hectare is estimated to be lost annually (Yeld, 1993). This removal of topsoil may expose bedrock and promote the formation of gullies, but also affects areas down valley or down wind, where sediments are deposited, blanketing areas with silt and sand, clogging reservoirs and canals with sediments (Morgan, 1986).

Processes and conditions of natural ecosystems that are responsible for the retention of soil and the prevention of soil erosion are a major ecosystem service in agricultural areas. In South Africa, soil erosion has been a major concern both ecologically and economically since the early 1900s (see Senate S.C.2, 1914), and combating erosion has been vigorously pursued with both legislation and management action. For example the Soil Erosion Advisory Council was established in 1930 and provided subsidies to farmers engaged in anti-erosion projects, and the Soil Conservation Act of 1946 provided the legislative framework for enforcing soil conservation on farms (Donaldson, 2002; Beinart, 2003). The ecosystem services which are

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* Corresponding author. Current address: CSIR, Natural Resources and the Environment, PO Box 320, Stellenbosch 7599, South Africa.
E-mail address: POFarrell@csir.co.za (P.J. O'Farrell).

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responsible for soil retention, enhancing rainfall infiltration, and reducing wind speeds, given this history, deemed to be of major importance in South African agricultural landscapes.

Renosterveld vegetation, which occupies 25% of the Cape Floristic Region in South Africa (Low and Rebelo, 1996; Mucina and Rutherford, 2006), is described as being dominated by small-leaved, evergreen asteracious shrubs, particularly *Elytropappus rhinocerotis*, with an understory of grasses and geophytes, the latter having both high biomass and diversity (Boucher, 1980; Cowling, 1990). Rainfall and soil nutrients geographically determine the extent of this vegetation type. Where rainfall is less than 250–300 mm renosterveld is replaced by succulent karoo shrublands. Fynbos replaces renosterveld, on highly leached soils, where rainfall is above 500–800 mm (Mucina and Rutherford, 2006). Mucina and Rutherford (2006) have split renosterveld into 29 vegetation units, based on distribution, vegetation and landscape features, geology and soils, and climate (Fig. 1). They identify the majority of these renosterveld vegetation units (86% of the total vegetation types area), as occurring on shale, but they note renosterveld is found to a lesser degree on granite, dolerite and alluvium substrates. Shale-derived soils are also highly suitable for cereal cultivation, resulting in this vegetation type becoming highly fragmented due to transformation for cultivation (Hoffman, 1997). Levels of fragmentation vary amongst renosterveld vegetation units, with those units found in the west and southwest now being over 80% transformed (Mcdowell, 1988; Kemper et al., 2000). Only 5% of renosterveld vegetation is formally conserved in protected areas, with the remainder being held by private landowners, the majority utilising this vegetation type for livestock grazing. Renosterveld is regarded as a conservation priority given its plant species diversity, the limited area of natural vegetation remaining, and the fact that what little remains is highly fragmented and under further threat of transformation. Kemper et al. (1999), demonstrated that small fragments, despite being disturbed by grazing, trampling, crop spraying and frequent fires, retained a similar community structure to large fragments, and that all renosterveld fragments should be considered conservation-worthy. Whilst acknowledging the conservation contribution that a variety of different sized fragments can contribute, conservation planning and the provision of formal reserves are difficult in highly fragmented landscapes. If important ecosystem services and benefits, derived from the retention and appropriate management of the remaining renosterveld fragments, can be demonstrated at a farm scale, then this would act as an additional motivation for their conservation (Edwards and Abivardi, 1998; Kemper et al., 1999). However, if the same ecosystem services are derived from transformed areas then using these services to promote conservation becomes less relevant.

In Australia, natural vegetation fragments have been identified as supplying important ecosystem services, including the provision of soil stability and the maintenance of hydrological processes (Hobbs, 1992). Studies in South Africa have noted that farmers' perceive renosterveld to provide soil stability and acts as a windbreak (O'Farrell, 2005). South African farmers, however, perceive rainfall infiltration in renosterveld vegetation to be poor compared with transformed renosterveld areas that they have sown with an annual legume, *Medicago sp*, and managed to enhance the growth of this annual through the application of fertiliser and the removal of weedy species.

The aim of this study was to contrast the soil retention and water infiltration potential of natural renosterveld fragments with transformed renosterveld, in effect testing land owner perception. It was hypothesised that renosterveld remnants are better at holding soil, are areas of higher rainfall infiltration, and reduced ground-level wind speeds. If correct this would demonstrate some of the value of conserving or retaining renosterveld fragments, and possibly encouraging natural processes of reestablishment in certain areas, at the farm-scale in order to maintain or benefit from these services.

We examined both the erosion and hydrological processes in fragments of one renosterveld vegetation unit as identified by Mucina and Rutherford (2006), in natural and adjacent transformed states of the same vegetation unit. We carried out rainfall simulations on either side of a natural renosterveld/transformed renosterveld boundary, examining infiltration rates, run-off volumes and sediment loads. We also investigated differences in wind speeds and aeolian sediment loads in renosterveld, and transformed renosterveld.

2. Material and methods

2.1. Study area

This study was carried out near the town of Nieuwoudtville, on the Bokkeveld Plateau, situated 350 km north of Cape Town, South Africa (Figs. 1, 2). The mean annual rainfall here is approximately 350 mm with a CV of 33%, and falls primarily in the winter months between May and October (Fig. 3). The study area receives wind predominantly from a south-westerly direction, and also blows most strongly from this direction (Fig. 4).

