THE USE OF PALM LEAF MATS IN SOIL EROSION CONTROL

By

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Submitted in partial fulfillment of the requirements
for the degree PhD (Soil Science)
in the Faculty of Natural & Agricultural Sciences
University of Pretoria
Pretoria

February 2014

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Declaration

I, **D G PATERSON** declare that the thesis, which I hereby submit for the degree PhD Soil Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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SUMMARY

Geotextiles have been used for many years in different parts of the world to promote soil conservation and to combat erosion. Such geotextiles may be synthetic (usually some form of plastic, sometimes with wire), or natural (usually some form of fibrous material). Work carried out at the University of Wolverhampton (UK) on the effectiveness of mats made from palm tree leaves sourced from the Gambia, West Africa led to a research project funded by the EU, which ran from October 2005 to February 2009, comprising the participation of four EU countries (UK, Belgium, Hungary and Lithuania) and six "developing" countries (Brazil, Gambia, South Africa, Thailand, China and Vietnam).

Research carried out in South Africa used mats made from the leaves of the Lala palm (*Hyperhene coriacea*). These mats are easy to make, flexible, durable and completely bio-degradable. They cover approximately 40% of the soil surface, allowing space for vegetation to emerge, and add 1.3 kg of dry organic matter to each m^2 of soil. Furthermore, they have a water retention capacity of 1.8 l kg^{-1} m^{-2}, their N, K, S and P percentages are high, they have low sodium and aluminium values and a favourable C/N ratio.

Firstly, trials were done on 20 South African soils and 10 mine tailings materials using a rainfall simulator. The soils varied considerably with respect to their textural, chemical and mineralogical properties as well as annual precipitation and geological origin. Erosion parameters varied greatly within, and to a much lesser extent between, the two different materials. Several significant correlations were obtained. Sediment load (SL) had the best correlation with kaolinite content and with fine sand content, while for runoff, the best correlation was with organic carbon content. When the samples were covered with palm mats values for final infiltration rate (FI) percentage stable aggregates (SA) and inter-rill erodibility (K*i*) values were similar to those of bare materials and the amount of runoff was slightly higher. SL, however, was reduced by ±65%.

The next stage was to carry out a range of field trials, using runoff plots. Plots at four localities (Bergville, Ladybrand, Roodeplaat and Mabula) were used. Results showed that average runoff under the palm mats decreased by between 38% and 70%, compared to bare soil. Sediment concentration under the mats decreased by between 38% and 89%, using three combinations of slope, mat density and mesh size. Splash erosion at Roodeplaat decreased by between 62% and 68%, while re-vegetation at Ladybrand and Mabula increased by between 38% and 58%, with organic carbon content and topsoil accumulation also increasing under the mats. Various trials (using both the rainfall simulator and runoff plots) were carried out to evaluate the effects of reduced mat density and increased mesh size.

Results from the other participating countries (25% to 95% reduction in runoff) confirm that there is much potential to use organic, bio-degradable, easy to manufacture geotextiles such as palm leaf mats, especially to combine employment opportunities with enhanced environmental protection in many susceptible areas of South Africa.

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ACKNOWLEDGEMENTS

- This research forms part of the *Borassus* Project 'The environmental and socio-economic contributions of palm-leaf geotextiles to sustainable development and soil conservation' (INCO-CT-2005-510745), funded by the European Commission (EC), Specific Targeted Research Projects (FP6 - STREPs) for Developing Countries (INCO-DEV) Programme. The financial support is gratefully acknowledged.
- Prof. Mike Fullen (University of Wolverhampton, UK), for advice, support and project management assistance.
- Management of the Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW), for funding the continuation of the project at Ladybrand, for providing facilities and allowing the research for this study to take place.
- Dr Christl Bühmann (Project Leader), Dr Dave Turner and Dr Hendrik Smith (Divisional Managers), Ms Rinda Pienaar, Dr Jay le Roux and other colleagues at ARC-ISCW, for their support and advice.
- Mr Frikkie Calitz and Ms Nicolene Thibaut (ARC Biometry Unit), for help with statistical processing of data.
- The three anonymous referees for their comments and suggestions, which enabled meaningful improvements to be made.
- Prof. Robin Barnard (Supervisor) and Prof. John Annandale (Co-Supervisor), for their help and encouragement.

- Mat manufacture: thanks to Never Solomon.
- At Potshini: thanks to Nicholas Madondo.
- At Ladybrand: thanks to Andri van Greunen.
- At Roodeplaat: thanks to James Joubert.
- At Mabula: thanks to Jock McMillan and Johan Schroeder.
- Thanks also to Faith Seabi, Nicky Mushia, Martiens Mmamadisha, William Mashobane and Anastasia Kgopane (ARC-ISCW), for assistance with data collection, sample preparation and various other actions.

- Thanks to my wife Reanne and my son David for their love and support.

ABSTRACT

Geotextiles, whether synthetic or natural, have long been used to promote soil conservation and to combat erosion. Work done at the University of Wolverhampton, UK on the effectiveness of palm leaf mats in erosion control led to a project funded by the European Commission involving ten countries. It ran for more than three years and comprised several work packages, looking at a wide range of aspects into the production and utilization of palm leaf geotextiles.

As agriculture developed in many parts of the world throughout history, the practitioners often took steps to conserve their environment, but its expansion in more modern times in response to accelerating population pressures has led to a steady decline in both the condition and long-term stability of the soil resource. Soil conservation research has been carried out since the 19th century, but the main acceleration took place in the USA between the wars with the development of many field trial plots. These results eventually led to the development of the Universal Soil Loss Equation (USLE), which attempted to predict soil erosion in various scenarios.

In South Africa, the increasing rate of soil erosion was noticed from the early 1900’s and was exacerbated by the severe droughts of the 1930’s. This situation prevails throughout Africa, with South Africa itself having 45% of the surface area classed as having a high risk of soil erosion. Many of the worst areas are in the former “homelands”, where a lack of knowledge adds to the problem. It was estimated that natural erosion rates of less than 1 t ha^{-1} yr^{-1} rise to between 6 and 25 t ha^{-1} yr^{-1} for certain cultivation practices and may be as high as 30-40 t ha^{-1} yr^{-1} in the worst cases.

Soil erosion is a natural process, but is accelerated by land use practices that remove the vegetation layer. The two stages in the erosion process are particle detachment from the surface followed by their removal downslope, leading to a bare soil surface, lowered organic matter content, surface crusting and increased runoff.

The factors influencing soil erosion include parent materials, soil factors, terrain factors, climatic conditions and, as previously mentioned, vegetation cover (or lack thereof). Measures to control soil erosion include chemical and physical methods, the latter being

either preventative (pre-erosion) or curative (post-erosion). Post-erosion measures include a range of soil coverings which intercept rainfall, stabilise the topsoil and allow re-vegetation. Almost any type of material may be used, but the critical factor is that the covering remains in place for long enough to allow the above actions to take place. When crop residue was applied to pineapple fields in the Eastern Cape area of South Africa, soil loss was reduced from >45 t ha^{-1} $yr^{-1}$to <2 t ha^{-1} yr^{-1}.

Synthetic geotextiles originated in the engineering industry and have been used in many applications throughout the world, but most are not bio-degradable, which is not desirable for environmental sustainability. A more desirable alternative would be to use materials which would decompose over time. One such material, otherwise unused, is the leaves of palm trees, such as the Borassus palm (*Borassus aethiopium*), occurring in West Africa. Field studies in the Gambia and then in the UK using mats woven from palm leaf fronds showed promising reductions in soil sediment load and runoff, and this was supported by laboratory studies in Belgium, but testing and quantification of the effectiveness of the palm mats in other, tropical and sub-tropical areas (such as South Africa) was needed.

A rainfall simulator is a useful tool for erosion research. They were first developed in the 1940’s and their mechanisms were later improved, especially with rotating water source and pressure nozzles to give an improved spread. Studies have been carried out in many countries, in some cases using a portable simulator, although this has a small surface area. In South Africa, Israeli co-operation helped to develop an apparatus at the Soil and Irrigation Research Institute in the 1970’s, which has been used in several studies including soil crusting, although work at the University of the Free State into grassland type has also been carried out.

Rainfall simulators are limited in size, so larger field runoff plots are used to give more reliable results on soils *in situ*. Such plots were first developed in the USA in the 1930’s, looking at the effectiveness of several surface mulch types. Since then, a great variety of field plots (from 10 m^2 to 300 m^2) has been used in many countries to look at various erosion factors. In South Africa, the first plots were established at the University of Pretoria and at Glen (Free State), while work was also done at the University of the Free State and in KwaZulu-Natal.

Studies using geotextiles on field plots are not widespread, as their development was generally linked to commercial engineering companies that are not always research-oriented. However, some work has been carried out in the USA, UK and Israel. These studies almost always involve synthetic materials, and only isolated studies (India, Hawaii) have looked at natural, generally coir-based materials. The *Borassus* Project was the first comprehensive investigation of natural geotextiles and their effectiveness.

The mats used in this study are made from leaves of the Lala palm, which is closely related to the above-mentioned Borassus palm from West Africa. These palms produce large, fan-shaped leaves whose fronds can be woven into rigid, yet flexible 50 x 50 cm waffle-like mats which are laid on the soil surface. The mats cover approximately 40% of the surface and have favourable characteristics for a mulch as they slowly decompose. The mats absorb a lot of water and are surprisingly strong, even being comparable to many synthetic materials.

Rainfall simulator studies at ARC-Institute for Soil, Climate and Water looked at a range of 20 South African soils and ten mine tailings materials, using a slope of 15% and rainfall intensity of 45 mm hr^{-1}. The soils were selected so that ten stable and ten more erodible soils were included. Two runs were carried out to assess the effect of crusting. Erosion variables such as runoff (RO), sediment load in the runoff (SL), final infiltration rate (FI), percentage of stable aggregates (SA) and inter-rill erodibility (K*i*) were determined for both the bare soil and when covered with palm mats. When comparing bare soil to mat-covered soil, RO increased slightly, but SL decreased considerably, showing the effectiveness of the mats. Values for FI and SA remained similar from Run 1 to Run 2, while K*i* decreased slightly. When comparing selected soil parameters, SL was better correlated than RO, especially with fine sand content and negatively with kaolinite content. The stable soils contained more clay, more kaolinite and more organic carbon than the erodible soils. The estimated rate of soil loss fell from 12.67 t ha^{-1} to 5.51 t ha^{-1} when palm mats were applied to the bare soil, with the reduction being higher for the erodible soils than for the stable soils. Finally, four soils from Roodeplaat were investigated using three different slope angles and three different levels of mat coverage. Results for RO were inconclusive, but SL showed a clearer tendency to increase with increased slope angle and lower mat density. Estimated soil loss for the palm mats was on average only 22% of the bare soil.

In order to investigate the effectiveness of the mats at a larger scale, a series of field trials was carried out at four locations, namely run-off plots at Bergville (KwaZulu-Natal), Ladybrand (Free State) and Roodeplaat (Gauteng), with a field trial on the edge of an eroded area at Mabula (Limpopo). At Bergville, runoff from the palm mat plot was measured to be only 40% of that from the bare plot while at Ladybrand, where a range of treatments were compared, the comparative figure was 41% for 2008-09 and 38% for 2009-10, even though the mat density was reduced to 50% for the latter season and rainfall increased. The palm mats also performed better than all the other treatments except the fully synthetic geotextile, which did not biodegrade and was metal-reinforced. For sediment concentration at Ladybrand, the average from the palm mats was 36% of the bare soil, while there was around 60% more re-vegetation on the palm mats, compared to the bare soil. In addition, estimated soil loss fell from 21 t ha^{-1} (classed as high in South Africa) to 3.5 t ha^{-1} (classed as low to moderate) when the palm mats were applied to the bare soil.

At Roodeplaat, two sites with varying slope angle were investigated for sediment concentration, and the palm mat plots produced values of only 5.4% (5% slope) and 22.4% (2.5% slope) of the bare plots in 2008-09 and 10.2% (5% slope) and 32% (2.5% slope) in 2009-10, despite a reduction in mat density to 50% for the latter season. Splash erosion was also measured at Roodeplaat 2 in 2009-10, and also showed a significant reduction (38%) between the bare soil and the palm mats. A slightly different trial at Mabula involved pegs being inserted into the ground, and the results over two rainfall seasons showed a 5 mm accumulation of topsoil in the area covered by the mats, compared to a 2 mm loss of topsoil from the bare area. This was accompanied by a more than doubling of the amount of vegetation growth and an almost equivalent increase in organic carbon.

The various field sites were also assessed using two predictive soil erosion models, namely USLE (Universal Soil Loss Equation) and SLEMSA (Soil Loss Estimator for Southern Africa). It was not always easy to correlate the required model parameters with the specific site treatment details, so a lot of estimation had to be done. The reductions in sediment loss predicted by SLEMSA were found to be not too dissimilar to the results obtained from Ladybrand, where both sediment concentration and runoff were measured.

The economic aspects of the mat production were also investigated. In other countries of the *Borassus* Project, part-time mat production was able to provide a meaningful income to local participants. In a pilot project in KwaZulu-Natal in South Africa, however, Government-prescribed minimum wages meant that eight mats per day could be produced for R60, or R30 per square metre. This is less than commercial geotextiles, but more expensive than imported jute (which is thinner and less durable). A logical solution would be for subsidized projects to be initiated in areas where there is a strong weaving tradition within the local community, so that the twin objectives of poverty relief and environmental protection might well be achieved.

In conclusion, the palm mats have been shown to be an effective natural product, completely biodegradable yet still long-lasting, which has a significant effect on reducing runoff, sediment concentration and splash detachment, while promoting re-vegetation on a range of soils. Results from the other countries in the *Borassus* Project, using a range of available materials to make textile mats, also show beneficial effects, and would suggest that there is a variety of possibilities to use otherwise waste organic material, such as maize stalks, cane residue and various branches to construct similar mats for soil erosion control.

UITTREKSEL

Geotekstiele, beide natuurlik en sinteties, word vir ‘n geruime tyd gebruik om grondbewaring te bevorder en om erosie te beveg. Navorsingswerk is by die Universiteit van Wolverhampton (VK) gedoen om die doeltreffendheid van palmmatte in erosiebeheer te bestudeer. Dit het tot ‘n projek, wat deur die Europese Kommissie befonds is en wat tien lande betrek, gelei. Die projek het vir meer as drie jaar geduur en het verskeie werkspakette bevat. Daar is na ‘n wye reeks aspekte van die produksie en gebruik van palmblaar geotekstiele gekyk.

Soos landbou in verskeie dele van die wêreld deur die geskiedenis ontwikkel het, het die mense wat dit beeoefen het, dikwels stappe geneem om hulle omgewing te bewaar. Ongelukkig het die uitbreiding van landbou-aktiwiteite in meer moderne tye, in antwoord op versnellende bevolkingsdruk, tot 'n deurlopende agteruitgang, in beide die toestand en die langtermyn stabiliteit van die grondhulpbron, gelei. Grondbewarings navorsing het vanaf die 19de eeu plaasgevind, maar die groot versnelling hiervan was in die VSA tussen die twee wêreldoorloë met die ontwikkeling van verskeie veldpersele. Hierdie resultate het uiteindelik tot die ontwikkeling van die "Universal Soil Loss Equation" (USLE) gelei, wat gepoog het om gronderosie onder verskeie praktyke te voorspel.

In Suid-Afrika is die toenemende tempo van gronderosie vanaf die vroëe 1900's opgemerk en die toestand is deur die ernstige droogtes van die 1930's bespoedig. Hierdie toestand heers ook deur die res van Afrika en 45% van die oppervlak van Suid-Afrika is geklassifiseer as 'n hoë risiko vir gronderosie. Heelwat van die ergste sones kom in die voormalige tuislande voor, waar 'n gebrek aan kennis die problem vererger. Dit word beraam dat 'n natuurlike erosietempo van minder as 1 t ha jaar^{-1} kan tot tussen 6 en 25 t ha jaar^{-1} styg onder sekere bewerkingspraktyke en mag dalk tot so hoog soos 30-40 t ha jaar^{-1} in die ergste gevalle wees.

Gronderosie is 'n natuurlike proses, maar word versnel deur praktyke wat die plantegroei-laag verwyder. Die twee stappe in die erosieproses is die losmaak van deeltjies op die oppervlak gevolg deur hul verwydering met die helling af, wat tot 'n kaal grondoppervlak, 'n verlaagde vlak van organiese material, oppervlak korsvorming en verhoogde afloop sal lei.

Die faktore wat gronderosie beïnvloed sluit moedermateriaal, grond- en terreinfaktore, klimaatstoestande en, soos voorheen genoem, plantegroeibedekking (of die gebrek daarvan) in. Maatreëls om gronderosie te beheer sluit chemise en fisiese metodes in en laasgenoemde mag óf voorkomend (voor-erosie) óf regmakend (na-erosie) wees. Na-erosie maatreëls sluit 'n reeks grondbedekkings in, wat reënval absorbeer, bogrond stabiliseer en hervestiging van plantegroei toelaat. Amper enige soort materiaal mag gebruik word, maar die kritiese aspek is dat die bedekking lank genoeg in plek moet bly om bogenoemde aksies te laat plaasvind. Toe gewasoorblyfsels op pynappellande in die Oos-Kaap omgewing in Suid-Afrika toegepas is, het grondverlies vanaf >45 t ha jaar^{-1} tot <2 t ha jaar^{-1} gedaal.

Sintetiese geotekstiele het oorspronklik in die ingenieursbedryf ontstaan en is op verskeie plekke in die wêreld gebruik, maar hulle is nie bio-afbreekbaar nie, wat nie optimaal is vir omgewings volhoubaarheid nie. Die ideale situasie sal wees om materiaal te gebruik wat wel degradeer. ‘n Tipe materiaal, andersins ongebruik, is blare van palmbome, soos die Borassus-palm (*Borassus aethiopium*) wat in Wes-Afrika voorkom. Veldstudies in Gambië, en later in Engeland, het matte wat van palmblare gevleg is, gebruik en belowende resultate om sedimentlading en afloop te verminder, is verkry. Hierdie word ondersteun deur laboratoriumstudies in België, maar dit was nodig om die doeltreffendheid van die palmmatte in ander tropiese en subtropiese areas (soos Suid-Afrika) te toets en te kwantifiseer.