Mucina and Rutherford (2006) have identified two distinct renosterveld vegetation units occurring in this area, Nieuwoudtville Shale Renosterveld and Nieuwoudtville-Roggeveld Dolerite Renosterveld, both having particularly high diversity of annuals and geophytes (Manning and Goldblatt, 1997). In this study we focussed only on the Nieuwoudtville Shale Renosterveld. This vegetation type is found in a narrow 1–4 km wide band along a north-south axis, extending for 36 km. It is constrained by geology and associated soil types with sandstone-derived substrates to the west on which fynbos vegetation grows and dolerite derived substrates to the east on which succulent karoo vegetation and Nieuwoudtville-Roggeveld Dolerite Renosterveld is found. Nieuwoudtville Shale Renosterveld is found on Dwyka sediment-derived soils including Estcourt, Glenrosa, Klapmuts, Sterkspruit and Swartland (Soil Classification Working Group, 1991) in the terms of the World Reference Base classification system, Eutric Planosols, Skeletic Leptosols, Albic Luvisols, Abruptic Hyperochric Cutanic Luvisols, and Hyperochric Rhodic Luvisols (Deckers et al., 1998).

Nieuwoudtville Shale Renosterveld, hereafter referred to as renosterveld, occupies an area of 159 km^2, but a combined area of 78 km^2 has been transformed (Fig. 2). Typically, flat areas, gentle slopes and valley bottoms are the landforms that are transformed,

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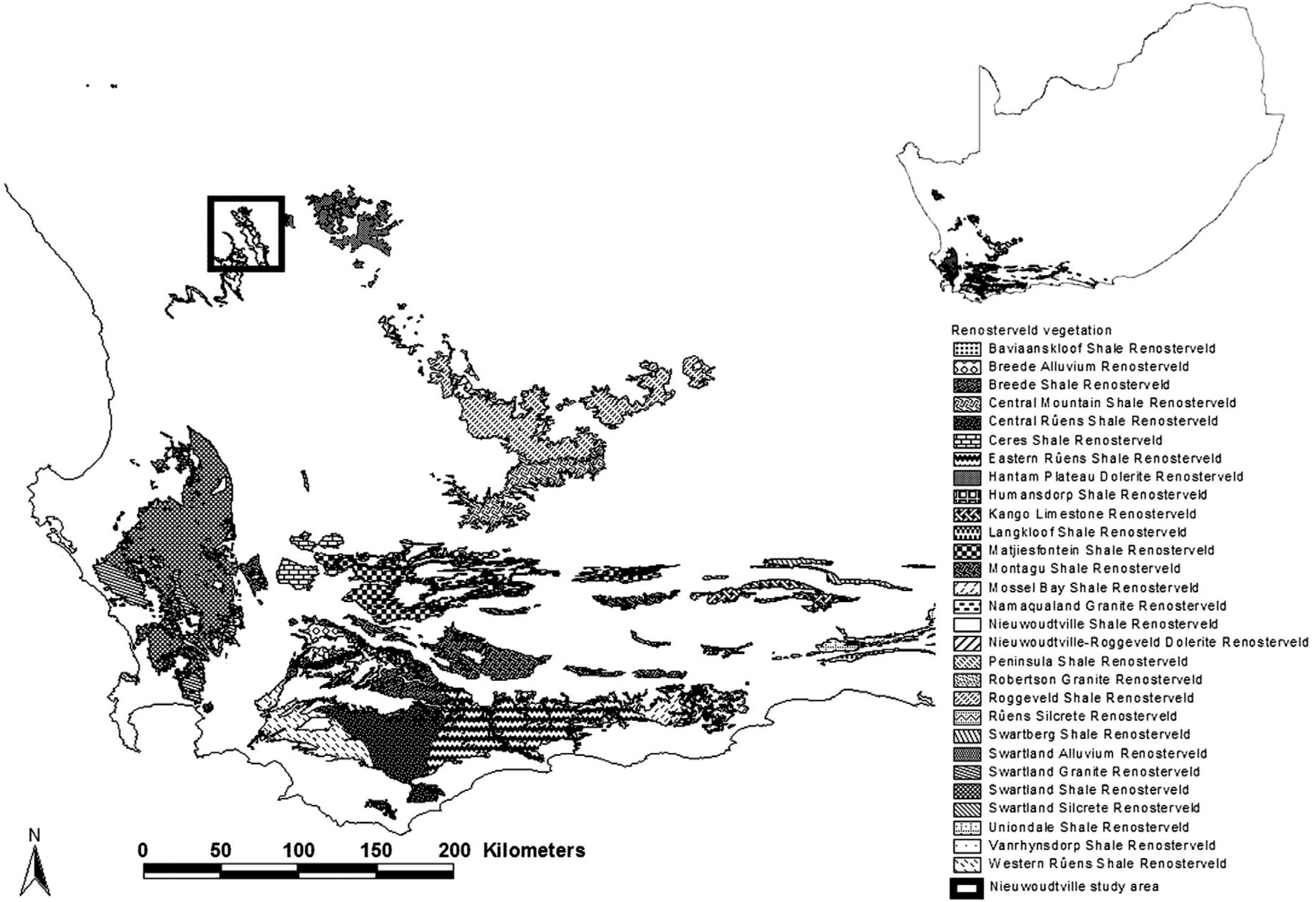