‘n Reënvalsimuleerder is ‘n bruikbare hulpmiddel in erosienavorsing. Hulle is eers in die 1940’s ontwikkel en die meganismes is later verbeter, veral in terme van ‘n roterende waterbron en hoëdruk-spuitnaalde om ‘n verbeterde verspreiding te gee. Studies is in verskeie lande uitgevoer, in sekere gevalle met ‘n draagbare simuleerder, maar dit het ‘n klein oppervlakarea. In Suid-Afrika, met samewerking van Israel, is ‘n toestel by die Navorsingsinstituut vir Grond en Besproeiing in die 1970’s ontwikkel wat in verskeie studies (insluitend grondkorsvorming) gebruik is, alhoewel werk by die Universiteit van die Vrystaat op grasland-tipe ook uitgevoer is.

Reënvalsimuleerders het beperkings van grootte, dus word groter veldafloop-persele gebruik om meer betroubare resultate *in situ* te gee. Sulke persele is oorspronklik in die VSA in die 1930’s ontwikkel om te kyk na die doeltreffendheid van verskeie tipes van organiese materiaal. Sedertdien is ‘n groot verskeidenheid veldpersele (vanaf 10 m^2 tot 300 m^2) in baie lande gebruik om verskeie erosiefaktore te bestudeer. In Suid-Afrika is die eerste persele by die Universiteit van Pretoria en by Glen (Vrystaat) gevestig, terwyl werk ook by die Universiteit van die Vrystaat en in KwaZulu-Natal gedoen is.

Studies wat kyk na geotekstiele op veldpersele is nie wydverspreid nie, want hulle ontwikkeling word gewoonlik met kommersiële ingenieursmaatskappye, wat nie altyd op navorsing gefokus is nie, verbind. Nietemin is werk in die VSA, Engeland en Israel uitgevoer. Hierdie studies het amper almal betrekking tot sintetiese materiale gehad en slegs in enkele gevalle (bv Indië en Hawaii) is natuurlike materiaal (hoofsaaklik op coir gebaseer) gebruik. Die *Borassus*-projek is die eerste detailondersoek na natuurlike geotekstiele en die doetreffendheid daarvan.

Die matte wat in hierdie studie gebruik is, word van die blare van die Lala-palm gemaak, wat baie eenders is as die Borassus-palm vanuit Wes-Afrika. Hierdie palms het groot, waaiervormige blare wat gevleg kan word in stewige, maar buigbare 50 x 50 cm matte wat op die grondoppervlak gelê word. Die matte absorbeer heelwat water en is verbasend sterk, selfs vergelykbaar met baie van die sintetiese materiale.

Reënvalsimuleerder studies by LNR-Instituut vir Grond, Klimaat en Water het ‘n reeks van 20 Suid-Afrikaanse gronde en tien mynafval materiale ondersoek met ‘n helling van 15% en reënvalintensiteit van 45 mm uur^{-1}. Die gronde is gekies om tien stabiele and tien meer erodeerbare gronde in te sluit. Twee lopies is uitgevoer om die effek van korsvorming te bepaal. Erosie veranderlikes soos afloop (RO), sedimentlading in die afloop (SL), finale infiltrasie-tempo (FI), persentasie stabiele aggregate (SA) en tussen-groef erodeerbaarheid (K_i) is bepaal vir beide kaal grond en grond wat met matte bedek is. Wanneer kaal grond met mat-bedekte grond vergelyk word, het RO effens toegeneem, maar SL het merkwaardig afgeneem, wat die doeltreffendheid van die matte wys. Waardes vir FI en SA was baie dieselfde tussen Lopie 1 en Lopie 2, terwyl K_i ietwat afgeneem het. Wanneer uitgesoekte grondparameters vergelyk word, is SL beter gekorreleer as RO, veral met fynsand-inhoud en negatief met kaoliniet-inhoud. Die stabile gronde het meer klei, meer kaoliniet en meer organiese koolstof as die erodeerbare gronde bevat. Laastens is vier gronde vanaf Roodeplaat, met drie hellings en drie verskillene matdigthede, ondersoek. Uitslae vir RO was onduidelik, maar SL het wel toegeneem met verhoogde helling en laer mat-digtheid. Beraamde grondverlies vir die palmmatte was slegs 22% gemiddeld van die kaal grond.

Ten einde die doeltreffendheid van die matte op ‘n groter skaal te ondersoek, is ‘n reeks veldproewe by vier lokaliteite uitgevoer, naamlik afloopplotte by Bergville (KwaZulu-Natal), Ladybrand (Vrystaat) en Roodeplaat (Gauteng) asook ‘n veldproef op die rand van ‘n erosiegebied by Mabula (Limpopo). By Bergville, is afloop vanaf die palmmat-plot gemeet op slegs 40% van die afloop vanaf die kaal plot terwyl op Ladybrand, waar ‘n reeks behandelings vergelyk is, was die selfde syfer 41% vir 2008-09 en 38% vir 2009-10, ten spyte dat mat-dekking vir laasgenoemde seisoen tot 50% verminder is terwyl die rëenval toegeneem het. Die palmmatte het ook beter as al die ander behandelings (behalwe die volle sintetiese geotekstiel, wat nie afbreekbaar is en met metaal versterk is) vertoon. Vir sedimentkonsentrasie by Ladybrand, was die gemiddelde syfer vanaf die palmmatte 36% van die van die kaal grond, terwyl daar 60% meer plantegroei was, in vergelyking met die kaal grond. Verder, beraamde grondverlies het vanaf 21 t ha^{-1} (geklassifiseer as hoog in

Suid-Afrika) tot 3.5 t ha^{-1} (geklassifiseer as laag tot matig) gekrimp wanneer die palmmatte op die kaal grondoppervlak toegepas is.

By Roodeplaat is twee persele met verskillende hellings ondersoek tov sedimentkonsentrasie, en die palmmatte het waardes van slegs 5.4% (5% helling) en 22.4% (2.5% helling) van die kaal plotte gelewer vir 2008-09 en 10.2% (5% helling) en 32% (2.5% helling) vir 2009-10 ongeag ‘n matdigtheid van 50% vir laasgenoemde seisoen. Spatsel-erosie is ook by Roodeplaat 2 in 2009-10 gemeet, en het ook ‘n duidelike vermindering (38%) tussen die kaal grond en die palmmat-plotte getoon. By ‘n ietwat anderse proef by Mabula, is penne in die grond ingeslaan, en oor twee reënseisoene is ‘n akkumulasie van 5 mm bogrond getoon in vergelyking met ‘n 2 mm verlies binne die kaal area. Dit het gepaard gegaan met ‘n verdubbeling in die getal plantegroei hervestiging en amper dieselfde toename in organiese koolstof.

Die verskeie veldpersele is ook deur twee erosie voorspellingsmodelle, naamlik USLE Universal Soil Loss Equation) en SLEMSA (Soil Loss Estimator for Southern Africa), beraam. Dit was nie altyd maklik om die nodige model parameters met die spesifieke behandelings op die persele te korreleer, en baie raaiwerk is gedoen. Die afname in sedimentlading wat deur SLEMSA voorspel is, is redelik naby aan die werklike resultate vanaf Ladybrand waar beide sedimentlading en afloop gemeet is.

Die ekonomiese aspekte van mat produksie is ook ondersoek. In ander lande binne die Borassus-projek, deeltydse mat produksie kon ‘n betekenisvolle inkomste aan plaaslike inwoners voorsien. In KwaZulu-Natal het ‘n Loodsprojek bewys dat met Regerings voorgeskrewe lone, agt matte per dag is geproduseer vir R60, of R30 per vierkante meter. ‘n Logiese oplossing sou wees om gesubsidieerde projekte, binne areas waar daar ‘n sterk tradisie van vlegwerk binne die plaaslike gemeenskap is, te loods, om die doelwitte van armoedeverligting tesame met omgewingsbeskerming dalk te laat realiseer.

Om saam te stel, is die palmmatte ‘n doeltreffende natuurlike produk, heeltemal afbreekbaar maar tog duursaam, wat ‘n betekenisvolle effek op die afname in afloop, sedimentlading en grond losmaak deur spatsels toon, terwyl hervestiging van plantegroei bevorder word. Uitslae vanaf die ander lande in die *Borassus*-projek, wat ‘n wye reeks plaaslik beskikbare materiale gebruik om tekstielmatte te produseer, wys ook voordelige effekte. Dit dui op ‘n reeks moontlikhede om ander “afval” produkte, soos mieliestamme, suikerriet-oorblyfsels en verskeie takke te gebruik om soortgelyke matte te maak ten einde gronderosiebeheer te verbeter.

1. INTRODUCTION AND BACKGROUND

Materials that can be laid upon the soil surface, known collectively as geotextiles, have been used in one or other form for many years in different parts of the world to promote soil conservation and to combat erosion. Such geotextiles may either be synthetic (usually some form of plastic, sometimes reinforced with wire), or natural (usually some form of fibrous material) and may either be laid on top of the soil surface or buried at shallow depth. Work which was originally carried out at the University of Wolverhampton, UK, on the effectiveness of woven mats made from palm tree leaves sourced from Gambia, West Africa (Davies, 2000 & 2005) eventually led to a research proposal to expand research into their efficiency to other areas and to other environmental zones.

Consequently, the European Commission (EC) funded a comprehensive research project (INCO-CT-2005-510745) under the Program "Specific measures in support of international co-operation with developing countries" (INCO-DEV), comprising the participation of four EC countries (UK, Belgium, Hungary and Lithuania) and six "developing" countries (Brazil, Gambia, South Africa, Thailand, China and Vietnam). The title of the project was "***The environmental and socio-economic contribution of palm geotextiles to sustainable development and soil conservation***". Since the original palm mats made in the Gambia used leaves from the Black Rhûn palm (*Borassus aethiopium*), the project become known as the "*Borassus* Project" and the South African component of the overall project was registered at Agricultural Research Council-Institute for Soil, Climate and Water (as ISCW Project No. GW/56/006).

The duration of the research project was for just over three years, namely from October 2005 to February 2009.

Under this project, a number of broad tasks, or "Work Packages" were established, as follows:

WP1 (UK): "Effects of palm leaf geotextiles on runoff and erosion of arable soils in a temperate agricultural environment".

WP2 (UK): "Construction engineering: a manufacturing and geotextile appraisal of vegetation fibre geotextiles for soil strengthening".

WP3 (Belgium): "Laboratory studies on the effectiveness of palm mat geotextiles in reducing rates of erosion by water".

WP4 (Hungary): "Investigations of the suitability of palm geotextiles in a sub-humid temperate climate".

WP5 (Lithuania): "Use of palm geotextiles for stabilization of soil and sand-dune erosion".

WP6 (South Africa): "Socio-economic production of palm geotextiles and their utilization on soil and mine dam slopes for erosion reduction".

WP7 (Brazil): "Gully management and rehabilitation of eroded slopes, through sustainable employment and social awareness".

WP8 (China): "Sustainable development of rural economies and agriculture using geotextiles as a potential soil conservation technique".

WP9 (Thailand): "Uses of geotextiles to improve water-use efficiency for sustainable multiple cropping on sloping land".

WP10 (Vietnam): "Effectiveness and economic viability of palm geotextiles".

WP11 (Gambia): "The socio-economic development of palm leaf geotextiles within rural communities in The Gambia".

From the above list of titles, it is clear that the project covered a wide range of research topics in a number of environments (Fullen *et al.*, 2011), as well as socio-economic aspects concerning the production and utilization of the palm mats. The work team in each of the participating countries carried out laboratory-based experiments and/or established field trials according to:

- The facilities and resources existing at the host institution, along with the expertise and experience of the participating researchers;
- The natural environments in the vicinity (slope, soils, agricultural practices) and their relevance to local conditions and;
- The type of materials available locally in order to produce the geotextile mats required for the study.

The activities involved are summarized in Table 1.1.

Table 1.1 *Borassus* Project: Activities per participating country

Partner Country	Type of Activity
UK	Experimental plots; mat strength
Belgium	Rainfall simulator laboratory studies
Hungary	Experimental plots
Lithuania	Experimental plots
Brazil	Field rehabilitation site; mat manufacture
Thailand	Experimental plots; mat manufacture
China	Experimental plots; mat manufacture
Vietnam	Experimental plots; mat manufacture
Gambia	Mat manufacture
South Africa	Rainfall simulator laboratory studies; experimental plots; mat manufacture

Due to the easy availability of local materials (such as rice straw, maize stems and bamboo) other than those from palm trees in the Asian participating countries (China, Vietnam and Thailand), these easily utilizable materials were used in those countries, although the overall name of the project referred to palm geotextiles. The mats produced were still kept as close to the original size and form as possible, in order to optimize comparison of results between participating countries.

From previous work and existing knowledge, it had been clearly established that placing a form of covering on the soil surface will improve soil conditions by reducing runoff and sediment load and providing a stable environment for plant growth to re-establish. It was hypothesized that palm mats would also perform these functions well. However, most existing research had focused on synthetic geotextiles, with little published or other information on natural materials, especially on new, innovative types of biogeotextiles. The *Borassus* Project thus had as its main objective the quantification of the effectiveness of these various types of mats, in widely varying terrain and environments in order to support the hypothesis with comparative analytical results (Fullen, 2009; Fullen *et al.,* 2011).

One of the original aims of the *Borassus* Project was for the various participating countries to design and implement trials with similar specifications and dimensions (obviously with variation in slope and climate. However, for a number of reasons, this was not completely adhered to, so that while the plots in South Africa and China were reasonably similar, the sites in Lithuania and Hungary concerned *in situ* measurements of roadside dunes and orchards respectively, while Thailand used much larger plots and Vietnam used conservation agriculture fields. While results from all of the participating countries were all very positive concerning the efficacy of the mats' performance, it was not possible to use a wide range of compatible data for further, more detailed, comparative research.

The various field trial sites in the *Borassus* Project represented the local conditions of the participants (Booth *et al.*, 2005). For example, while the sites in Europe were laid out on slopes in the order of 7-8% (UK and Hungary), much of the terrain used for agriculture in Asia (and thus subject to greater pressures of soil erosion) is significantly steeper and the field trials there were laid out on slopes varying from 30% (Vietnam) to almost 100% (Thailand). In South Africa, soil erosion is a significant problem even on comparatively gentle slopes, so the relatively gentle slopes occurring (between 2.5% and 9%) were representative both of much of the agricultural environment of this country as well as slopes which do show a significant degree of soil erosion if incorrectly managed. This thesis therefore focuses on the South African component of the overall project. It is concerned with studies on various aspects of how the palm mats produced locally for the project can be used for soil erosion control, using both laboratory experiments and field trials.

It will quantify how the use of palm mats benefits both the environment and, by utilizing existing weaving skills, how many local communities involved in their production may also benefit.

1.1 Publications

The research carried out in South Africa as part of the *Borassus* Project has been incorporated into a number of published articles covering the various aspects of the topic, both scientific (Bhattacharyya *et al.,* 2011; Smets *et al.,* 2011) and socio-economic (Subedi *et al.,* 2012).

In addition, a total of three papers have been published in South Africa which deal with specific aspects, including the rainfall simulator trials covered in Chapter 5 (Paterson *et al.*, 2011), the various field trials addressed in Chapter 6 (Paterson & Barnard, 2011) and a comparison of the palm mats within the wider scope of other soil conservation measures (Paterson, Smith & van Greunen, 2013).

2. LITERATURE STUDY

2.1 World situation

Agriculture, whether involving the cultivation of land or the grazing of stock animals thereupon, has been practiced for thousands of years, generally dating back to the Mesopotamians in around 6000 BC (Jones, 1952; Rimwanich, 1988) and spreading to southern Europe by 4000 BC (Hutcheson *et al.*, 1936) and further northward with time (Slicher van Bath, 1963). As populations migrated and expanded throughout history (including forced migrations due to conflict), the land that was able to be cultivated often became steeper and more inaccessible. Examples include the areas in the Andes inhabited by the Inca people from 250 to 900 AD (Métraux, 1987), as well as many severely sloping regions of south-east Asia. In many cases, these peoples realized the fragility of their resources and therefore practiced techniques designed to maximize the sustainable utilization of their landscapes, including terraces and canals which minimized erosion, whilst also creating land sufficiently gently sloping to be cultivated.

Increasing population pressure following the agrarian revolution of the 17^{th} and 18^{th} centuries in Europe (18^{th} and 19^{th} centuries in USA and other areas such as South Africa) led to an expansion of agriculture, both in terms of the physical areas involved as well as the intensity and sophistication of the practices concerned. This led eventually but inevitably to a steady decline in the condition of the agricultural soil resource (Vogt, 1949; Kellogg, 1941). The first mention of specific soil conservation research comes from a German scientist, Eval Wollny, who conducted research on raindrop impact for several different crops on different slopes between 1877 and 1895 (Rimwanich, 1988). The next acceleration in the field of soil conservation research occurred in the USA between the two World Wars, with the establishment of the USDA Soil Conservation Service, coupled with research activities such as field plots in Missouri to study the effect of soils, slope and crop type on runoff and erosion (Smith & Wischmeier, 1962).

Traditionally, the general approach to soil conservation has not changed significantly from the original principles developed in the US in the 1930's (Sanders, 1988), namely:

- Identification of the problem;
- Planning of control measures;
- Implementation of a plan.

However, this approach is always based on the remediation of an already degraded soil resource base, and it may not always be possible to rehabilitate the damaged areas satisfactorily.

The ideal scenario would be to practice sound, sensible, sustainable agricultural practices in order not to degrade the environment, as well as look at predictive methodology for future use. This approach was pioneered by trials at ten Federal Experimental Stations throughout the USA (Smith & Wischmeier, 1962). The research culminated in such developments as the Universal Soil Loss Equation (USLE) by Wischmeier and Smith in the 1960's (Wischmeier & Smith, 1965). The USLE has been refined and adapted for use in many parts of the world, and has proved useful in predicting soil erosion in many areas. The original USLE model has been further adapted, such as the *Modified* USLE, or MUSLE (Williams & Brendt, 1977) and *Revised* USLE, or RUSLE (Renard *et al.*, 1994).

2.2 South Africa

One of the first instances of concern being raised about the soil erosion problem in South Africa was at the first South African Irrigation Congress (Bradfield, 1909), where mention was made of a range of problems, such as "sluiting" ("donga", or gully formation) in several areas, mainly in the areas of the present Eastern Cape and KwaZulu-Natal. The author states that "..*you can see how the rich pockets of earth, the debris of the ages, have been eaten out*". This was followed, one year later, by an article called "The Donga" (Joubert, 1910), where the dangers of soil erosion were again highlighted.

This situation is illustrated by maps of many of the early soil surveys in the 1920's and 1930's that were carried out (usually on irrigation schemes along the major rivers), where map areas marked "erosion" are often seen. This situation was exacerbated by the droughts suffered in South Africa during the 1930's (Laker, 1993), so that by 1936, General Jan Smuts described soil erosion as "… the biggest problem confronting the country, bigger than any politics" (Hoffmann & Ashwell, 1999). Even when better climatic conditions followed drought periods, there was often no considered, logical recovery plan, but rather a desire to restock the veld as quickly as possible, despite the fragile nature of the topsoil and surface vegetation cover (Snyman, 1999).