Fig. 1. Map showing the variety of renosterveld vegetation units (19) as defined by Mucina and Rutherford (2006), their location within South Africa, and the location of the study area in the vicinity of Nieuwoudtville. **Q1**

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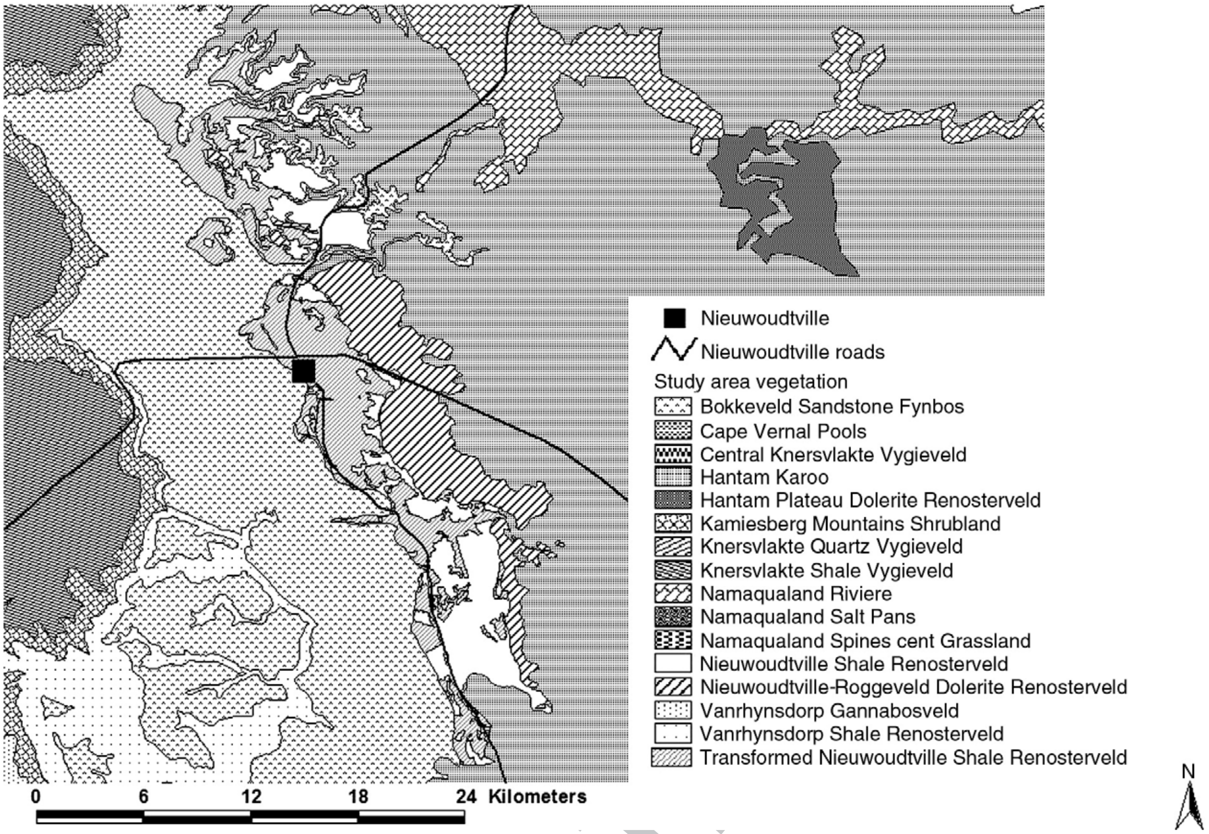

Fig. 2. Map showing the location of the town of Nieuwoudtville relative to the major roads in the area, and the vegetation units of this region as defined by Mucina and Rutherford (2006). The Nieuwoudtville Shale Renosterveld vegetation unit has been overlain with a coverage showing the extent of its transformation.

and intact areas are more likely to be found on relatively steeper slopes. The economic and land-use activities in the study area are livestock production for both meat and wool, crop production predominantly of wheat — *Triticum aestivum*, oats — *Avena sativa*, and *Medicago sp.* pasture, and ecotourism particularly focused on spring flower displays. The study was carried out on five farms and a municipal nature reserve.

Natural renosterveld fragments and transformed renosterveld areas were investigated using fenceline contrasts. Transformed renosterveld was defined as croplands that have been abandoned for more than 10 years. For the purposes of this study these were further subdivided into two land-use classes: transformed renosterveld that received no management inputs and transformed renosterveld that is actively managed as a *Medicago sp.* pasture. Management activities primarily consist of the initial sowing of pasture, and the application of a fertiliser, double superphosphate (P_2O_5), which is applied every second year as a top dressing in March and April before the first winter rains. This requires a substantial investment of between R100 and R300 per ha (Donaldson, 2002). Transformed lands

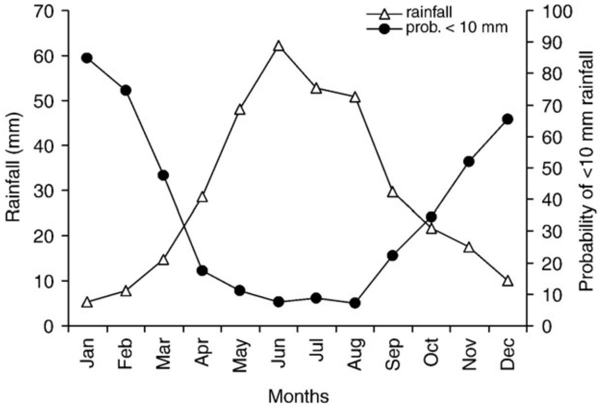

Fig. 3. Mean monthly rainfall recorded for the town of Nieuwoudtville (1913–2000), and the probability of receiving less than 10 mm of rainfall in a month.