It has been estimated that 65% of all the cultivated land and 31% of all the rangeland in Africa has been affected by human-induced soil degradation (Oldeman, 1993), which is above the world average of 38% and 21% respectively. When coupled with the steady loss of fertility caused by the expansion of generally unsustainable cropping practices and other, more detrimental forms of agriculture (Moss, 1968; Vogt, 1949), this situation poses a very real threat to food security in many areas.

In South Africa, around 45% of the country is assessed as having either a ***high*** (13%), ***very high*** (12%) or ***extremely high*** (20%) risk of erosion (Le Roux *et al.*, 2006). According to the latest available survey (Van den Berg *et al.,* 2008), remote sensing imagery has indicated that over 5 million ha in South Africa (4.1% of the land surface) can be assessed as "degraded and/or eroded".

It has been estimated that in South Africa, the rate of soil erosion per person of the population is as high as 20 times the world average (Laker, 1990). Many of the worst affected areas in South Africa are in the former "homelands", where poor land use practices coupled with a lack of knowledge of how differing soils will be affected by erosion, has led to some very severely degraded areas (Laker, 1990), especially when coupled with incorrect stocking rates (number of livestock units per hectare) and stocking ratios (cattle *vs* sheep *vs* goats). However, it has also been stated that incorrect and poorly thought-out measures, such as contour-banks in areas of Lesotho, have actually exacerbated the situation in many cases (Showers, 2005).

Under natural conditions, it has been estimated using run-off plots at Cedara, KwaZulu-Natal Province (Mathee, 1984), that while undisturbed veld (rangeland) with a 5% slope angle experiences soil loss rates of between 0.02 and 0.75 t ha^{-1} yr^{-1} (depending on local soil and rainfall conditions), these rates could easily rise to 5.9 t ha^{-1} yr^{-1} (for rotational cultivation), 7.6 t ha^{-1} yr^{-1} (for continuous maize cultivation) and as high as

25.7 t ha^{-1} yr^{-1} (for bare soil, either from fallow periods in cultivation or from overgrazing by stock). This is supported by Smith (1999), who estimates that erosion rates of between 30 and >40 t ha^{-1} $yr^{-1}$are probable in highly disturbed and/or degraded areas.

2.3 Soil erosion

Erosion refers to the naturally occurring process whereby the land surface is worn away by various agents, including water, wind and ice (Van der Watt & Van Rooyen, 1990). However, when this process is accelerated and becomes more rapid than normal, the results are often serious. Accelerated soil erosion by water occurs when the runoff of excess water over the soil surface also contains appreciable amounts of soil (Brady, 1974). It is usually caused by the removal of the vegetation layer that would otherwise prevent the soil from being removed and is a world-wide problem (Oldeman, 1993). There are two stages in the soil erosion process, namely ***detachment*** (usually caused by the impact of raindrops on the bare soil surface) and ***removal*** (whereby the detached particles are transported downslope by surface runoff). Although the particles that are detached by splash erosion usually do not move far (typically 5-15 cm vertically and 10-30 cm horizontally, depending on particle size, wind speed, raindrop characteristics and slope angle), it is a vital step in the erosion process, since this enables the particles to subsequently be transported by running water (d'Huyvetter & Laker, 1985).

The degradation or removal of the vegetation layer generally has the following general consequences (Laker, 1993):

- The bare soil surface becomes exposed to the prevailing rainfall, leading to splash erosion, soil dispersion and crusting.
- Topsoil organic matter content is significantly reduced, further destabilizing the soil surface.
- Surface crusting lessens water infiltration, leading to increased runoff, especially as slope angle increases.
- Increased runoff leads to faster water flow, with the water becoming concentrated in localized channels, or rills, which may spread or deepen as the process continues.

- Downslope water (containing removed sediment) accumulation and the possibility of off-site effects, such as flash flooding.

In addition, soil erosion contributes to the wider suite of environmental problems, such as silting up of rivers and dams, which can lead to negative effects on the aquatic life, such as development of young fish (Wood & Armitage, 1997).

The initial detachment of soil particles from the soil surface may lead to one of two forms of erosion. If the flow across the soil surface is relatively constant, the process of sheet erosion, or inter-rill erosion occurs. However, if the process becomes concentrated for any reason, such as micro-topography, influence of livestock or intermittent vegetation coverage, localized surface channels, or rills may develop, which in time may develop into deeper flow paths, called gullies ("dongas" in South Africa). The difference between the two is that cultivation can generally take place across rills, but gullies are too deep to cultivate (Le Roux, 2012).

It is difficult to measure a combination of rill and sheet erosion *in situ* due to the often complicated and interwoven erosion patterns present, as well as the difficulties in isolating each erosion type from the other (Whiting *et al.,* 2001). Using radionuclide techniques in Iowa, Whiting *et al.* found that rill erosion produced up to 29 times more sediment than sheet erosion. With the potential of such serious soil degradation if sheet erosion is allowed to occur unchecked, it is essential to attempt to quantify the process in order to try and address the problem (Stroosnijder, 2003).

2.4 Factors contributing to soil erosion potential

These can be divided into: parent material factors; vegetation (including land use) factors; soil factors; terrain factors; and climatic factors. These factors each have an effect, but in combination, the effects are often multiplied.

Parent materials contribute hugely to the erodibility of the soils that form from them. Examples are the erodible Beaufort mudstones identified by Sumner (1957) and D'Huyvetter (1985) compared to the types of geology that give rise to more stable soils, such as dolerite (Rapp, 1998; Smith, 1990). The high sodium content of such rocks as the Beaufort mudstones, coupled with the high clay content, commonly gives rise to fine-textured soils which easily disperse upon exposure, causing severe crusting and surface sealing.

Despite the potential variety of parent materials and soils occurring, few soils will erode to any noticeable degree if a satisfactory **vegetation cover** is maintained, since the vegetation will absorb much of the raindrop energy, reduce the amount of surface runoff and (especially the root mass) act as a binding mechanism to keep the soil body intact (Box & Bruce, 1995). Even after cultivation, by leaving crop residues or cover crop materials on the surface, rather than ploughing them in to the soils, runoff is significantly reduced (Gomez *et al.*, 2011). In South Africa, a study in north-west KwaZulu-Natal showed that where the soil surface was bare, runoff increased to 60% of rainfall, compared to less than 16% with a vegetation cover (Kosgei et al., 2007), while for sites in the Karoo, Boardman and Foster (2008) state that the lack of a vegetation cover will lead to at least a 10-fold increase in runoff.

It is important to note that, while any type of vegetation, such as trees and shrubs, will play an important role in stabilizing topsoil, it is the basal (ground-level) cover, mainly in the form of a grass layer, which will be especially effective (Snyman & van Rensburg, 1986). The importance of such a vegetation layer in tropical areas was shown by Defersha & Melesse (2012), where results from Kenya showed that grassed plots produced between 33% and 53% of the sediment than similar bare plots.

Soil factors include *clay mineralogy*, where soils dominated by smectite are much more susceptible to erosion than those dominated by kaolinite (Rapp, 1998; Bühmann *et al.*, 1996). Even when a relatively small portion (approximately 15-25%) of the soil mineralogical fraction comprises illite or smectite, such soils are much less stable than where kaolinite alone is dominant (Bloem, 1992; Stern, 1990). *Sodium* levels, where higher exchangeable sodium percentage (ESP) values often lead to increased erosion (Levy, 1988; Rapp, 1998, Bloem, 1992), are also a critical factor in soil erodibility. Problematic ESP values are typically 12 or more (Laker & d'Huyvetter, 1988), although Bloem and Laker (1994) found problems with soil erosion at lower ESP levels than 12%.

According to Evans (1980), particle size distribution is among the most important parameters, and that while sands and coarse loamy sands are generally not erodible due to rapid infiltration, soils with a high silt and/or fine sand fraction are particularly susceptible. Smith (1990) showed that citrate-bicarbonate-dithionate (CBD) extractable iron levels in "stable" soils derived from basic igneous rocks were much higher than in the less stable soils derived from acidic rocks.

The main **terrain** factors are the angle, length and shape of the slope, especially a combination of long, steep slopes, such as in the Lesotho Highlands (Smith *et al*, 2000).

When the slope ***angle*** increases, then the speed of surface runoff will also increase, meaning that any sediment will more easily be transported by the runoff, and will be more difficult to deposit (Boardman & Foster, 2008). With increased slope ***length***, even minimal runoff can become a serious problem if there is nothing to stop the process over a significant distance. This is very evident on parts of the Springbok Flats, north of Pretoria, where clay-rich vertisols derived from basic igneous rocks predominate. Here, despite prevailing slope angles of 1-2% at most, perpendicular contour ridges are necessary at approximately 300 m intervals to prevent significant runoff on fields where slopes may be more than 2 km long. Slope ***shape*** is also an important factor, and convex slopes will typically be the most problematic, with water acceleration downslope (d'Huyvetter & Laker, 1985). All of the above supposes that slopes are relatively constant and/or even, but where micro-topographical features, such as basins, depressions or channels occur, the prevailing slope factors can cause flow to be concentrated in these parts, and it is often here where significant erosion commences.

When the terrain is combined with susceptible parent materials, the erosion susceptibility drastically increases. This is clearly illustrated by d'Huyvetter and Laker (1985), who found that, for three catchments in the former Ciskei, the previously applied slope threshold value for cultivation of 12% (5.4^{o}) was too high for all but the most stable (dolerite-derived) Shortlands soils and that for the most erodible (mudstone-derived) Valsrivier and Estcourt soils, the slope threshold for cultivation was as low as 3.2% (1.4^{o}).

The ability of the prevailing rainfall (along with the runoff thus caused) to cause soil detachment and transport is called ***erosivity*** (Lal & Elliot, 1994). The critical **climatic factor** is thus rainfall, both the frequency and intensity thereof. This is especially crucial in the summer rainfall areas of South Africa, where a large percentage (generally 80-85%) of the annual rainfall occurs between October and March as thunderstorm events (which are often intense) and where the seasonal rainfall can vary from year to year by a factor of 400% or more (ARC-ISCW, 2006).

Rainfall intensity in these areas of South Africa, as in many tropical areas of the world, can be significant. Many such rainfall events produce precipitation of more than 25 mm (1 inch) in a comparatively short time (often as short as 20-30 minutes) (ARC-ISCW, 2006). It is therefore not the amount of precipitation *per se* which will cause excessive amounts of erosion, but a combination of the specific amount of precipitation with the intensity (and frequency) at which it occurs, as well as the antecedent soil water content.

In the former Ciskei, D'Huyvetter (1985) concluded that for virtually all soil forms occurring, erodibility decreased with increasing rainfall. This is supported by Laker (1990), who stated that increased rainfall would lead to more intense weathering, more advanced soil formation and a greater degree of soil stability. One of the correlating factors with increasing rainfall is often the increased leaching of soluble cations from the soil profile, so that exchangeable sodium percentage (ESP) values, often a strong indicator of erodible soils, are lower (Laker & d'Huyvetter, 1988).

A map of South Africa (Figure 2.1) shows the distribution of various classes of sediment delivery potential (Le Roux *et al.*, 2006), where the areas with the highest potential are a combination of erodible parent materials and/or steeper slopes, concentrated in parts of the Western Cape, Eastern Cape, KwaZulu-Natal and Limpopo Provinces.

This potential map agrees well with actual sediment production values (Smith *et al.,* 1995 & 2000), with these susceptible areas often being even more severely impacted when human-induced factors (population pressure, overgrazing of livestock, cultivation of the wrong soils) are present.

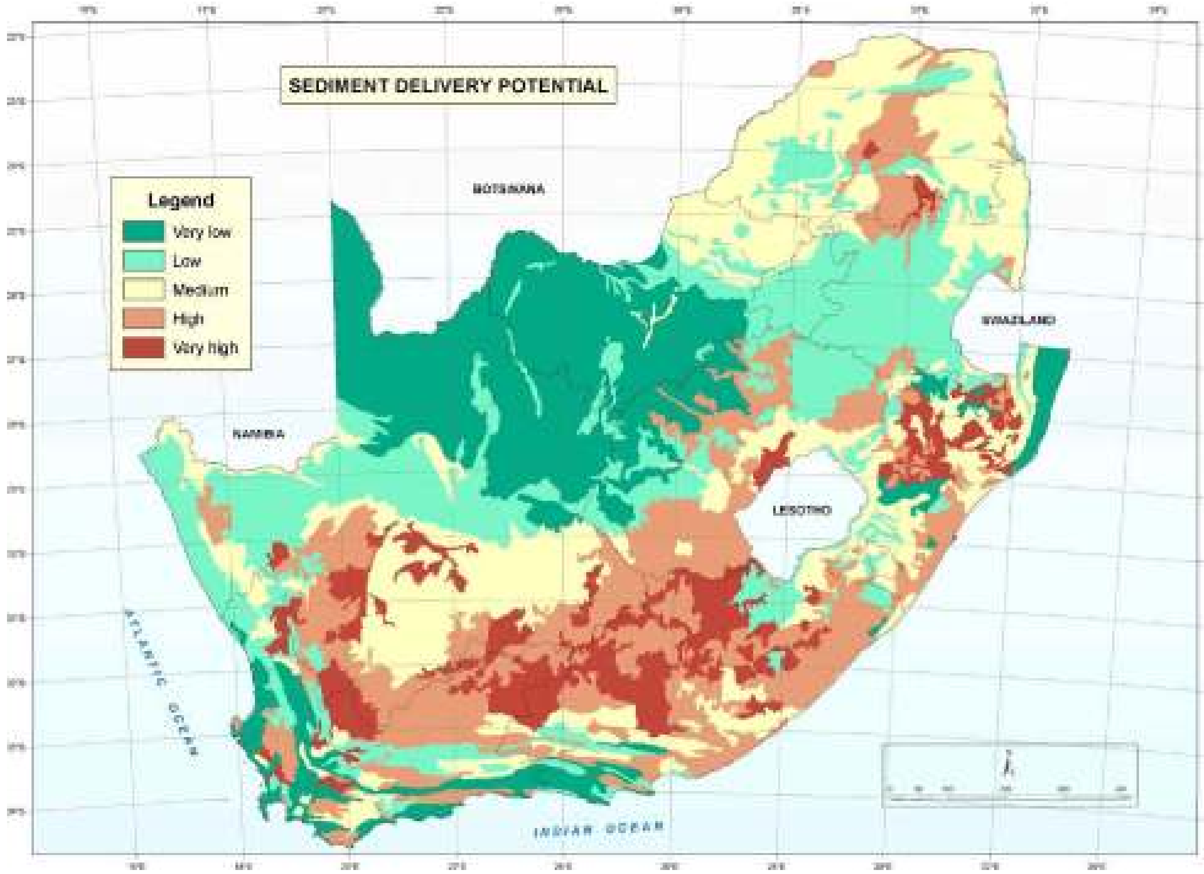

Figure 2.1 *Sediment delivery potential map of South Africa*

2.5 Erosion control measures

Where soil erosion by surface water is concerned, a range of preventative measures can be taken. These can be divided into chemical and physical.

Chemical measures include materials such as phospho-gypsum and various polymers to try and reduce soil crust formation and thus to increase infiltration (Smith, 1990; Stern, 1990). However, such measures are generally applied in conjunction with other physical steps, such as contouring.

Physical activities can be divided between ***pre-erosion***, or preventative measures (reduced or restricted tillage, contouring or terracing, mulching etc) and ***post-erosion***, or curative measures (such as surface covering, re-vegetation, slope stabilization etc).

It is obviously more desirable, not to mention cost-effective, to apply relevant, sustainable preventative measures on all land surfaces and if this was carried out, there would be no need for any erosion studies. However, in many areas this is unfortunately the exception, rather than the rule, so that detailed research into the erosion processes, as well as possible mechanisms to address the problem, is required (Laker, 2004).

The second of the above scenarios, namely post-erosion measures, is the one with which this thesis is concerned, specifically in the field of surface covering. The aim of surface covering is quite simply to act as a mechanism to intercept as much precipitation as possible before it can strike a bare soil surface. In this way, the damaging effects of soil particle detachment, surface sealing and increased overland flow are significantly reduced (Snyman, 1999).

Virtually any type of material may be used as a surface cover. This will range from plant or crop residue that remains on the surface, to branches, leaves, twigs, cuttings and many types of compost (Xiao & Gomez, 2009). However, especially on steeper slopes, the most effective type of cover will be that which will remain in place, especially in the susceptible initial stages of soil protection, before a vegetation cover has had a chance to re-establish itself. A study in Belgium (Smets *et al*., 2008) looked at a range of surface coverings, including straw, hay, cut grass and crop residues in order to establish a "mulch factor" (MF) which was a ratio of sediment load with a mulch cover to sediment load from the corresponding bare soil. Even allowing for experimental variation (plot size, slope etc), the MF varied between 0.011 and 0.132, more than a ten-fold difference.

In the pineapple growing areas of South Africa, soil erosion is a serious problem, due mainly to the fact that many of the cultivated fields were established on erodible, "duplex" type soils and sloping topography without much thought to the environmental sustainability (Theron, 1988). However, Hill (1990) used run-off plots at two sites to show how the residue of the pineapple crop, known as "plok", can be applied as a surface mulch between the cultivated rows, and when this is combined with correct contour-based cultivation, soil loss can be reduced from >28 t ha^{-1} and 23 t ha^{-1} to <2 t ha^{-1} on a 12% and a 5% slope respectively.

Geotextiles (materials specifically designed to cover the soil surface and to stabilize areas susceptible to, or suffering from erosion) were originally used mainly as civil engineering applications in many areas and may be defined as a permeable, textile material used in conjunction with soil, rock or other geotechnical engineering-related material (Rickson, 1988). However, they are becoming increasingly used in agriculture and other applications where soil stabilization is required (Morgan, 1987).

Many of these geotextile materials are synthetic, taking advantages of advances in materials technology, as well as having the ability to adjust the mesh size as conditions dictate. Agassi (1997) looked at sloping banks of earth dykes in Israel, finding that runoff was reduced significantly by using geo-membranes, with the most effective type showing a reduction from over 50 mm hr^{-1} to less than 20 mm hr^{-1}. However, he also noted that plant emergence was almost non-existent, due mainly to the fine mesh.