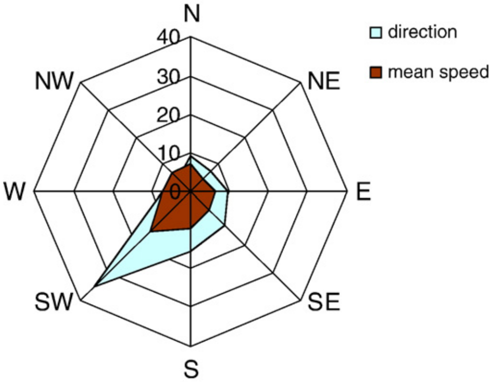

Fig. 4. Wind direction as a percentage from that direction, and mean wind speed (km/h) recorded for the period 2002–2003.

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are hereafter referred to as transformed renosterveld, and managed transformed renosterveld. The transformed renosterveld was dominated by the annuals *Rhynchopsidium pumilum* and *Cotula naudicaulis*, and soil surfaces have a hard, capped appearance. Managed transformed renosterveld was typically dominated by *Medicago sp*., and the alien grasses *Avena fatua* and *Bromus pectinatus*. Soil surfaces here were not capped and there was extensive evidence of soil invertebrate activity. There are no shrub species or other forms of perennial species present in either of these transformed renosterveld land-use classes.

2.2. Rainfall simulation

A rainfall simulator was used to simulate rainfall events in September and October 2002, in renosterveld, transformed renosterveld and managed transformed renosterveld (Fig. 5). A rainfall simulator was selected based on the findings of Boers et al. (1992) who compared infiltration and erosion rates using an infiltrometer, a rainfall simulator and a permeameter. They concluded that rainfall simulators are the most suitable method for research on soil erosion and infiltration as conditions are close to those under natural conditions and results are realistic. Ten pairs of sites were selected along a renosterveld and managed transformed renosterveld interface, and seven pairs of sites were selected along a renosterveld and transformed renosterveld interface along a fence line. Fence line contrasts were used so as to minimise the environmental variables, such as soil type and slope. Sites were randomly selected but slope was controlled for and kept constant using an abney level, with plots being moved a meter to the left until a consistent slope was achieved.

The simulator was set to generate rainfall of 1 mm every min, within an area of 1 m^2. A UniJet spray-nozzle tip of 1.3 mm, and a drop height of 2 m were used to simulate winter rainfall conditions that occur between May and October. This was considered appropriate given the intensity of recorded rainfall events in the study area (daily rainfall was examined for the period 1913–2000 (see O'Farrell et al., 2007), and the need to generate a large enough rainfall event to ensure run-off. The rainfall simulation was screened from the effects of wind by covering the simulator frame in plastic sheeting (Fig. 5). The simulation continued for 30 min once run-off had been achieved, with time to run-off recorded. A water run-off sample from the outlet point of the plot, located at the lowest point of the ring, was taken every 2 min for 10 s over a 30 min period. Water volumes were measured and the samples were oven-dried at 80 °C, and the remaining sediment weighed. Vegetation cover, including surface litter, was estimated from above (aerial cover) as a percentage of the total 1 m^2 area. Three soil depth measurements derived by hammering a calibrated steel rod in to the soil, and a 10 cm soil core sample were taken at each site. Soil samples were analysed for organic soil carbon, total nitrogen, and soil texture. Organic carbon was determined using the Walkley-Black method and total nitrogen was determined by digestion in a LECO FP-528 nitrogen analyser (Nelson and Sommers, 1982) (BemLab, Somerset-West). Soil texture was analysed using the Bouyoucos particle size method (Bouyoucos, 1962).

Paired sites of renosterveld and transformed renosterveld, and renosterveld and managed transformed renosterveld were compared using a paired Wilcoxon signed rank test. The relationship amongst the biophysical variables and infiltration measurements was established using a Pearson Correlation matrix containing all measured variables for all sites.

2.3. Wind erosion

Hand-held anemometers were used to measure relative wind speeds in renosterveld and adjacent, transformed renosterveld and managed transformed renosterveld. Wind speeds were

Fig. 5. Single nozzle rainfall simulator used to simulate winter rainfall in September and October 2002 pictured here in managed transformed renosterveld.

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recorded at 20 cm above the ground, given the height of the vegetation and in order to avoid the affect of rocks. A total of 320 readings, each measured for 20 s, were taken over a three-day period in November 2002, in the three vegetation types, given the homogeneity within each vegetation type.

Suspension sediment bottles were erected to catch windblown or suspended material from all four major wind directions (Fig. 6). These were largely based on the Modified Wilson and Cook sampler (Wilson and Cooke, 1980). These were set up at 110 sites, and divided between the renosterveld (55 sites), transformed renosterveld (28 sites), and managed transformed renosterveld (26 sites). At each site two traps were fixed to a metal stake in the ground. One trap was positioned at 10 cm above ground level and the other at 80 cm above ground level. Traps were set up at the start of the summer in early November 2002 and emptied in March 2003 and the sediment weighed.