Thus, from the point of view of environmental sustainability, the more desirable geotextiles are natural products that will biodegrade with time as vegetation re-establishes itself (Davies *et al*., 2006). Examples of such natural products include jute or coir-based fabrics, again with mesh of varying sizes. Vishnudas *et al.* (2006) studied coir strips on dam embankments in a poor community at Kerala, India and found that soil water more than doubled, while length of grass increased by more than one third compared to bare soil. They also found that this was an excellent way of using a waste product (less than 10% of the coconut husk is used in production) and that by utilizing local labour, the product was extremely cost-effective. Also in India, Jute has been used to construct roads in rural areas (Basu *et al.,* 2009).

Rickson (1988) examined a range of geotextiles, both synthetic and natural, and found that soil loss by splash erosion was as little as 18% (under low intensity rainfall) and 11% (under high intensity rainfall) of the bare soil surface. She concluded that among the benefits of natural fibre geotextiles are: the thickness of the fibres themselves, as well as the favourable water retention properties, both of which help to absorb water and maintain contact with the soil surface. Gimenez-Morera *et al.* (2010) looked at cotton-based geotextiles, and found that the soil surface was protected, leading to increases of around 50% in soil water content.

One source of organic material, which would otherwise go to waste, is the long fronds of various types of palm tree. Palms, which include the oil palm, coconut palm and date palm, are known world-wide as supplying a wide range of products to local communities, from food and fibre to oil and milk, as well as building and roofing materials (Ecenbarger, 2005). The palm leaves are woven into many articles, such as mats in Thailand, roofing thatch in Samoa and even sails in Indonesia.

In a project initiated at the University of Wolverhampton, UK, field studies in West Africa (Davies, 2000) suggested the potential of woven palm leaf mats from the Borassus, or Black Rhûn palm (*Borassus aethiopium*), in combating soil erosion. These mats were then tested on research plots in the UK (Davies *et al.,* 2006), where promising results were obtained. Initial results showed that on 10 m long research plots, cover of Borassus mats reduced sediment load in surface runoff by 80% and the runoff itself reduced by 68%. However, the effectiveness of the mats in more severe, tropical and sub-tropical conditions (such as those in South Africa) had not yet been fully assessed.

Extensive reviews suggest palm leaf materials are not currently used in the geotextile soil erosion control industry (Smets *et al.,* 2007). After Cocos (coconut), Borassus-type palms (including the Lala palm found in southern Africa) are the most widely distributed of the *Palmae* and have been used extensively for over 6 000 years, providing over 800 resources for human use (Davis & Johnson, 1987). Preliminary investigations suggest palm-mat geotextiles could be an effective and cheap soil conservation method, with enormous global potential. Under laboratory conditions in Belgium, Smets *et al.* (2007) found a reduction in soil loss of between 83% (45% slope) and 95% (15% slope), when comparing Borassus palm mats to bare soil.

One of the other areas where palm mats have been tested concerns the protection of archaeological sites on the Isle of Man (UK) in the off-season (Fullen, 2009), where it was important to protect such sites in the winter “off-season”. Here, over two winter seasons, palm mats were found to possess the optimum combination of longevity, flexibility and time required to put in place and remove, compared to either jute sheets, or coverage with soil and other organic material.

2.6 Rainfall Simulator

Simulated rainfall, applied in a form as near as possible to natural rain, but under controlled and measured conditions, is an effective and useful tool in soil erosion research. However, despite the many advantages, the characteristics of the simulated rain must be clearly understood in order to accurately analyze the results (Meyer, 1965; Mutchler & Hermsmeier, 1965), as well as the limitations of using such an artificial, laboratory-based environment (Smets *et al.*, 2007).

Probably the first rainfall simulator was reported by Parsons (1943), called the "dripolator" rainfall simulator. It used yarn hanging from gaps in muslin cloth over chicken wire in order to concentrate the water and to form drops. However, this type of simulator could only apply drops to fixed points and drop size was more than 4 mm. This was improved upon by Ekern and Muckinhirn (1947), who used a simulator with hypodermic needles, which was able to give drop sizes below 2.8 mm, as well as an improved spread of fall, due to a vertical falling distance of some 35 feet (10.67 metres). Then, Mutchler and Moldenhauer (1963) developed a simulator using rotating tubes, where the intensity and drop size of an improved range of natural rainfall characteristics could be produced.

However, the most effective method of rainfall simulation is by using nozzles, with the water under pressure. Mutchler and Hermsmeier (1965) report that the first serious work in nozzle development occurred due to the interest in rainfall simulation by soil conservation workers in the US Bureau of Standards in the 1930's, following which, various types of nozzle, dubbed "D", "E" and "F" were developed. Nozzles thus enabled rainfall intensity to be increased and to be better regulated, so that intensities of around 4 to 4.5 in hr^{-1} (102 to 114 mm hr^{-1}), which approximated to the maximum naturally occurring intensities, could be established (Smith & Wischmeier, 1962). In Israel, a rotating-disc rainfall simulator was developed whereby water pressure as well as the nozzle size and direction, could be regulated to vary the flow rate and rainfall distribution (Morin *et al.*, 1967). The main aim was to achieve the combination of relatively low rainfall intensity, together with large drops and high impact velocity, to best simulate the kinetic energy of natural rain.

Studies using rainfall simulation have been carried out in many areas, varying from shrublands and natural (though overgrazed) grasslands in Mongolia (Kato *et al.*, 2009), rangeland in Spain (Cerda *et al.,* 1998) and rehabilitated mine land in Australia (Loch, 2000). One of the most recent studies (Chul Hee Won *et al.,* 2012) looked at woven rice straw mats in Korea. In several cases, a portable, field-based rainfall simulator was used (Seeger, 2007; Kato *et al.,* 2009), which has the advantage of being able to be used on natural soils *in situ*, but Seeger (2007) reports that the limitation of a small test area (0.28 m^2) causes significant variability in the results. This finding was supported by Smets *et al.* (2007 & 2008) in research at the University of Leuven in Belgium.

Work in South Africa has largely been based on the rainfall simulator developed at ARC-ISCW, based on the original work done in Israel (Agassi & du Plessis, undated), which led to a number of studies, mainly concerning crusting (Smith, 1990; Stern, 1990), as well as clay mineralogy and cations (Levy, 1988). However, work at the University of the Free State has used a rotating-boom rainfall simulator on field runoff plots at the University's experimental farm, mainly looking at soil loss and runoff under various types of natural grassveld, ranging from pioneer species to climax vegetation (Snyman *et al.,* 1986 & 1987).

2.7 Run-off Plots

Rainfall simulators are of necessity limited in size, both due to the physical construction, mass of soil required and water supply. The next logical step in assessing surface erosion is thus to use a larger surface area, which more closely approximates the processes occurring in a field- or hillslope-size area, as well as using generally undisturbed soil (Smets *et al.,* 2008 & 2011), at least as far as the soil profile is concerned.

The first field trials to try and quantify run-off and sediment load were prompted largely by the soil losses caused by the drought-related "dust-bowl" conditions in the 1930's and took place across twelve states in the mid-West corn belt of the United States from the 1930's and 1940's onwards (Smith & Wischmeier, 1962). Despite variations in results from year to year due mainly to the variation in prevailing rainfall, such plots have provided valuable data to researchers. Most of these trials involved the study of the effectiveness of various types of mulching in croplands, and the data collected from these trials was collated and co-ordinated by the Runoff and Soil Loss Laboratory at Purdue University, Indiana (Smith & Wischmeier, 1962).

The size of run-off plots used in field experiments also varies. From the original American research, the standard size of plot used was 0.01 acre (72.6 x 6 feet, or $\pm$ 22 x 2 m), and the data from these plots were used to calculate the soil erodibility factor in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965; Wischmeier, 1976). This plot size has thus become widely known as a "Wischmeier Plot". However, many different plots sizes have been used and Smets *et al.* (2008) reported on 41 studies, which include both field and laboratory studies.

While the laboratory trials (generally using a rainfall simulator) reviewed by Smets *et al.* varied from 0.2 m^2 to 0.4 m^2, the field plots varied from 10 m^2 to 300 m^2 (average 52.4 m^2; n=15). These plots involved a large range of mulch types, such as straw, crop residue, cut grass and woodchips (Smets *et al.*, 2008), on slopes varying from 1% to over 30% and the general finding was that the effective mulch factor (MF, the ratio between the rate of soil loss from a bare slope and one covered by a mulch) increased linearly with increasing plot length.

Runoff plots have been established in many parts of the world, such as below erodible logging roads in Australian forestry sites (Croke & Nethery, 2006), in semi-arid grasslands in Mongolia (Kato *et al.*, 2009) and against earth dykes in Israel (Agassi, 1997). A study by Barthes *et al.* (2000) compared plots in three tropical countries, namely Benin (240 m^2), Cameroon (100 m^2) and Mexico (800 m^2) and found that erosion increased and aggregate stability decreased with increasingly intensive cultivation practices. In the Mediterranean area, a similar study by Gonzalez-Hidalgo *et al.* (2007) looked at plots varying from 8 m^2 to 40.3 m^2 in Spain, Italy, Morocco, France and Portugal and the relation between erosion and rainfall. They found that in some cases, up to 50% of annual erosion was caused by only three specific daily rainfall events.

Other studies in Spain have also used runoff plots to look at erosion. Castillo *et al.* (1997) found that on a 75 m^2 plot, vegetation removal increased sediment load by 127%, while Desir and Marin (2007) used a 400 m^2 plot over 12 years to show that a rainfall intensity threshold of around 6 mm hr^{-1} was significant for erosion occurrence. Trials in Shropshire, U.K. (Mitchell *et al.,* 2003) looked at the effectiveness of jute matting compared to both grass cover and bare soil and found over 95% reduction in sediment yield, despite rapid deterioration of the jute.

In South Africa, some of the first research was carried out in the 1940's and 1950's, where field plots have been used at the University of Pretoria (Haylett, 1960), at Glen (Du Plessis & Mostert, 1965) and at Cedara (Mathee, 1984) to compare runoff between a range of cultivation treatments. Similar field plots have been used to look at how no-tillage practices reduced runoff by around 50% at a site in KwaZulu-Natal (Kosgei et al., 2007), while at the University of the Free State, (Snyman & Opperman, 1984; Snyman & Fouche, 1991), studies into the erosion arising from differing veld (rangeland) conditions showed that surface runoff increased from 4.75% of rainfall for "good" veld to 10.21% for "poor" veld.

2.8 Geotextiles

The use of geotextiles on field plots to assess their effectiveness in combating erosion is much more restricted than the studies of other mulch materials (Rickson, 2006). This is due primarily to the fact that most geotextiles were first developed for use in stabilizing engineering slopes, mainly in the United States, from the 1950's onwards (Sutherland, 1998a). Such applications obviously had a large monetary aspect, especially with penalties imposed for failing to comply with various relevant legislation such as in USA, UK (Rickson, 2006) and Australia (R.J. Morse, PO Box 987, Picton, NSW – personal communication). In Australia, for example, construction sites are monitored to ensure that excessive sediment does not leave the site due to runoff, and contractors may be penalized for breaching these conditions.

Sutherland (1998a) states that it is surprising that more work on geotextiles, as opposed to other surface coverings, such as mulches and residues, has not been carried out, but he speculates that many of the geotextiles were commercially developed, so that much of the data could have been withheld by such companies, who were not interested in "pure" research publications. Also, according to Rickson (1988), many geotextiles were developed by civil engineers with only the basic knowledge of, or interest in, possible agricultural applications.

As part of a summary of existing research into geotextiles, Sutherland (1998a and b) looked at the properties of a range of commercially available (USA-based) products, virtually all of which were produced in rolls which could be applied to the surface and cut to the desired size, but which were not biodegradable. Sutherland states that such materials typically range from 250 to 700 g m^{-2} (average 440 g m^{-2}, n=34) with an average of 49% open space and a tensile strength of between 1 and 10 kN m^{-1} (average 5.4 kN m^{-1}, n=14). He also states that only in the late 1960's, such as for work carried out by Swanson *et al.* (1967), was any quantitative work carried out on the effectiveness of the products, such as loss of seeds prior to re-seeding, as well as the phosphorous content of the topsoil.

In somewhat similar studies to that of Sutherland (1998a), Rickson (2006) also looked at the effectiveness of a range of products in the UK, which were also mostly non-biodegradable, in controlling splash detachment and sediment transport. The density ranged from 265 to 700 g m^{-2} (average 417 g m^{-2}, n=7) with an average open space of 57%. In another study in Israel, Agassi (1997) used five synthetic geomembranes, ranging from 90 to 200 g m^{-2} (unfortunately the mesh sizes and tensile strength values were not recorded).

Little work has been carried out into any type of geotextile woven (or otherwise created) from organic plant material. Only isolated references to research into coir-based (coconut fibre) geotextiles are found, such as from Vishnudas *et al.* (2006), who looked at their effectiveness in stabilizing steep (70^{o}, or 155%) slopes on reservoir banks in India, finding that the coir matting improved grass re-establishment by around 50%. Sutherland and Ziegler (2007) looked at three coir-based products in Hawaii, finding that sediment production from a coir-covered surface was between 2% and 22% of that from bare soil.

Following initial fieldwork in Gambia, West Africa, looking at mats woven from palm leaves, work started by Davies (2000 & 2005) was developed at the University of Wolverhampton, UK, and a comprehensive assessment of palm mat geotextiles in a variety of countries was thus carried out as part of the EU-funded Borassus Project (Fullen, 2009). Findings from runoff plots with a 15^{o} (33%) slope in Shropshire, UK concluded that Borassus palm mats reduced runoff by 83% and sediment load by 93%, compared to bare soils (Bhattacharyya *et al.*, 2008).

Results from other countries (Fullen, 2009; Bhattacharrya *et al.,* 2011) confirmed this, with a significant reduction in runoff reported from all of the participating countries. In studies carried out in orchards and vineyards in Hungary, the reduction was around 25% (Kertesz *et al.*, 2007), while a reduction of as much as 95% was achieved on roadside plots on sand dunes in Lithuania (Jankauskas *et al.*, 2008).

For more tropical environments, the results were also impressive. A reduction in runoff of around 73% was obtained for experimental plots using subsistence agriculture in Vietnam (Dao Chau Thu *et al.*, 2006) and around 87% on research plots at the Agricultural University of Yunnan, Kunming in China (Xing Xiang-xin *et al.*, in press), while sediment load values reduced by between 57% on research plots in Thailand (Panomtaranichagul *et al.*, 2006).

2.9 Conclusion

The field of geotextiles is wide, and much research has been carried out, but a comparatively small portion of this has addressed soil loss, especially in relation to agriculture. Even less work has been done on natural geotextiles in this situation, compared to the more well-known synthetic equivalents. There is thus a significant knowledge gap regarding the importance and effectiveness of many of these natural geotextiles, including low-input, more basic materials such as palm leaf mats. The quantification of these products is an area that needs to be thoroughly investigated.

3. OBJECTIVES

The broad aim of this study is to evaluate and quantify the effectiveness of woven palm-leaf geotextile mats in controlling soil erosion, using a number of South African soils. As discussed in Section 2, there have been a number of studies previously carried out into the effectiveness of geotextiles, but these have concentrated mainly on the synthetic materials, with little attention paid to natural materials, especially in the detailed quantification of their effectiveness in specific trial situations over a range of environmental conditions.

The study will look at the effectiveness of the geotextiles on **sheet erosion**. Sheet erosion involves the detachment and transport of soil particles by rain splash erosion and transport by shallow, overland flow which is relatively consistent across the soil surface (Lal and Elliot, 1994). Rill erosion is a process in which the overland flow becomes channeled and numerous small channels of several centimetres up to about 30 cm in depth are formed (Bergsma *et al.,* 1996). Since sheet and rill erosion normally occur together, and since the boundary between the two processes is often extremely undefined, it is virtually impossible to separate them. However, rill erosion cannot develop without the process of sheet erosion occurring as a mechanism to eventually concentrate the runoff. Sheet erosion is thus the original erosion process, and by controlling this process, it will serve to restrict the subsequent formation of gullies. This study therefore focuses on the process of sheet erosion as the precursor of later gully/donga development.

The aim is to use a variety of methods, over several seasons, to improve this quantification and to provide reliable information that may be used for decision-making within a specific soil (sheet) erosion situation. This will help to both control the further development of such erosion as well as to reverse the process and to allow the improvement of the soil surface environment.

Also, virtually all of the current use of geotextiles in South Africa involves commercially manufactured materials, most of which are imported. It would appear that there is thus definite potential for a locally sourced and manufactured, low-level yet effective product which could be of direct benefit to communities that would otherwise not be able to afford or obtain any type of soil surface protection.

According to the guidelines of the South African National Landcare Programme (Department of Agriculture, 2001), one of the themes of Landcare is "Soilcare", which focuses, amongst others, "…. on issues of soil acidity and the reduction in soil fertility caused by the selective removal of fine particles, nutrients and organic matter. This theme ***will also address issues on soil erosion, including building innovative structures*** to combat (it) …"

It is therefore clear that the application of palm mats will attempt to address the central concept of Soilcare, including the combating of soil erosion, directly.

The following aspects will thus be studied:

1. Quantification of palm mat effectiveness

- Using a rainfall simulator, the performance of the mats on a range of soils in a controlled environment can be tested;
- By establishing a number of field sites in different areas of South Africa, the effectiveness of the mats in a variety of natural environments can be assessed, compared to bare soil surfaces as well as synthetic geotextiles;
- By varying the physical layout and density of the mats, it can be determined whether this will make a significant difference to sediment detachment and removal.
- Guidelines to assess the potential beneficial effect of the palm mats in various conditions and situations can be developed.

2. Socio-economic production of palm mats in the South African environment

- By utilizing locally produced mats, meaningful income and employment could be created for the benefit of rural communities. In addition, a methodology whereby locally occurring soil erosion could be countered could be provided.

4. MATERIALS

4.1 Mat manufacture

The mats used in the study are made from the leaves of the Lala palm (*Hypahene coriacea*), which is a naturally-occurring tree along the lower-lying coastal margins of southern Africa (Coates Palgrave, 2003), and is closely related in both appearance and environment to several other species, most notably the Black Rhûn palm (*Borassus aethiopium*), which occurs extensively in west Africa, as well as parts of Asia.

Figure 4.1 *Lala palm tree*

The Lala palm grows to a mature height of around 3-5 m, producing large, fan-shaped leaves which can easily be harvested. Each leaf may easily exceed 1 metre in diameter, with around 30 fronds of around 2-5 cm width, radiating from a central point (Figure 4.2).

Figure 4.2 *Detail of palm leaf, showing pointed "fronds"*

In order to manufacture the mats used, the leaves of the Lala palm were cut, and the fronds stripped from the hard central spine (Figure 4.3a). While still relatively green and pliable, these fronds were then woven, using a simple 50 x 50 cm wooden template (Figure 4.3b), into a more or less regular grid form. The edges of the mats were then finished off by being roughly bound to form a more solid edge (Figure 4.3c).