Recorded wind velocities and sediment volume differences for each vegetation type were compared using Kruskal-Wallis ANOVA and a post-hoc test was performed using a multiple comparison of mean ranks for all groups.

3. Results

3.1. Rainfall simulation

The rainfall simulation exercise demonstrated that rain water infiltrated faster in the soil of renosterveld compared with transformed renosterveld (Table 1). Furthermore, water infiltrated the soil for a longer time period before run-off was achieved compared with the transformed renosterveld. The vegetation cover was also significantly greater in renosterveld. No significant differences in the volume of soil sediments collected, or any of the other soil properties measured, between these vegetation types was found.

In contrast, when comparing renosterveld and managed transformed renosterveld, the latter functioned better than the renosterveld. The amount of time passed before run-off was achieved and the rainfall infiltration rates were significantly higher on the managed transformed renosterveld compared with

Table 1
The mean (±SE) values of infiltration and erosion measurements, on remnant renosterveld and in transformed renosterveld.

	Renosterveld	Transformed renosterveld	Z	p (n=14)
Time before run-off (min)	22.7±5.2	9.5±2.4	2.37	0.05
Infiltration rate (mm/h)	40.9±5.9	27.0±2.9	2.37	0.05
Sediment collected (g)	626.3±391.2	697.1±557.6	0.34	NS
Soil depth (cm)	13.0±1.0	12.0±1.8	0.68	NS
Vegetation cover (%)	50.0±6.2	27.0±2.9	2.37	0.05
Soil nitrogen (%)	0.0±0.0	0.0±0.0	1.01	NS
Soil carbon (%)	0.8±0.1	0.7±0.0	1.26	NS
Clay (%)	9.8±1.4	8.4±1.1	1.86	NS
Silt (%)	15.7±1.4	16.8±2.0	0.31	NS
Fine sand (%)	47.0±1.6	48.2±1.3	1.18	NS
Medium sand (%)	13.2±0.9	13.3±0.9	0.17	NS
Coarse sand (%)	14.3±1.6	13.2±2.1	0.00	NS

Significant differences tested using a Wilcoxon paired test, Z values and significance levels are given.

Fig. 6. Sediment traps to capture wind suspended sediments at 10 cm and 80 cm above ground level in renosterveld (left) and on transformed renosterveld (right), between October 2002 and March 2003. Pictures taken in March 2003, give an indication of plant vegetation structure of land-use classes with the renosterveld having a dense cover of the shrub *Elytropappus rhinocerotis* (background) and a *Merxmuellera stricta* grass clump (foreground). Transformed renosterveld can be seen to be devoid of vegetation cover during the late summer.

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Table 2
The mean (±SE) values of infiltration and erosion measurements, on remnant renosterveld and in managed transformed renosterveld.

	Renosterveld	Managed transformed renosterveld	Z	p (n=18)
Time before run-off (min)	16.5±2.8	64.6±11.2	2.66	0.01
Infiltration rate (mm/h)	36.0±2.6	85.0±10.2	2.66	0.01
Sediment collected (g)	1173.8±481.6	1072.0±565.2	1.24	NS
Soil depth (cm)	13.1±1.0	19.1±0.6	0.95	NS
Vegetation cover (%)	53.2±3.3	61±5.1	1.18	NS
Soil nitrogen (%)	0.0±0.0	0.1±0.0	2.55	0.05
Soil carbon (%)	0.9±0.1	1.4±0.1	2.31	0.05
Clay (%)	9.1±0.6	7.0±1.0	2.31	0.5
Silt (%)	17.0±1.0	15.7±0.8	1.26	NS
Fine sand (%)	42.9±1.8	45.5±1.3	1.42	NS
Medium sand (%)	12.8±0.5	15.5±0.7	2.67	0.01
Coarse sand (%)	18.2±2.0	16.2±1.7	1.48	NS

Significant differences tested using a Wilcoxon paired test, *Z* values and significance levels are given.

renosterveld (Table 2). Both soil nitrogen and soil carbon were significantly higher on the managed transformed renosterveld. The percentage clay content of soil samples was significantly higher in the renosterveld than the managed transformed renosterveld. The reverse was true for the medium sand percentage, which was significantly higher in managed transformed renosterveld.

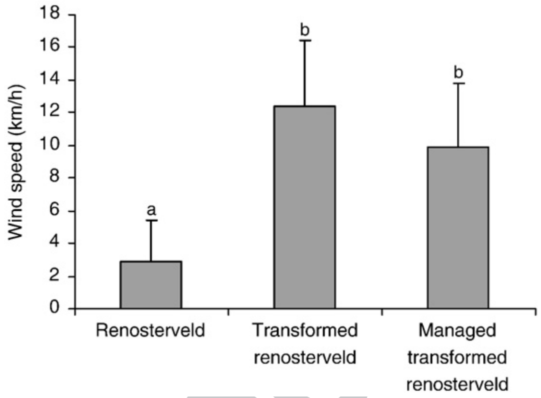

Fig. 7. Mean wind speeds and standard deviations recorded in renosterveld, transformed renosterveld and managed transformed renosterveld, at a height of 20 cm, over three days in November 2002, ($H=207.8$, $p<0.01$, $n=320$).