In this way, one 50 x 50 cm mat could be produced in no more than one hour, especially by inhabitants of areas where there is a strong local culture of weaving of plant materials, such as KwaZulu-Natal and Mpumalanga.

Once completed, the mats are reasonably rigid, yet flexible enough to easily be laid on the ground to form a continuous adjoining sheet. The mats are then connected to each other using fibres (if required), before being fastened to the ground by sticks, logs or stones, depending on what is available.

Figure 4.3 (a-c) *The mat-making process (**a** - the cut fronds ready for weaving; **b** - using the template frame; **c** - the finished mats)*

4.2 Mat characteristics

4.2.1 Composition

The mats would obviously vary somewhat, being hand-made, but in general, each one measures approximately 50 x 50 cm (surface area 0.25 m^2), which through experience (from Gambia, Brazil and also in South Africa) has been shown to be more or less the maximum size that could comfortably be handled by one person in the manufacturing process. Each mat usually has 10 interlocking, perpendicular strands, so that the "mesh" size is around 4.5 x 4.5 cm. This means that the average surface coverage of each mat is around 40% (therefore approximately 60% open space), which was carefully measured by digitizing a detailed photograph of a mat. Mat thickness is approximately 8-10 mm.

Selected physical and chemical properties of the palm mats indicate their suitability as mulch. The mats add 1.3 kg of dry organic matter to each m^2 of soil (Table 4.1). They have a water retention capacity of 1.8 l m^{-2} (Kugan *et al.*, 2008). Their N, K, S and P percentages are high and the Al content is low. The palm mats have, generally speaking, the ideal chemical composition of organic mulch (Bühmann *et al.*, 2007).

Table 4.1 Average values of selected parameters of a palm mat

DM kg m^{-2}	**SCF** %	**WR** kg m^{-2}	**C/N ratio**	**Ash** %	**N** %
1.332	40-45	1.850	56.0	3.7	1.01

Na *	**K***	**Mg ***	**Ca ***	**Al***	**S***	**P***
1450	9400	1400	1600	50	1474	1463

DM: dry mass; **SCF**: soil cover factor; **WR**: water retention; *: mg kg^{-1}.

Due to the flexibility of the mats (being made from natural palm fibres), it was found that as they start to become moist following rainfall (whether simulated or natural), they adhere well to the soil surface. This helps in creating a virtually continuous barrier to surface flow as well as speeding up the decomposition process as re-vegetation occurs under the prevailing conditions of water containment.

4.2.2 Decomposition

As the mats become affected by environmental conditions, mainly the combination of heat (from the sun) and water (rainfall), they will begin to decompose *in situ*. To try and quantify this process, mats were collected at different times from the various field sites where they had been applied. The figures are somewhat of an approximation, as it was not possible to sample the exact same mat each time and there are a few non-controllable variables, such as condition of the palm fronds at manufacture, conditions and length of storage etc. However, the retention of various soil properties is shown in Table 4.2 (the periods involved before sampling varied between 9 and 19 months) (Bühmann *et al*., 2007).

Table 4.2 Change in mat properties over time

Property		"Average" Original Value	Ratio of weathered/ unweathered mats
Nitrogen	%	0.8 – 1.1	0.72 – 0.89
Carbon/Nitrogen Ratio		46 - 59	0.82 – 1.02
Sodium	$mg\ kg^{-1}$	780 – 1 740	0.16 – 0.31
Potassium		8 100 – 11 700	0.10 – 0.23
Magnesium		1 120 – 1 810	0.62 – 0.86
Calcium		1 080 – 1 810	0.50 – 0.94
Phosphorous		960 – 1 640	0.32 – 0.51

From the above table, it can be seen that organic carbon and nitrogen, as well as (to a slightly lesser extent) calcium and magnesium are retained. Potassium and sodium seem to be leached quickest, although not completely, and most of the elements are therefore still available to plants for a significant time as the re-vegetation process starts to occur after the mats are laid in place.

If the potential contribution of the mats to plant nutrition is considered, a dry matter amount of greater than 13 t ha^{-1} would be added, which with observed decomposition processes and rates (Table 4.2) would eventually add 106 kg N, 60 kg P and 152 kg K per hectare.

The mats also play a role in helping to increase soil moisture content when compared to similar bare soils. Kertesz *et al. (*2011) compared several of the countries in the Borassus project where soil moisture studies were carried out and found that in each case, the soil moisture content under the mats increased. The increase varied between 9% (Vietnam) and 35% (Brazil), where the prevailing sandy soils would be expected to lose water rapidly through evaporation and drainage in the natural, bare state.

4.2.3 Mat strength

Despite the fact that they are composed of organic, not synthetic materials, when the palm mats were studied in the Engineering Faculty at the University of Wolverhampton, it was found that the Borassus palm mats have favourable physical properties regarding their strength (Kugan *et al.*, 2008). The similarity of the Borassus palm and Lala palm mean that the results obtained will be very representative of the mats used in this study.

Since the mats are approximately square, there is no specific weaker dimension, as is sometimes the case with other geotextile fabrics, such as jute, where a roll of jute may be significantly stronger in the longer (downslope) direction than the shorter (cross-slope) direction, where tears may more easily occur.

It was found in the studies at Wolverhampton that the tensile strength of the Borassus palm mats was around 2.5 - 2.6 kN m^{-1}, which compares well to a range of commercially produced geotextiles (Sutherland, 1998a). In that study, of the 14 geotextiles that were listed, seven had higher values than the palm mats, while seven were lower. Also, Kugan *et al.* (2008) found that in the short-term (± one month), neither continuous soaking nor burial of the mats had any appreciative effect on tensile strength, suggesting that exposure to rainfall on the soil surface should not lead to significantly rapid deterioration or decomposition, an important property in combating soil erosion.

A more recent study (Kugan & Sarsby, 2011) suggests that the mats lose an appreciable degree of strength and integrity when buried, either in permanently or partially saturated soil, for periods of 12 months or more. This confirms that, unlike certain other biotextiles (mainly synthetic), the mats cannot be used as a subsurface layer to improve topsoil cohesion, but are best applied on the soil surface, where their adhesion, soil nutrition and soil moisture retention properties are optimally utilized.

5. RAINFALL SIMULATOR STUDIES

5.1 Introduction

Many regions, including South Africa, are characterized by relatively long dry seasons followed by shorter, wetter rainy seasons, often with high intensity precipitation events, inducing high runoff and increased erosion rates (Boardman *et al.*, 2003). South Africa comprises an area of just over 122 million ha and about 80% of the country falls into the above climatic category. On-site effects of this removal of topsoil are related predominantly to the loss of organic matter and plant nutrients, which averages 3 kg N, 2.4 kg P and 33 kg K per ha per annum (van der Merwe, 1995). Off-site effects are associated with the siltation of reservoirs on which South Africa is strongly dependent, due to the average annual rainfall across the country of only 454 mm (ARC-ISCW, 2006).

Erosion in South Africa is not restricted to sediments and soils but is also a major problem in mine tailings dams. South Africa mines 55 different minerals from over 713 mines and quarries and exports mineral commodities to 87 countries (Chamber of Mines, undated). Though mining fuels economic growth, the activities of the industry have a major negative impact on the environment, much of which is associated with the approximately 270 tailings dams (Rosner *et al.*, 2001). Tailings often have very poor physical and chemical properties in terms of encouraging vegetative growth, resulting in a very high degree of water and wind erosion. The rehabilitation of tailings and other mine discard is particularly problematic as their pH may be very high or very low. Many tailings are fine-textured, poorly sorted silt and organic carbon may be severely lacking or absent (van Deventer, 1997).

One of the most promising methods of restricting surface erosion is the use of geotextiles, such as the mats made from palm leaves (Booth *et al.*, 2005; Guerra *et al.*, 2005; Davies *et al.*, 2006).

The few available studies, however, have seldom specifically addressed the quantification of the effectiveness of such palm mats in reducing rates of sheet, or inter-rill erosion. The first objective of the present study was therefore to determine possible differences in erosion variables, using simulated rainfall, between a representative selection of **bare** soils and mine dam tailings compared to the same materials covered with palm mats (Paterson *et al.*, 2011).

Rainfall simulation has been selected as investigative tool as it is reported to be a very reliable approach of obtaining inter-rill erodibility information for a range of representative conditions, such as slope angle, rainfall intensity and water composition (Gabriels *et al.,* 2002). Laboratory experiments also allow several different soils to be investigated simultaneously, as a particular field site does not offer the range of soil and slope conditions that can be found elsewhere in the region or country. Such results can provide valuable information for extrapolation in order to develop guidelines concerning the suitability of palm mat use for specific sites.

However, despite the controlled, easily observable nature of the rainfall simulator process, there are limitations in the technique. The fact that soil is removed from the natural environment and transported to the laboratory for the rainfall simulation process to take place means that natural soil conditions are not possible. The soil is sieved and re-packed as carefully as possible, to ensure an even surface, but the soil structure, with implicit implications for water flow, is largely lost, meaning that inherent characteristics, such as textural and/or structural differences in the soil profile, will not be as evident or important in the rainfall simulator laboratory as in the field.

5.2 Materials and Methods

5.2.1 Mat manufacturing

The characteristics and properties of the palm mats have been reported in Chapter 4. Selected chemical parameters of the mats were determined using routine analytical methods (Non-Affiliated Soil Analysis Work Committee, 1990).

5.2.2 Rainfall simulator tests

Rainfall simulator tests were carried out on 20 South African soils (originating in eight of the nine provinces in SA) and ten mine dam tailings (the exact locations of some of the sites could not be supplied due to confidentiality). The soils cover a range of South African conditions, reflecting different parent materials (e.g. Archaean granites, Karoo sedimentary rocks, Jurassic basalt) and climatic zones (annual precipitation ranges from 72 mm to 1 037 mm). The soils (listed as sites S1-S20) were selected on the basis of their soil taxonomic properties and field evidence in the vicinity. Half of the soils were assessed as being potentially highly ***erodible*** (S1, S4, S5, S8, S12, S13, S14, S16, S17, S18) while the other half were identified from taxonomic and field evidence as being potentially more ***stable*** (S2, S3, S6, S7, S9, S10, S11, S15, S19, S20). Details of the soil sampling sites are given in Table 5.1.

Within the South African soil classification system (MacVicar *et al.*, 1977; Soil Classification Working Group, 1991), the ***soil form*** (comprising a diagnostic topsoil horizon over one or more diagnostic subsoil horizons) is the basic unit of nomenclature. Each of the diagnostic horizons has a set of inherent characteristics (which may vary slightly) and properties (which will not vary substantially). The name of a specific soil form therefore has several implied associations or assumptions, one of which is inherent erodibility. As an example, ***duplex*** soils (where a relatively sandy topsoil horizon overlies (often abruptly) a more clayey, usually structured subsoil horizon), are known to be very susceptible to water erosion if the surface becomes exposed. This is due to the fact that the increased clay content of the subsoil, often associated with a sodic character, will usually lead to the soil surface creating a seal, leading to increased runoff and decreased infiltration.

Soil forms where the name will convey the duplex nature of the soil will include Estcourt, Klapmuts, Sterkspruit (S12), Sepane, Valsrivier (S5, S13, S14), Swartland, Kroonstad (S1) and occasionally Tukulu (S16), Longlands and Katspruit (Fey, 2010). Although the duplex nature of the soil will not play a role in the rainfall simulator exercise (which uses topsoil only), the underlying parent material will produce a soil which should be inherently more susceptible to erosion.

Mine tailings were selected based on the element or mineral mined, namely gold, platinum, diamonds, chromium, silicon and vanadium, with sampling sites occurring throughout the mining belt of the South African Highveld. Details of the tailings sites (T1-T10) are shown in Table 5.2.

About 50 kg of material was collected for each of the soils and tailings. In the case of soils, only the upper 10-15 cm was sampled. All samples were dried at 40 °C and gently ground to pass a 2 mm sieve. Selected parameters were determined using routine analytical methods (Non-Affiliated Soil Analysis Work Committee, 1990). These included (for all samples): particle size (sand, silt and clay %); citrate-bicarbonate-dithionite (CBD) extractable Fe, Al, and Mn; exchangeable cations; and organic carbon; as well as (for selected samples): modulus of rupture; electrical conductivity; sodium adsorption ratio (SAR); and resistance.

For the rainfall simulation exercise, the samples were packed in 35 x 50 cm boxes, with a 20 cm deep layer of soil or tailings material placed on top of a porous cloth over 80 mm of coarse sand and gravel. The boxes were placed in the rainfall simulator at a slope of 15%, which was chosen as it represents a slightly steeper slope that that which is legally able to be cultivated in South Africa, but which often becomes affected in certain areas due to poor land use practices. The soil or tailings material was first saturated by suction from beneath and then subjected to constant simulated rain until a steady final infiltration rate was observed. The rainfall simulator was originally developed in Israel (Morin *et al.*, 1967). The general layout of the rainfall simulator is shown in Figure 5.1, which shows how the water is delivered through the sprinklers onto the sloping, soil-filled boxes (in this example without the palm mats on the surface). The whole apparatus rotates, enabling an even distribution of rainfall onto the soil/tailing material below.

Beneath each box is the outflow, from where the runoff is collected in plastic collection cups for volumetric content and sediment load determinations.

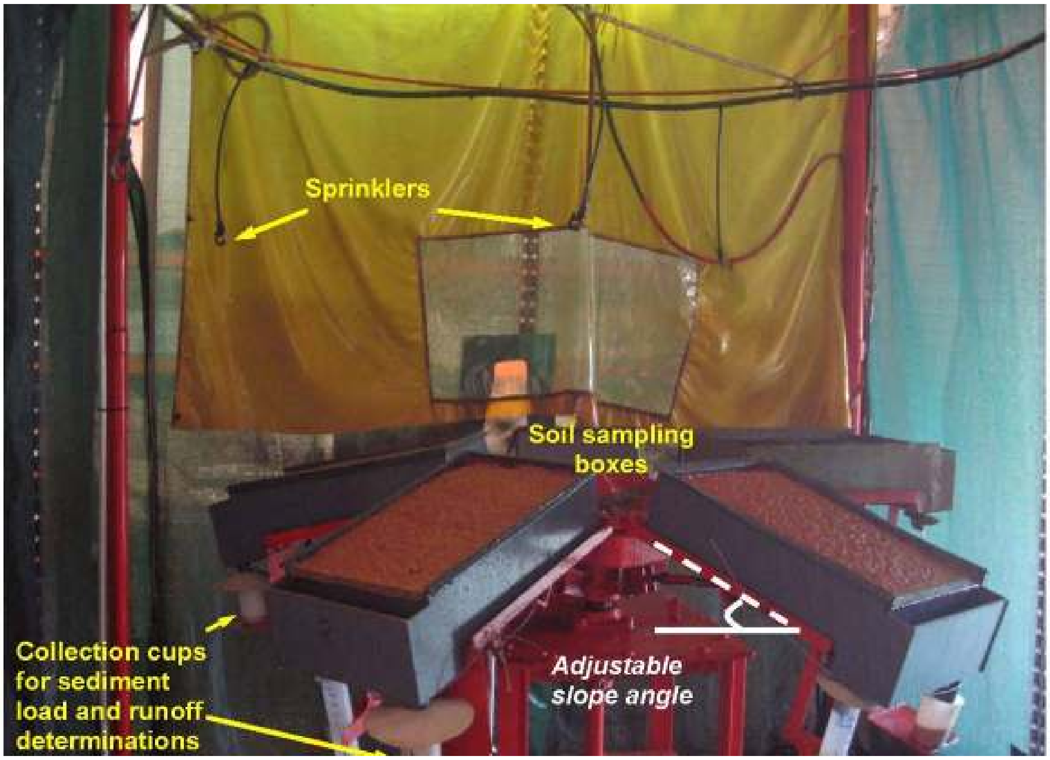

Figure 5.1 *Layout of Rainfall Simulator room*

Table 5.1 Soil sampling sites (stable soils in green, erodible soils in orange)

Soil	Locality	Longitude (E)	Latitude (S)	AP (mm)	Slope angle	Altitude (m)	Parent material	Particle Size	Soil Classification	
									SA[1]	WRB[2]
S1	Bergville	29° 21' 59"	28° 48' 53"	795	5%	1 316	Colluvium	fiSaLm	Kroonstad	Gleyic Planosol
S2	Towoomba	28° 19' 26"	24° 54' 55"	628	<1%	1 102	Basalt	Cl	Arcadia	Haplic Vertisol
S3	Towoomba	28° 19' 29"	24° 54' 54"	628	<1%	1 102	Basalt	Cl	Shortlands	Rhodic Nitisol
S4	Lusikisiki	29° 34' 45"	31° 16' 10"	983	6%	680	Shale (Ecca)	SiLm	Cartref	Haplic Cambisol
S5	Marico	26° 24' 00"	25° 34' 18"	415	2%	1 105	Colluvium	ClLm	Valsrivier	Calcic Planosol
S6	Long Tom	30° 34' 38"	25° 06' 48"	904	5%	2 078	Shale (Pta)	coSaLm	Inanda	Humic Ferralsol
S7	Eshowe	31° 13' 15"	28° 55' 20"	681	15%	556	Sandstone	ClLm	Inhoek	Mollic Fluvisol
S8	Musina	30° 25' 01"	22° 20' 33"	347	6%	481	Gniess	fiSaLm	Addo	Calcaric Cambisol
S9	Delmas	28° 49' 35"	26° 14' 27"	861	1%	1 590	Shale	fiSaLm	Avalon	Acric Plinthosol
S10	Badplaas	30° 47' 34"	25° 47' 27"	1 037	5%	1 452	Gneiss	SaClLm	Griffin	Acric Ferralsol
S11	Rietgat	27° 55' 22"	24° 57' 02"	555	1%	1 071	Granite	meSaLm	Glencoe	Petric Plinthosol
S12	Aliwal North	26° 45' 59"	30° 38' 38"	519	2%	1 311	Mudstone	LmfiSa	Sterkspruit	Haplic Solonetz
S13	Rouxville	26° 33' 36"	30° 32' 22"	464	3%	1 386	Colluvium	fiSaLm	Valsrivier	Luvic Planosol
S14	Witsieshoek	28° 52' 54"	28° 24' 35"	668	7%	1 654	Mudstone	Cl	Valsrivier	Luvic Planosol
S15	Pietersburg	29º 20' 14"	23° 56' 57"	540	3%	1 320	Granite	coSaLm	Hutton	Eutric Ferralsol
S16	Ladysmith	29° 37' 01"	28° 23' 37"	819	3%	1 218	Sandstone	Lm	Tukulu	Haplic Cambisol
S17	Rietrivier	24° 21' 17"	28° 55' 26"	369	2%	1 039	Colluvium	fiSaLm	Augrabies	Calcaric Cambisol
S18	Brandvlei	21° 11' 05"	30° 20' 32"	171	3%	928	Shale (Ecca)	fiSaLm	Augrabies	Calcaric Cambisol
S19	Tankwa	19° 38' 55"	32° 21' 24"	72	1%	304	Tillite	SaClLm	Glenrosa	Leptic Cambisol
S20	Malmesbury	18° 49' 33"	33º 21' 35"	379	10%	372	Shale	SaClLm	Shortlands	Rhodic Nitisol

[1] Soil Classification Working Group, 1991
[2] IUSS Working Group WRB, 2006
AP – Annual Precipitation

Table 5.2 Tailings sampling sites

Site	Locality	Mining type	Longitude (E)	Latitude (S)	AP (mm)	Slope angle	Alt (m)	Parent material
T1	Springs	Gold	28° 26’ 57”	26° 15’ 26”	681	40%	1580	Conglomerate, Witwatersrand
T2	Northam	Platinum	27° 21’ 27”	24° 47’ 52”	524	40%	1017	Pyroxenite, Bushveld Complex
T3	Cullinan	Diamond	28° 32’ 11”	25° 36’ 33”	760	40%	1312	Kimberlite
T4	Rustenburg	Chrome	Confidential*		619	40%	1156	Pyroxenite, Bushveld Complex
T5	Rustenburg	Platinum	Confidential*		619	50%	1149	Pyroxenite, Bushveld Complex
T6	Witbank	Coal	Confidential*		891	<2%	1617	Shale, Karoo (Vryheid Formation)
T7	Rustenburg	Silica	Confidential*		619	<2%	1270	Quartzite, Magaliesberg Formation
T8	Stilfontein (acidic)	Gold	Confidential*		560	50%	1365	Conglomerate, Witwatersrand
T9	Stilfontein	Gold	Confidential*		560	50%	1359	Conglomerate, Witwatersrand
T10	Brits	Vanadium	27° 34’ 39”	25° 34’ 15”	650	<2%	1885	Magnetite, Namaqualand Suite

** Certain sites are identified by locality only, with the specific position withheld by the mining organisation.*

The most important properties of the rainfall produced were: a median drop velocity of 6.02 m s^{-1}, kinetic energy of 18.1 J mm^{-l} m^{-2} with rain intensity of 45 mm hr^{-1} for 1.67 hr (Agassi & du Plessis, undated). The intensity used can be considered typical of a heavy rainfall event in the South African summer rainfall zone (see Table 6.10 and 6.11), where the majority of the rain falls in the form of irregular thundershowers. Although not common, such events often have very high erosivity values, which can be as high as 20 000 to 40 000 MJ mm ha^{-1} yr^{-1}, comparable to values recorded in the tropical cyclone zone of northern Australia (Le Roux *et al.*, 2006).

Distilled water with an electrical conductivity value of 1.0 mS m^{-1} was used to simulate rain. The volumes percolating through the soil were recorded at 2 min. intervals during an event of 2 hours for each storm. Timed run-off samples were collected at 2 min. intervals during the 2 hour event, weighed, oven-dried at 105 °C and re-weighed to determine runoff rate, sediment concentration and sediment yield. Measurements were carried out in duplicate form.

After the first run (run 1), the soils were allowed to dry overnight at room temperature and were then subjected to the same treatment for a second time (run 2). Run 2 therefore takes seal/crust formation into account. Water infiltration, percentage stable aggregates, surface runoff and sediment yield were determined as described by Levy (1988). Inter-rill erodibility was determined according to Kinnell (1993). No rills formed during the rainfall process due to the fact that the surface of the soil boxes was evened out prior to rain application, as well as the limited time involved.

Erosion variables such as runoff (RO), sediment load in the runoff (SL), final infiltration rate (FI), percentage stable aggregates (SA) and inter-rill erodibility (K*i*) (Kinnell, 1993) were determined for the bare soils and tailings and again for the same material, covered with palm mats. Due to the size (35 x 50 cm) of the soil boxes being smaller than the mats, mats were cut to size so that they would fit closely to the soil surface of each box.

5.3 Analytical properties – South African soils and tailings

Within the constraints of the investigation, the samples reflect the wide range of soils and mine tailings present in South Africa. The twenty soils and ten tailings samples varied considerably with respect to their textural, chemical and mineralogical properties (Table 5.3). The figures supplied include the range of values, the average and the standard error.

5.3.1 Soils

When comparing the two groups of soils, the stable soils tended to have higher clay contents in relation to the erodible soils, although there was more variation in the stable values, as shown by higher standard deviations. The silt content, which has been identified as a prominent soil parameter in erosion models (Le Roux, 2012) was also markedly lower for the stable soils. The pH parameter often plays a dominant role in determining the dispersion/ flocculation behaviour of clay systems and related erodibility (Chorom *et al.,* 1994), as pH modifies the charges on edge positions in phyllosilicates and also those of variably charged minerals. Charges are positive under acid conditions (pH <7) and negative in alkaline environments (pH >9). Acid pH therefore favours edge-to-face associations, flocculation and therefore stable aggregates, while alkaline conditions promote dispersion (Churchman *et al.,* 1993). As would therefore be expected, pH for the stable soils was lower (average value 6.05) than for the erodible soils (average value 7.25).

The stable soils had higher kaolinite but less quartz than the erodible soils, but there was a large degree of variation in the values. The organic carbon (OC) content of the stable soils was more than double that of the erodible soils, on average, but there was a moderately strong relationship between OC and rainfall (r^2 = 0.485 for the stable soils, r^2 = 0.444 for the erodible soils), although degree of surface vegetation was not taken into account. For all the soils, the exchangeable cation population was dominated by Ca and the Na content was low, as was the percentage of secondary Fe minerals.

Table 5.3 Ranges and average values for selected parameters for stable soils (n=10), erodible soils (n=10) and mine tailings (n=10)

Parameter	Stable soils		Erodible soils		Tailings	
	Range	Average*	Range	Average*	Range	Average*
Sand (%)	31.2-78.8	**55.74 ± 5.94**	9.6-81	**48.25 ± 7.00**	9.2-92.4	**64.69 ± 8.13**
Silt (%)	7.0-26.9	**17.10 ± 1.84**	11.5-55.8	**28.88 ± 4.27**	5.9-55.6	**24.47 ± 5.45**
Clay (%)	7.7-51.8	**25.63 ± 5.08**	5.4-51.9	**20.89 ± 4.02**	0.3-24.9	**8.67 ± 2.39**
pH (H_2O)	4.5-8.16	**6.05 ± 0.36**	5.2-8.9	**7.25 ± 0.40**	2.67-9.96	**7.34 ± 0.76**
Kaolinite (%)	6-68	**33.10 ± 7.27**	0-42	**14.50 ± 4.07**	0-48	**17.40 ± 6.21**
Smectite (%)	0-90	**19.40 ± 10.23**	0-50	**11.40 ± 3.58**	0-85	**19.60 ± 8.44**
Mica (%)	0-51	**16.10 ± 5.79**	0-44	**27.40 ± 5.37**	0-30	**9.50 ± 4.06**
Quartz (%)	1-89	**26.40 ± 8.07**	0-93	**44.40 ± 9.13**	0-59	**25.30 ± 6.50**
Org. Carbon (%)	0.05-3.62	**1.57 ± 0.36**	0.12-2.45	**0.76 ± 0.21**	0.1-15.6	**1.63 ± 1.55**
Na (cmol kg^{-1})	0.07-0.48	**0.21 ± 0.05**	0.06-0.72	**0.29 ± 0.07**	0.1-0.61	**0.28 ± 0.06**
K (cmol kg^{-1})	0.04-1.18	**0.51 ± 0.14**	0.1-1.31	**0.53 ± 0.12**	0.04-1.69	**0.24 ± 0.16**
Mg (cmol kg^{-1})	0.1-9.67	**2.62 ± 0.99**	0.07-10.52	**3.24 ± 0.89**	0.18-3.05	**1.28 ± 0.38**
Ca (cmol kg^{-1})	0.04-35.7	**10.08 ± 4.38**	1.7-17.49	**8.73 ± 2.29**	0.98-22.4	**6.42 ± 2.27**
CEC (cmol kg^{-1})	5.3-45.81	**14.52 ± 4.15**	3.45-19.96	**11.67 ± 1.61**	1.31-18.4	**6.01 ± 1.77**
CBD-Fe (%)	0.6-4.77	**1.85 ± 0.42**	0.17-4.86	**1.14 ± 0.44**	0.04-0.51	**0.19 ± 0.06**
CBD-Al (%)	0.1-1.76	**0.58 ± 0.12**	0.02-1.21	**0.24 ± 0.11**	0.01-0.13	**0.04 ± 0.01**

*Average followed by the standard error of the mean

CBD *= citrate-bicarbonate-dithionite extractable;* ***CEC*** *= Cation Exchange Capacity.*

5.3.2 Tailings

The tailings materials generally had, on average, much less clay than either of the soils groups, and while the average pH of the tailings was similar to the erodible soils, the range in values was much greater, reflecting the range of post-mining chemical processes that were active. Organic carbon was generally low, except for one extreme value of over 15% in T6, coal-rich material from the Witbank area, which greatly pushed up the average value. Without this anomaly, the average value falls from 1.63% to 0.07%

5.4 Erodibility parameters

Major differences existed in the range of erodibility parameters across the various soils but comparatively smaller variations in the average values and in the range between the two different soil groups (stable *vs* erodible). The tailings materials reflected the larger range in clay content with a consequent larger variation in most of the parameters.

Table 5.4 Ranges and average values of erodibility characteristics for stable soils (n=10), erodible soils (n=10) and tailings (n=10)

Parameter		Run	Stable soils		Erodible soils		Tailings	
			Range	Ave.	Range	Ave.	Range	Ave.
RO	bare	1	2756-3837	**3356**	3110-4142	**3780**	383 - 4497	**3046**
		2	2511-4125	**3313**	3110-4028	**3768**	331 - 4432	**2697**
	palm	1	2415-3492	**3108**	2978-3796	**3514**	391 - 4295	**2596**
		2	2445-3542	**3297**	2763-3732	**3420**	419 - 4184	**2544**
SL	bare	1	75-374	**204**	111-510	**239**	1 - 699	**251**
		2	72-533	**237**	83-387	**178**	7 - 551	**212**
	palm	1	48-155	**97**	29-215	**111**	9 - 328	**144**
		2	27-176	**94**	20-190	**83**	4 - 244	**126**
FI	bare	1	4.5-14.5	**8.7**	4.5-12.2	**7.3**	1.11 - 37.85	**14.9**
		2	4.5-16.7	**8.3**	4.5-7.8	**6.6**	1.34 - 37.85	**14.4**
	palm	1	4.5-12.3	**6.9**	4.5-6.7	**5.9**	3.3-41.2	**14.5**
		2	4.5-15.6	**9.5**	4.5-11.1	**6.3**	4.5-40.1	**15.3**
SA	bare	1	4.5-17.3	**9.9**	4.7-17.9	**8.9**	1.83 - 40.21	**17.2**
		2	4.5-21.4	**11.8**	1.6-23.1	**8.8**	2:77 - 40.48	**17.0**
	palm	1	6.6-14.4	**9.8**	5.1-10.4	**8.1**	3.6-44.1	**17.5**
		2	6.1-20.2	**12.8**	5.4-14.1	**9.2**	5.1-43.1	**18.4**
K*i*	bare	1	2.6-17.9	**7.4**	3.3-14.3	**7.1**	0 - 17.13	**5.4**
		2	2.2-19.5	**7.1**	2.6-11.2	**5.4**	1.43 - 15.04	**5.3**
	palm	1	1.7-4.9	**3.1**	1.0-5.9	**3.1**	1.0-9.7	**4.6**
		2	1.1-6.5	**3.1**	0.9-5.0	**2.3**	1.0-6.5	**3.9**

RO *= runoff (cm^3);* ***SL*** *= sediment load in the runoff (g);* ***FI*** *= final infiltration rate (mm h^{-1});* ***SA*** *= percentage of stable aggregates;* ***Ki*** *= inter-rill erodibility (kg m^{-3} s^{-1}) according to Kinnell (1993);* ***bare*** *= bare materials;* ***palm*** *= materials covered with palm mats; 1 = first simulation run; 2 = second simulation run.*

5.4.1 Runoff

The average runoff values for the erodible soils were higher than for the stable soils, for both runs combined (Table 5.4) which is an indication of the crust-forming tendency of many such soils in South Africa. Some of the tailings, however, showed much lower runoff rates and figures of less than 400 cm^3 were measured for several of these samples which had very coarse texture and therefore less cohesion and consolidation, so that more runoff infiltrated the tailings material.

When the mats were applied, average runoff for both soil groups decreased (by 4.1% for the stable soils, by 8.2% for the erodible soils) as well as for the tailings (by 7.7%), on average, compared to the bare soil ($p<0.05$). This is illustrated in Figure 5.2.

The variation in the results for the stable soils is probably due to the fact that the soils were not pre-selected by any analytical or other empirical process, but rather collected from field and database indication of where such soils were likely to be found. The greater decrease in runoff within the erodible soil group when mats were applied would suggest that these soils are more representative and that the mats have a meaningful effect on such soils.

The variation in tailings texture can be seen in the very low levels of runoff for TS4, TS5 and TS10, which are very coarse.

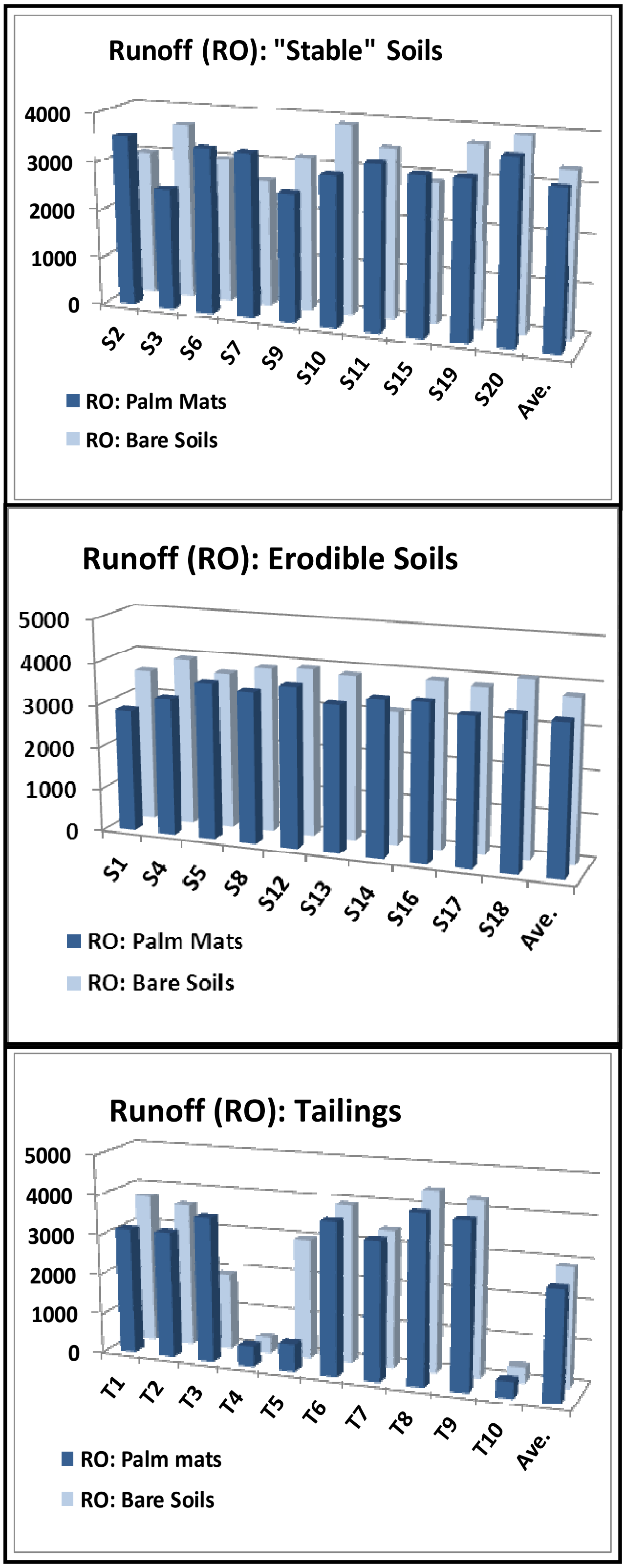

Figure 5.2 Runoff (cm^3) for bare soils *vs* palm mats

5.4.2 Sediment Load

The sediment load values for the erodible soils were slightly higher than for the stable soils for the first run (Table 5.4), but were lower for the second run which is to be expected, given the crust-forming tendency of many such soils in South Africa. The tailings gave similar average results, but with much greater variation (standard deviation more than three times greater).

When the mats were applied, average sediment load values for both soil groups decreased dramatically (Table 5.4). The decrease was 56.7% for the stable soils, 55.4% for the erodible soils and 41.9% for the tailings, on average ($p<0.001$). The decrease was most consistent within the stable soils (r^2 = 0.708), while the erodible soils showed the most inconsistency (r^2 = 0.394)

The decrease in sediment load is illustrated in Figure 5.3, where the greater variability of the tailings can clearly be seen.