The Spearman Rank Correlation showed that time before run-off and infiltration rate were strongly positively correlated with each other, vegetation cover, soil nitrogen, soil carbon, and percentage medium sand content, but were negatively correlated with percentage clay content (Table 3). Soil sediment loads collected from run-off samples showed that the volume of sediment was negatively correlated with percentage medium sand content. Vegetation cover was positively correlated with soil nitrogen and carbon. Soil nitrogen was positively correlated with soil carbon and soil depth. Percentage clay content was negatively correlated with fine and medium sand. Both silt and

Table 3
Spearman Rank correlation matrix for all variables investigated for all sites.

	Time to runoff (min)	Infiltration rate (mm/h)	Soil sediment (g/ml)	Soil sediment (g)	Mean Depth (cm)	Vegetation cover (%)	Soil nitrogen (%)	Soil carbon (%)	Clay (%)	Silt (%)	Fine sand (%)	Medium sand (%)
Infiltration (mm/h)	0.97**											
Soil sediment (g/ml)	0.45**	0.38*										
Soil sediment (g)	0.04	−0.04	0.04*									
Mean Depth (cm)	0.017	0.17	0.2	0.03								
Vegetation cover (%)	0.77***	0.77***	0.5**	0.07	0.19							
Soil nitrogen (%)	0.59***	0.56***	0.22	0.13	0.37*	0.38*						
Soil carbon (%)	0.64***	0.62***	0.3	0.08	0.35	0.43*	0.87***					
Clay (%)	−0.56***	−0.57***	0.1	0.27	0.12	−0.29	−0.11	−0.3				
Silt (%)	0.11	0.07	0.05	0.03	0.15	0.11	0.03	0.32	−0.08			
Fine sand (%)	0.05	0.1	−0.15	−0.27	−0.13	−0.04	−0.27	−0.2	−0.44*	−0.06		
Medium sand (%)	0.44*	0.5**	−0.09	−0.38*	−0.14	0.21	0.06	0.5	−0.55**	−0.26	0.27	
Coarse sand (%)	0.04	0.03	0.1	0.27	0.01	0.08	0.28	0.13	0.08	−0.46**	−0.68***	−0.16

Significant correalations are indicated as ***$p<0.001$, **$p<0.01$, *$p<0.05$.

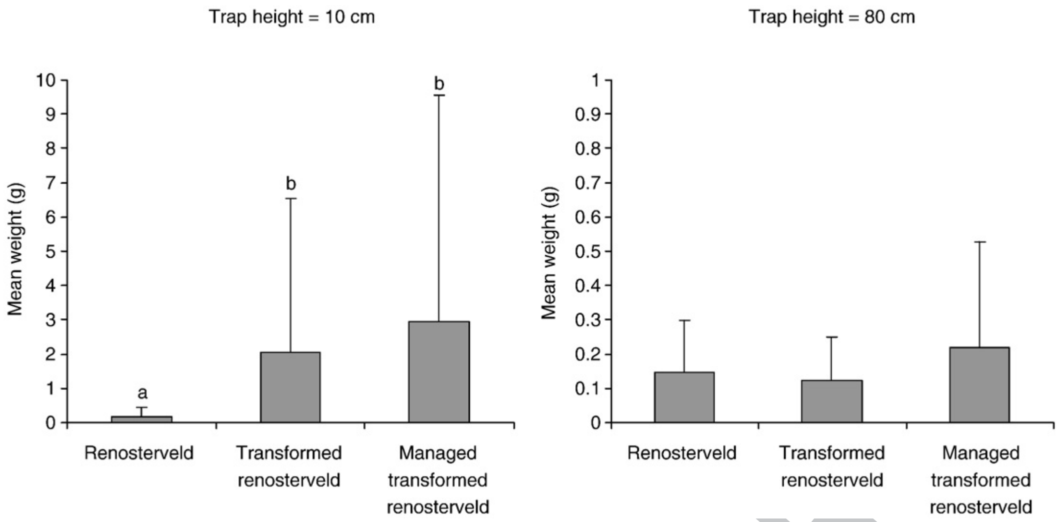

Fig. 8. Mean sediment (±SD), trapped at 10 cm ($H=43.4$, $p<0.001$, $n=110$), and 80 cm (H=1.7, $p=\text{ns}$, $n=110$) above ground level, for renosterveld, transformed renosterveld and managed transformed renosterveld, for the period November 2002 to March 2003. Superscript denotes significant differences at the $p<0.01$ level.

fine sand were strongly negatively correlated with coarse sand. Soil sediment loads for all simulations were observed to be comprised mostly of fine sand and silt.

3.2. Wind velocity

Localised wind speeds recorded with a hand-held anemometer at 20 cm above the ground showed renosterveld to have significantly lower wind speeds, because of its structure, when compared with both the transformed renosterveld and managed transformed renosterveld (Fig. 7).

3.3. Wind-borne sediment

Suspension sediment bottles registered significant differences in the amount of wind-borne sediment in transformed renosterveld and managed transformed renosterveld when compared to renosterveld, with twelve times more sediment being captured in transformed renosterveld at 10 cm above ground level (Fig. 8). No differences were found in sediment loads captured at 80 cm above the ground. Sediment texture did not differ significantly between the vegetation types, at both heights and was comprised largely of fine sand.

4. Discussion

4.1. Land use, hydrological function, and service integrity

Past agricultural practices, which initially transformed the natural renosterveld vegetation of the Bokkeveld plateau for cereal production and later abandoned cultivation in favour of the grazing of small livestock, have altered the rainfall infiltration patterns of this region. This was evident in the comparison of infiltration rate and time before run-off, for renosterveld and transformed remosterveld areas. Rainfall infiltration differences between the renosterveld and these abandoned unmanaged transformed lands are primarily a function of vegetation cover, including leaf litter. Vegetation cover intercepts rainfall, and lessens raindrop impact. Rainfall interception is cited as one of the main reasons for the enhanced infiltration and reduced run-off experienced in vegetated areas (Woo et al., 1997; Casermeiro et al., 2004). A number of studies report similar findings (Wilcox et al., 1988; Martinez-Fernandez et al., 1995; Woo et al., 1997; Casermeiro et al., 2004). Similarly Cerda (1997), in his examination of *Stipa tenacissima* mosaics in south-east Spain, found higher surface run-off and erosion in bare patches and better infiltration in vegetated patches. Meeuwig (1969) notes the importance of vegetative cover in maintaining soil stability and permeability, with plant cover and litter accounting for 73% of the variance in the amount of water retained by study plots during a 30 min simulated rainfall test. Morgan et al. (1997) demonstrated that soil loss decreased exponentially with increasing vegetation cover. They suggested that vegetation exerts an important hydrological control by increasing the infiltration capacity of the soil and the time to, and duration of, run-off.

Water erosion happens when soil particles are detached from the soil mass and then transported (Morgan, 1986). Rain splash, negatively correlated with rainfall interception, is considered to be the most important detaching agent of soil particles (Morgan, 1986). Soil texture was found to influence infiltration and erosion in this study, with infiltration rates being positively correlated with medium sand and negatively correlated with clay. Mills et al. (2006) also found medium sand to be strongly correlated with infiltration rates in the laboratory. Takar et al. (1990) working in Somalia, also noted the effects of soil texture on erosion — infiltration rate and interrill erosion on sand were significantly higher than on clay, irrespective of cover and season. Raindrops compact soil as they land and then disperse from the point of impact (Morgan, 1986). When clay particles are detached from soil aggregates, by raindrops, they are dispersed into soil pores, clogging these spaces, with the end result being the formation of a surface crust just a few millimetres thick (Mills and Fey, 2004). Crusts therefore reduce infiltration capacity and promote greater

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surface run-off (Morgan, 1986). Mills and Fey (2004) working at the same study site on the Bokkeveld plateau found that soil crusting was significantly greater on exposed soils compared with soils covered with vegetation. They attributed crusting to lower soluble salt and labile carbon content linked to increased clay dispersion.

Transformed renosterveld areas are free of obstacles such as boulders, rocks and organic matter, which would act to decelerate the flow of water. This is also likely to have contributed to the infiltration differences found between these two land types, and is expected to promote overland flow, moving both sediments and organic matter, from transformed lands to lower lying areas (Ludwig et al., 2005). The relationship between infiltration and overland flow determines the amount of water and material retained or transported from an area or vegetation patch (Le Maitre et al., 2007). The soil of tilled lands is described as fragile and vulnerable to erosion (Martinez-Fernandez et al., 1995). Once soils have started to erode, other soil properties are affected. Rostagno (1989) found that eroded soils in Patagonia, Argentina were not able to store water as effectively as stable soils and produced greater run-off volumes. Changes in interception, leaf litter production and infiltration influence erosion, and increased erosion decreases soil moisture storage (Mills and Fey, 2004). Soil moisture is the primary driver of phytomass production which in turn influences interception and infiltration, creating a perpetual negative feedback loop affecting both hydrological function and livestock production.

The adopted management approaches by some farmers within the study area have improve soil fertility by applying phosphate, which stimulates root development, and increased vegetation cover through the establishment of *Medicago sp.* pasturage. This has improved the grazing potential and carrying capacity of these lands, and has increased soil nitrogen and soil organic carbon content of the soil. Mills and Fey (2003) note that whilst crop production removes nutrients from the landscape, depleting soil fertility, fertilization can increase nutrient levels beyond virgin soils improving soil quality. Soil organic matter and decomposing leaf litter bind and stabilises soil aggregates, and facilitate infiltration and nutrient cycling (Mills and Fey, 2003).

Decomposition and nutrient cycling are linked to the functional diversity of soil organisms and soil community structure (Brussaard et al., 1997; Brussaard, 1998; Brussaard et al., 2007). Soil organisms particularly macro-fauna such as earthworms, create burrows and disturbances increasing infiltration (Dean, 1992; Bouche and Al-Addan, 1997) and introduce plant matter into soils (Coleman et al., 1992). O'Farrell et al. (in press) who under took a soil invertebrate analysis at this Bokkeveld study site, found earthworm numbers, earthworm activity and infiltration rates, measured with a single ring infiltrometer, to be higher on managed transformed areas compared with the adjacent renosterveld. Improved vegetation cover, soil organic matter, and soil invertebrates are biotic elements that have all contributed to improved infiltration rates on managed transformed areas, validating the perception held by the majority of Bokkeveld plateau farmers. However, these improvements come at a cost, and the abandonment of this management system will see a rapid reversal of these gains.

Both transformed renosterveld vegetation types are dominated by annual growth form cover which is strongly influenced by annual rainfall variability, with low rainfall resulting in less vegetation cover. In the year the rainfall simulations were carried out, above-average rainfall resulted in a proliferation of annuals and grasses, which facilitated infiltration during spring when this field trial was conducted. If this field trial was to be carried out under drier conditions the differences in infiltration rates may have been greater. The sediment load in run-off samples from the rainfall simulations were also not significantly different between the vegetation types compared in this study. However, they would be expected to be significantly higher for the transformed renosterveld than the perennial-dominated renosterveld at the outset of the wet season in April and May, and during the dry summer season, November to April, when occasional summer thunderstorms occur. During these periods both the transformed renosterveld and managed transformed renosterveld are completely devoid of vegetation cover.