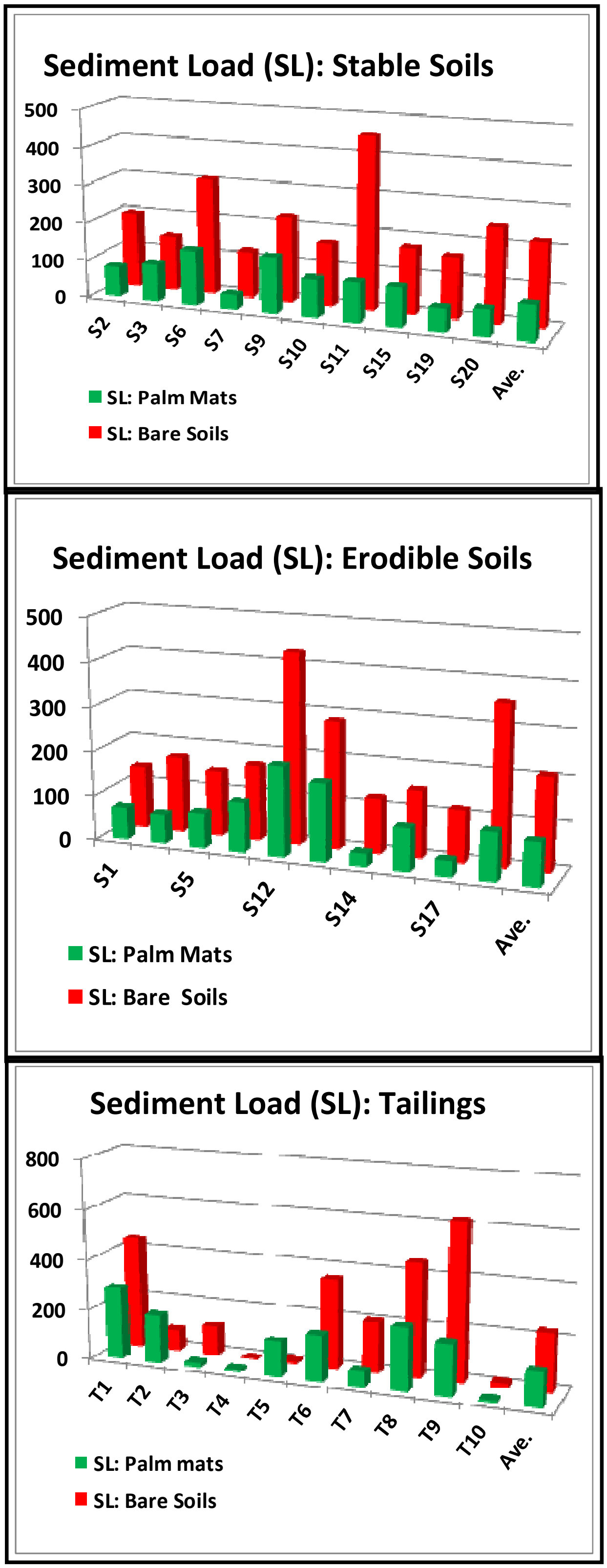

Figure 5.3 Sediment load (g) for bare soils *vs* palm mats

5.4.3 Final infiltration rates (FI)

The relationship between water infiltration and erodibility is far from straightforward. Development of a surface seal may increase surface runoff but may well stabilize a soil against erosion (Bradford *et al.,* 1987), although re-vegetation will be more difficult. The contact of the soil with water improves aggregate stability (Rapp, 1998) and therefore reduces erodibility. This discrepancy is reflected in the present study where most soils showed a decrease in FI while others remained unchanged and still others showed an increase.

After the first run (Table 5.4), FI (mm h^{-1}) differed somewhat between the groups, with rate for the stable soils being higher, especially in run 2. The tailings samples generated less runoff than the soils, so that FI was also higher on average, especially for the sandier materials. After the second run, infiltration curves and FI values were almost identical to those of the first run for the two most stable samples. Generally, infiltration rates decreased at a significantly earlier stage in the erosion-prone soils, indicating a much earlier onset of infiltration problems.

5.4.4 Percentage of stable aggregates (SA)

It has been reported that a high SA percentage markedly reduces soil erodibility (Barthes *et al.,* 2000; Barthes & Roose, 2002) and is especially important under more intense rainfall events (Tanaka *et al.,* 1999). The samples of the present study displayed a considerable degree of variation in SA. Results (Table 5.4) show that SA was, on average, higher for the stable soils, and actually increased for run 2, while the erodible soils showed a slight decrease. Raindrop action and soil dispersion during run 1 hardly reduced SA as values for the second run were generally higher than those of the first run. This pattern of observed changes reflects the influence of seal/crust formation (decrease in FI) and ageing (increase in aggregate stability), different processes being obviously dominant in different soils.

5.4.5 Inter-rill erodibility (Ki)

The two different soil groups varied within a similar range, as far as inter-rill erodibility (Kinnell, 1993) is concerned (Table 5.4), with average values being lower for the tailings. Application of the palm mats caused a marked reduction in K*i* (>50%) for both groups ($p<0.05$), while for the tailings, the improvement was slightly less. Walker *et al.* (1977) found that surface flow from inclined planes of soil ranged from 1 to 7 mm in depth. With the palm mats being approximately 8-10 mm thick (Section 4.2.1), and exhibiting good adhesion to the soil surface, it is logical to expect that the presence of such a surface covering would have a beneficial effect on slowing down surface water flow, along with the ability of the flow to remove sediment.

5.4.6 Soil loss

If the results obtained from the rainfall simulator trials for runoff (ml) and sediment load (g) are used in combination, an estimate of the actual rate of soil loss can be obtained. This is done by using the proportion of sediment contained in the volume of runoff recorded, and extrapolating that from the area of the rainfall simulator sample box up to a value per hectare (similar to the procedure explained more fully in Section 6.2.2.1). Admittedly, the large factor of uncertainty due to the small size of the sample area, as well as the fact that the soil was packed into the box by hand, means that this is somewhat of an approximation. Nevertheless, the results are interesting and quite promising.

In South Africa, classes of soil erosion severity (t ha^{-1} yr^{-1}) have been assessed as ***low*** (0-5), ***low to moderate*** (5-12), ***moderate to high*** (12-25), ***high*** (25-50) and **very high** (>50) (Le Roux *et al.,* 2006). If the data from the rainfall simulator runs are used, the combination of runoff and sediment load shows a clear decrease in soil loss when the mats are applied. For the stable soils, the approximate soil loss from the bare soils is 12.6 t ha^{-1}, which falls to 5.51 t ha^{-1} under the palm mats (56% reduction), while for the erodible soils, the approximate soil loss from the bare soils is 13.5 t ha^{-1}, which falls to 6.00 t ha^{-1} under the palm mats (55% reduction)

In terms of the South African erosion classes mentioned above, this is an average reduction from the lower end of the **moderate to high** class to the lower end of the **low to moderate** class. It is also interesting to note that the set of erodible soils showed slightly higher predicted soil loss figures, but a comparable predicted reduction using palm mats, which would indicate that the potential for the mats to work on a wide range of soils in South Africa is significant.

5.4.7 Soil properties

As listed in Table 5.3, a range of soil properties that may have a significant relationship with either run-off or sediment load (Bühmann *et al.,* 1996; Rapp, 1998; Stern, 1990) was selected and the relationship between them was studied. These results, using the r^2 values, are shown in Table 5.5. All correlations “better” than 0.20 or -0.20 are shown in bold.

From these figures, it is evident that, none of the properties shows a good correlation, for the twenty soils selected. If a greater range of samples could have been collected and tested, it is probable that the relationships may have been clearer, but time and money limitations precluded this. In general, sediment load is better correlated to the various soil factors than run-off, and especially so with the sand content, and negatively correlated with the kaolinite content.

However, as might be expected from a sample set of only 20 soils selected from various areas in South Africa, none of the trends can be regarded as significant at $p<0.05$.

Table 5.5 R^2 values of selected soil properties as related to runoff and sediment load (n=20).

SOIL PARAMETER	Sediment Load (g)				Run-off (cm^3)			
	Run 1		Run 2		Run 1		Run 2	
	Bare	Palm	Bare	Palm	Bare	Palm	Bare	Palm
Kaolinite	**- 0.33**	- 0.03	**- 0.24**	**- 0.22**	- 0.15	- 0.06	- 0.11	- 0.02
Swelling Clay	0.02	0.01	<0.01	<0.01	<0.01	- 0.07	0.09	- 0.12
Mica	0.03	- 0.01	0.02	0.08	0.07	0.08	0.17	0.05
Fine sand	**0.22**	**0.34**	**0.20**	**0.37**	- 0.05	0.05	- 0.04	0.01
Very fine sand	0.17	**0.22**	0.18	**0.35**	0.03	0.09	0.11	0.03
Total sand	<0.01	**0.27**	**0.22**	**0.43**	- 0.09	<0.01	<0.01	<0.01
Coarse silt	- 0.01	<0.01	**- 0.25**	- 0.02	0.11	0.02	<0.01	0.05
Fine silt	- 0.03	**- 0.21**	- 0.06	- 0.19	0.14	0.04	<0.01	0.04
Total silt	- 0.03	- 0.11	<0.01	- 0.14	0.17	0.04	0.17	0.06
Clay	- 0.19	**- 0.22**	- 0.12	**- 0.40**	<0.01	- 0.06	- 0.01	- 0.05
Exch. Na	<0.01	- 0.09	0.03	- 0.06	0.10	<0.01	0.15	<0.01
Na/CEC	0.10	0.03	0.14	0.12	0.04	0.02	**0.24**	0.03
CEC	- 0.04	- 0.11	- 0.03	**- 0.23**	0.02	- 0.06	< 0.01	- 0.09
Org. Carbon	- 0.08	- 0.03	- 0.03	**- 0.20**	- 0.04	**- 0.28**	- 0.06	**- 0.22**
CBD-Fe	- 0.06	<0.01	<0.01	<0.01	**- 0.20**	<0.01	- 0.15	0.01
CBD-Al	- 0.09	<0.01	- 0.04	- 0.03	- 0.09	<0.01	- 0.12	0.03
pH (H_2O)	0.02	- 0.04	<0.01	<0.01	**0.22**	0.08	**0.21**	0.02

The above data confirm that the processes governing soil erosion (including runoff and sediment delivery) are complex and multivariant. Separation of factors is not always easy or straightforward.

5.5 Selected Roodeplaat soils

The previous rainfall simulator study looked at a range of soils, but only one slope angle. In an attempt to investigate whether soil texture and/or slope angle could be identified as an important factor in quantifying the runoff process, a second rainfall simulator trial was initiated, using the same arrangement as previously defined.

For this exercise, four soils, with varying properties, were collected from the Roodeplaat research farm, located approximately 25 km outside Pretoria, where the parent material is alluvial in origin. The soils therefore had a similar mode of origin, as well as a similar prevailing climatic regime.

The soils were specifically selected to represent a range of textures (determined by the hydrometer method), namely:

- Soil 1 - Fernwood form (6% clay, ***coarse sand*** texture)
- Soil 2 – Oakleaf form (11% clay, ***loamy coarse sand*** texture)
- Soil 3 – Tukulu form (21% clay, ***fine sandy loam*** texture)
- Soil 4 – Mayo form (41% clay, ***clay*** texture)

Values were obtained for sediment load (SL, in g) and runoff (RO, in cm^3), using three different slope angles (5%, 10% and 15%) and three different mat coverages, namely ***nil*** (bare soil), ***intermediate*** (mat holes enlarged from 5 x 5 cm to 10 x 10 cm – see Section 6.3.2.1) and ***full*** (normal mat coverage). Once again, two runs were carried out.

The results of these determinations are shown in Figure 5.4 (runoff) and Figure 5.5 (sediment load).

It is clear from Figure 5.4 that, as far as runoff is concerned, Soil 4, which has the highest clay content, showed the clearest increase in RO with decreasing mat coverage, while increased slope angle did not appear to consistently lead to an increase in RO.

For sediment load (Figure 5.5), there is a better relationship between increased SL and both steeper slope angle and decreasing mat coverage, although the relationship is not consistent, with the variation probably being due largely to:

- the difficulty associated with packing the soil consistently in the boxes to achieve a uniform surface and degree of spatial arrangement,
- variations in mat topography,
- the small surface area involved (0.175 m^2).

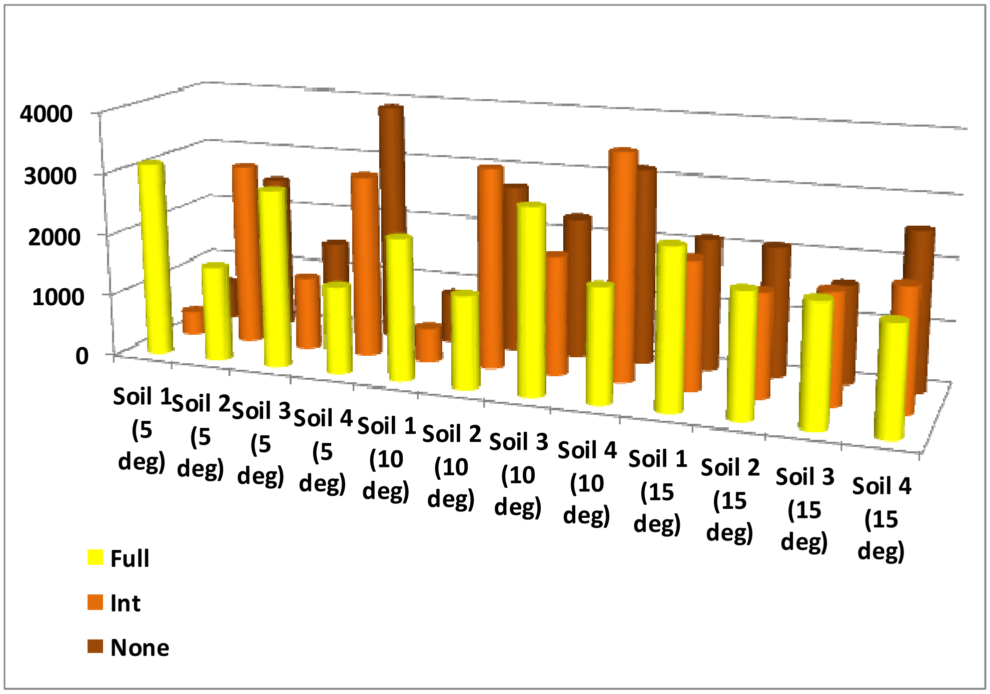

Figure 5.4 Runoff (cm^3) for four Roodeplaat soils with varying mat coverage and slope angle

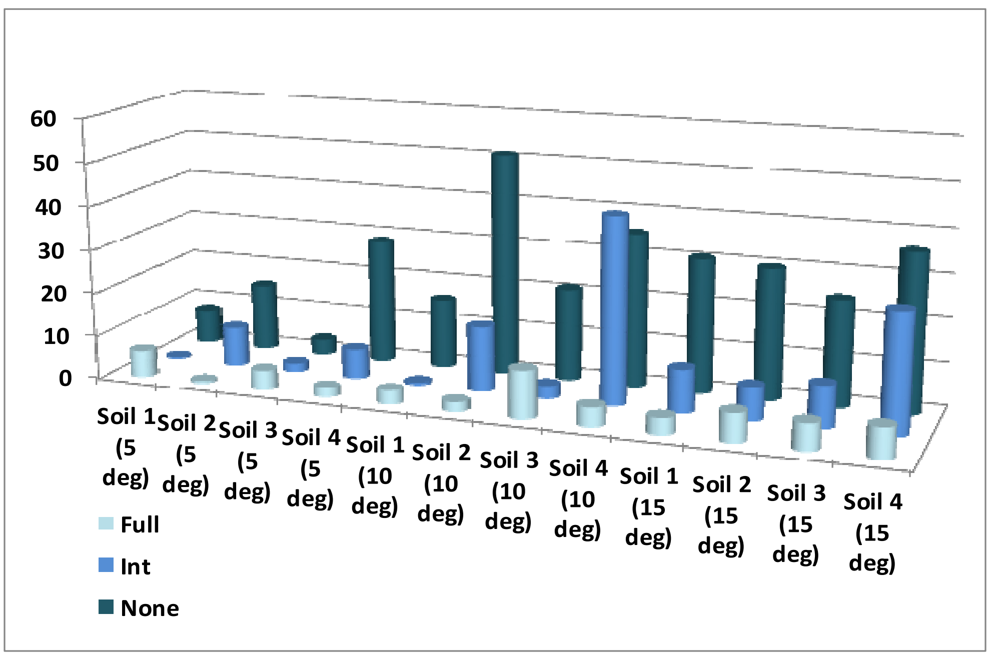

Figure 5.5 Sediment load (g) for four Roodeplaat soils with varying mat coverage and slope angle

Despite some inconsistencies, the results from the rainfall simulator experiments on the Roodeplaat soils clearly support the potential of the palm mats to reduce erosion, by documenting that the mats generally decreased the sediment load in the runoff, both at intermediate density and then at full density. The extent of reduction seemed to be related to decreasing clay content, so that Soil 1 (6% clay, coarse sand texture) showed the greatest decrease between bare soil and mat coverage (30.8 g to 7.9 g) for the steepest slope, compared to Soil 4 (41% clay, clay texture) for the same slope, where the sediment load fell only from 36.2 g to 28.6 g, despite a reduction in runoff.

The palm mats did not significantly improve water infiltration, however, and even led to slightly increased runoff volumes, especially for Soil 1 (coarse sand) and Soil 3 (fine sandy loam). However, this could well be a result of difficulty in maintaining consistent soil/mat contact given the restricted size of the soil containers used in the rainfall simulators, and a similar inconsistency in findings have been reported from experiments carried out at the University of Leuven in Belgium (Smets *et al.,* 2008) using slightly larger surfaces (approximately 2 m^2). In addition, differences in sediment potential have been recorded between otherwise similar microplots ($\pm$1 m^2) and larger plots ($\pm$25 m^2) in catchment studies in south-east Asia (Chaplot & Poesen, 2012).

In terms of approximate soil loss (see Section 5.4.6), there was a lot of variation between the four soils, and there was no clear increase in projected soil loss with increasing slope angle. There was, however, a reduction for all four soils across the treatments. When the intermediate mats were applied (larger mesh holes), projected soil loss was on average 42.8% of that from the bare soils. When the normal-sized mesh palm mat was applied, there was a smaller difference, with an average of 76.6% of the runoff of the intermediate mats. Overall, however, the decrease was clear, at 22% on average soil loss from the mats, compared to the bare soil.

However, there were large variations within the soil types. Soil 3 (21% clay, fine sandy loam texture), showed the smallest improvement, at 59% projected soil loss, while the other three soils were better, at 13%, 8% and 7% for Soil 1, Soil 3 and Soil 4 respectively.

5.6 Conclusion

In a comprehensive survey of experimental findings, Auerswald *et al.* (1992), who looked at various rainfall simulators in Germany and Switzerland, found that with decreasing size of soil surface area, runoff estimates become less reliable, and that a plot size of >4 m^2 is optimal. In contrast, Sharpley and Kleinman (2003) found that in Pennsylvania, plots of 2 m length produced more runoff flow than those of >10 m, due to more of the soil being saturated within the same time span. Pappas *et al.* (2007) used a system in Indiana where several 0.6 m^2 boxes could be connected in downslope sequence in order to study various combinations of soil surface covering for their relative efficiency. The rainfall simulator available at ISCW is smaller than optimal and cannot be adjusted with regard to layout, but time and expense dictated that it could not be replaced or expanded. For the studies reported here, the soil was pre-saturated from below in order not to in any way adversely affect the soil surface.

It is anticipated that these discrepancies will be largely negated by using larger field plots, and results of several such trials will be reported in the next chapter.

6. FIELD TRIALS

The rainfall simulator tests (Chapter 5) gave promising results, so the next logical step was to apply the palm mats on a larger scale, under field conditions, at several sites in South Africa (Paterson & Barnard, 2011). The locations are shown in Figure 6.1.