4.2. Wind and vegetation services

Wind erosion is a selective process in which the finest soil particles, that contain a disproportionally high amount of plant nutrients are removed, degrading soil structure, reducing soil moisture and crop productivity (Gomes et al., 2003). In arid and semi-arid regions, wind erosion frequently exceeds water erosion due to the infrequency of rainfall events. Wind erosion is the principal source of atmospheric dust which is closely connected to major climate changes and is exacerbated by human induced land-use change (Gomes et al., 2003). Hoffman and Ashwell (2001) identify wind erosion as the most important type of soil degradation in natural vegetation for a region which incorporated our study area. Our sediment trap data are consistent with these statements and studies. Interviews with farmers in the region also indicate that extensive wind erosion takes place in the study area. They identified the period 1930-1960 as particularly problematic due to extensive cropping, and livestock trampling because livestock had to walk great distance to water points, before plastic piping was available allowing water to be pumped to distant paddocks.

Wind erosion studies, carried out during summer months, show transformed renosterveld and managed transformed renosterveld both to be more vulnerable to wind erosion than renosterveld. Live vegetation cover has long been recognised as protecting soil against wind erosion (Miller and Donahue, 1990; Skidmore, 1994). Of the vegetation types considered, renosterveld is the only perennial-dominated vegetation type that provides cover throughout the year. The main factor in wind erosion is the velocity of moving air (Morgan, 1986). The analysis of wind speeds in renosterveld and transformed renosterveld shows that renosterveld does act as a windbreak, providing a vital service to farmers in arresting wind erosion and holding soil during the dry summer months when soil surfaces are most susceptible to wind erosion, as well as providing shelter for livestock. Calculating windbreak effects requires modelling the turbulence of the approach flow, the windbreak porosity and the windbreak height (Cleugh, 1998). A simple predictor of the distance of the shelter

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effect from an established windbreak can be calculated by multiplying vegetation height by eight (Redpath, 2009). The maximum height of renosterveld was estimated to be 1.6 m high (Mucina and Rutherford, 2006), therefore the windbreak effect is likely to extend up to 13 m from a renosterveld remnant. Cleugh (1998) and Boldes et al. (2002) have both demonstrated that windbreaks also serve to improve crop yield and quality. The existing service provided by renosterveld could be enhanced through the establishment of *E. rhinocerotis* windbreaks adjacent to croplands, serving as a motivation for the retention or for allowing the natural reestablishment of renosterveld patches in the area. Field observations indicate that this species, as well as a number of other shrub species, trap sediments. Deposited soil mounds of approximately 10 cm in height are evident around the base of these shrubs extending outwards towards the edge of the canopy. These depositional features are comprised mostly of organic matter and fine soil particles. Depositional mounds are not evident in either of the transformed renosterveld areas. Further research into depositional features and soil profile differences between land-use types would provide clearer indications of the magnitude of this service.

4.3. Sustainable, conservation friendly agriculture

Soil erosion is a major threat to sustainable agriculture (Visser et al., 2004), influencing soil moisture and fertility that in turn influence plant growth, forage production (Knight, 1991), and crop yields (Verity and Anderson, 1990). Renosterveld vegetation fragments provide these soil retention services and should be incorporated into land-use management decisions in order to maintain optimal forage productivity. This is particular important in areas with weakly developed skeletal, or young soils (such as the Glenrosa soil form) which characteristically lack a B horizon, and those which have a prismatic structured B horizon that forms a barrier to water and is described as quick wet/ quick dry (such as the Sterkspruit soil form) (Ellis, 2002). Any removal of A horizon soil in these areas will cause accelerated drying, hampering plant establishment and growth, and lead to accelerated erosion and loss of productivity for the Bokkeveld farmers. This is potentially further compounded by the rainfall variability in this area.

We have demonstrated that renosterveld supplies rainfall infiltration services, provides an effective windbreak, reduces wind speeds, and holds topsoil throughout the year. Transformation of renosterveld with no further intervention results in significantly less rainfall infiltration and significantly greater volumes of wind-borne sediment. Inputs into production may improve rainfall infiltration by increasing vegetation cover during the wet season. These inputs of seed and fertiliser are expensive and provide insight into the value of this service provided by the natural vegetation. Whilst converting renosterveld to managed pastures may be economically beneficial, annual pastures may supply significantly less fodder than anticipated during drought periods, compared with the perennial shrub species found in renosterveld. Management practices that improve vegetation cover and productivity, however, do not prevent wind erosion.

Conversion of renosterveld in a sense commits landholders into either continuously paying management costs, paying expensive rehabilitation costs, or paying very expensive restoration costs, as the alternative of unmanaged transformed areas offer little in the way of farming returns. Herling et al. (in press) assessed the landholder rehabilitation or restoration costs for comparable Karoo vegetation, finding these to be in the range of R4 000 - R20 000 per hectare, making rehabilitation and restoration not financially viable in the short term. We argue that farm management and planning needs to recognise the roles that natural vegetation plays in the provision of these ecosystem services. Retaining natural vegetation fragments where applicable and encouraging the natural re-establishment of this vegetation in areas where these services are most required can create win-win situations for farming and biodiversity.

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