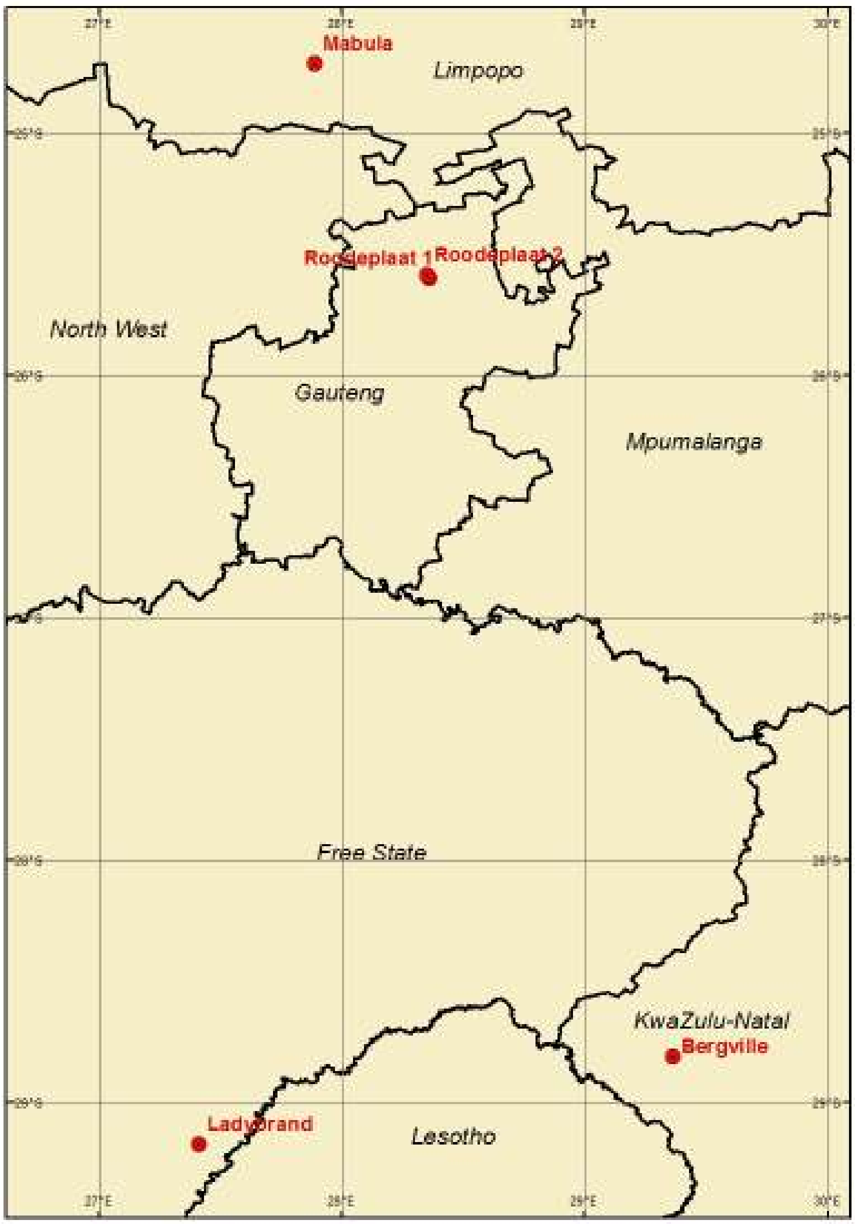

Figure 6.1 *Localities of field sites*

Due to the nature of the runoff plots, which each require a specific collecting apparatus at the bottom (either a tipping bucket for runoff, a collecting drum for sediment concentration, or both), it was neither logical nor practical to consider a series of replicates, as would have been possible in other situations, for example a crop growth trial. Rather, attention was paid to ensuring that the plots that were laid out occurred on a uniform, straight slope, with uniform soil properties. In this way, potential variation due to inconsistent environmental factors was, as far as possible, eliminated.

6.1 BERGVILLE, KWAZULU-NATAL PROVINCE

A trial was laid out at the beginning of the 2006-2007 rainfall season at the Potshini Community, in Emmaus Ward, approximately 15 km south-west of Bergville in the north-west of KwaZulu-Natal Province (see Figure 6.1).

6.1.1 **Site conditions**

The site comprised a uniform, south-west facing slope of 8% in a lower footslope position, with a small perennial stream approximately 30 metres downslope. The co-ordinates of the site are 28^{o} 48’ 45.7” S, 29^{o} 21’ 56.7” E and elevation is 1 316 metres above sea level. The area has a long-term annual rainfall of 795 mm, falling mostly in summer. The area has warm to hot summers and mild, dry winters. The main climate parameters, derived from the closest weather station (Bergville, $\pm$15 km E), are given in Table 6.1 (ARC-ISCW, 2006).

Table 6.1 Bergville climate

Month	Rainfall (mm)	Max. Temp (°C)	Min. Temp (°C)
Jan	152.6	27.5	15.3
Feb	103.8	27.8	15.1
Mar	117.1	25.5	12.8
Apr	46.1	23.7	9.5
May	9.5	22.2	4.5
Jun	13.7	19.6	1.9
Jul	2.0	19.9	1.4
Aug	23.2	22.3	4.3
Sep	23.9	24.9	7.7
Oct	72.0	24.9	11.3
Nov	121.1	26.6	12.8
Dec	109.5	27.7	14.3
Year	**794.6 mm**	**16.8°C (Average)**	

The average daily relative humidity varies between 22.5% (minimum) and 89% (maximum) in winter to between 46% (minimum) and 94.5% (maximum) in summer.

The soil occurring has a grey-brown, loamy sand orthic topsoil horizon overlying a grey, loamy sand eluvial E horizon overlying a grey, mottled, sandy loam soft plinthic horizon. The soil belongs to the Longlands form (Soil Classification Working Group, 1991), approximately equivalent to an Albic Plinthisol in the WRB system (FAO, 2006) or a Plinthic Inceptisol in the USDA system (Soil Survey Staff, 2003). Soil colours given are from the Munsell system (Munsell Color, 2000).

The soil description and analysis is as follows:

Table 6.2a Bergville site: soil description

Profile Site: Potshini, near Bergville
Co-ordinates: 28^{o} 48' 45.7" S 29^{o} 21' 56.7" E
Altitude: 1316 m
Soil Form: Longlands
Soil Series: Sherbrook (1000)
Classification (WRB): *Albic Plinthosol*
Classification (USDA): *Plinthic Inceptisol*

Terrain Type: Lower midslope
Slope Angle: 8%
Parent Material: Sandstone of Tarkastad Formation, Beaufort Group

Horizon	**Description**	**Diagnostic**
A1 *(0-350 mm)*	Dry colour 10YR6/2, moist colour 10YR4/3; few, fine, faint yellow and brown mottles; loamy sand texture; weak, medium subangular blocky structure; friable consistence; common roots; gradual, smooth transition.	**Orthic**
E *(350-800 mm)*	Dry colour 10YR6/2, moist colour 10YR5/3; few, medium, distinct yellow and brown mottles; coarse loamy sand texture; weak, medium subangular blocky structure; friable consistence; few roots; clear, smooth transition.	**E horizon**
B1 *(>800 mm)*	Dry colour 10YR7/3, moist colour 10YR5/3; many, coarse, prominent red mottles; sandy loam texture; weak, coarse subangular blocky structure; friable consistence; very few roots.	**Soft plinthic**

Table 6.2b Bergville site: analytical results

Horizon	**Particle Size (%)**							**pH (H_2O)**	**CEC (cmol kg^{-1})**
	Sand				Silt		Clay		
	coarse	*medium*	*fine*	*v fine*	*coarse*	*fine*			
A1	19.2	22.0	20.7	15.9	8.8	5.9	7.2	8.04	2.55
E	23.9	19.9	16.6	11.2	7.4	11.3	9.2	7.97	2.27
B1	18.2	16.5	16.2	14.5	9.2	7.4	18.4	8.08	3.47

The trial comprised three Wischmeier plots (Figure 6.2), each of 22 m by 2.5 m, with one plot (on the left) kept bare, and the other two covered by palm mats (middle) and jute matting (on the right).

Figure 6.2 *Bergville plot layout (looking up the slope)*

The length of the runoff plots, as well as the fact that they are situated on a relatively constant (neither convex nor concave) slope in both the down-slope and cross-slope directions, means that gravity will be the only force acting on the surface water flow and that it will not be artificially funneled or channeled across the slope (towards the side of the plots), which could lead to abnormally high rates being recorded.

The objective of this trial site was to test the effect of the geotextiles on runoff and sediment load under generally occurring representative conditions. In many areas of South Africa, overgrazing or other poor land management practices have led to the soil surface being denuded of vegetation, thus drastically increasing erodibility (Smith, 1999; Snyman, 1999). Unless remedial steps are taken, the physical nature (eg duplex character) of many of these soils means that they easily form a surface crust or seal, making them extremely difficult to re-vegetate. To replicate this commonly occurring scenario, the plots were kept in a vegetation-free state by periodic application of a broad-spectrum herbicide (such as “Round-Up” (glyphosate) or equivalent).

The jute matting began to deteriorate and disintegrate quickly, and the data for this plot initially had missing values (probably due to a software glitch), so that it was decided that the results from these plots were not reliable. Consequently, for the 2007-08 season, that plot was left under natural vegetation (grass), in order to allow comparison between grass coverage, palm mat coverage and bare soil.

For each plot, a “Hobo” datalogger[1] (Onset Computer Corporation, Bourne, Mass., USA) was connected via a magnetic switch to a tipping bucket to measure the number of tips after each rain event. This data was then uploaded onto a shuttle device, and from there to a computer.

The location of the research site was determined by the proximity to previous Conservation Agriculture trials, and the desire to supplement the data previously obtained in these trials. Unfortunately, the distance to Pretoria (where the research team was based) and the inability to find a reliable local supervisor for the trial meant that some problems arose with the operation of the trial, namely:

- Two of the three dataloggers were first stolen and then, after they were replaced (and locked for security), they were again interfered with and disconnected, resulting in loss of data for certain periods;

[1] Trade names do not imply any specific endorsement or approval

- One of the plots had its run-off pipe connected at an angle too shallow to allow throughflow for collection, so no sediment determinations could be done;
- On the remaining two plots, the cylindrical sediment collection tanks were very deep and difficult to sample. A method was established whereby smaller, more easily accessible buckets were installed within the tanks, but these were also removed by persons unknown. No sediment data could therefore be obtained.

6.1.2 Results

The run-off data that was obtained covers the period September 2006 to March 2007, as well as January to April 2008 (data from the first half of the 2007-08 season was lost, for reasons described above).

For the recording period within the 2006-07 season (mid-September to mid-March), 492 mm of rain was recorded and the cumulative number of tips from the palm mat-covered plot was 317, compared with 813 tips for the bare plot, a factor of 0.39, as shown in Figure 6.3. There was an excellent relationship between the bare and palm mat plots, with an r^2 value of 0.923. This confirms that the reduction in runoff was consistent and that anomalous values rarely occurred.

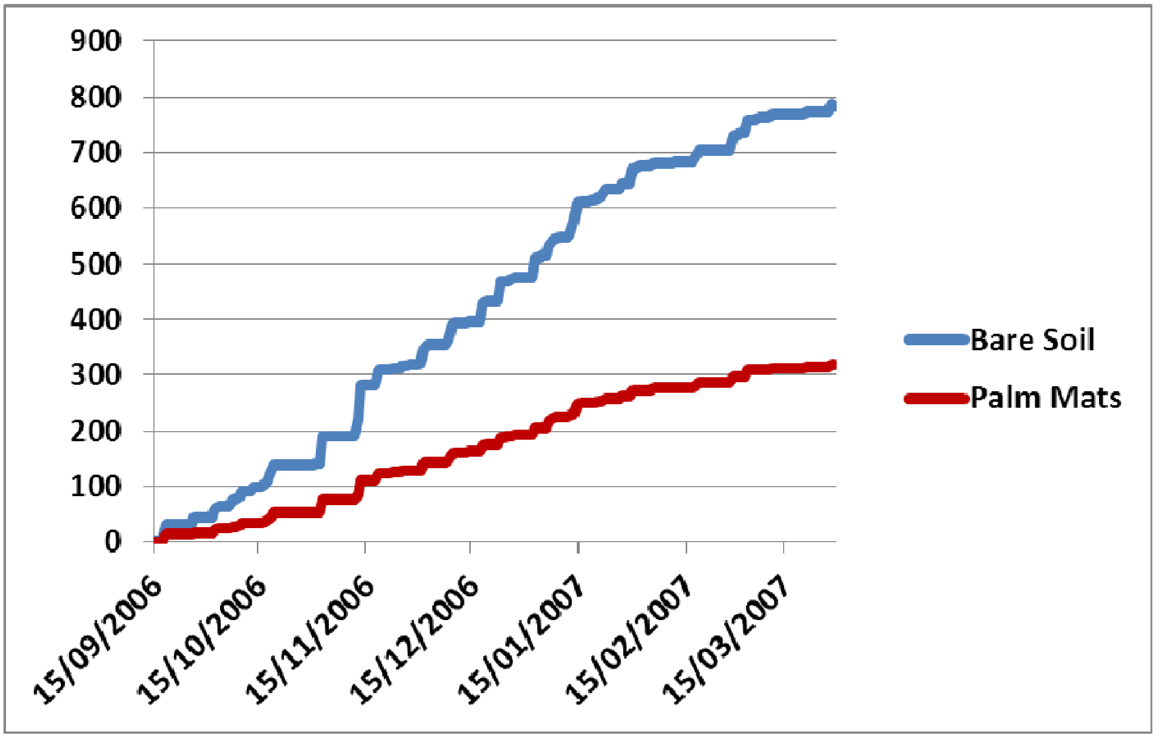

Figure 6.3 Bare soil tips *vs* palm mats, Bergville site, 2006-07 season ($p<0.05$)

In addition, for the 2006-07 season, the correlation between rainfall and runoff was good, with an r^2 value of 0.71 for the bare soil plot and 0.70 for the palm mats. The correlation equations were $y = 0.5175x + 0.3609$ for the bare soil and $y = 1.2529x + 0.4804$ for the palm mats, suggesting that for around 70% of the rainfall events, each mm of rain will cause one and a quarter tips on the bare soil plot and half a tip on the palm mat plot.

For the recording period of the 2007-08 season (mid-January to early April), 548 mm of rain fell, and the comparable number of tips was 1 910 for the bare plot, with only 773 for the palm mat-covered plot, a factor of 0.40, which is almost identical to the previous season (Figure 6.4). The relationship between the "bare and "palm" plots was not quite as good as the previous season, but still acceptable with an r^2 value of 0.820.

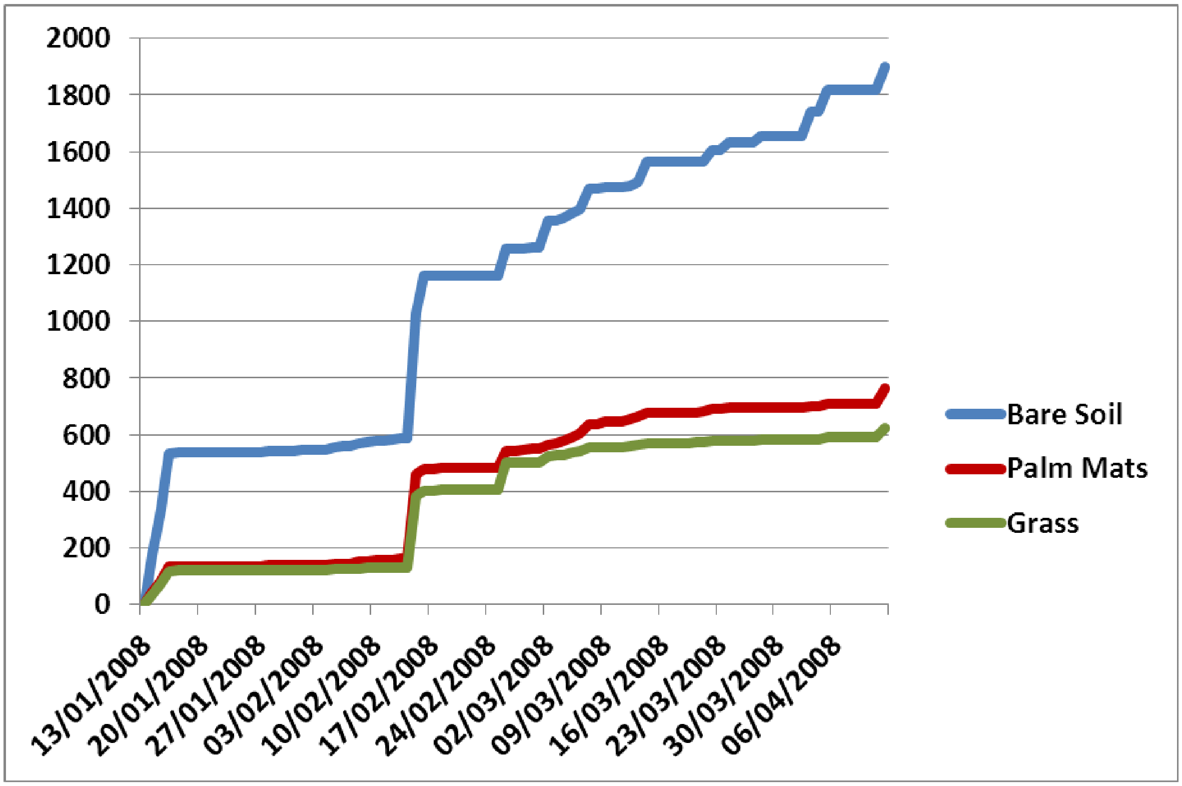

Figure 6.4 Bare soil tips *vs* palm mats *vs* grass cover, Bergville site, 2007-08 season ($p<0.05$)

For this period (January-April 2008), it was also possible to record the data from the grass-covered plot (which had been left in that condition after the disintegrated jute matting had been removed), where 624 tips were recorded (a factor of 0.32 compared to the bare soil). Figure 6.4 clearly shows that the performance of the mats was almost comparable to the natural grass cover, when compared to the bare soil surface.

Unfortunately, the correlation with rainfall for this season was not so good, with r^2 values varying from 0.34 (bare soil), 0.33 (palm mats) and 0.29 (grass cover), making predictions in relation to rainfall problematic. Given that the relationship factor between the number of tips from the bare plot and the palm mats was almost identical between the two seasons, it is difficult to explain the poor correlation with the rainfall. Rainfall was measured daily, and varying intensities over a shorter period than the daily amounts that were measured may have played a role.

However, the relative similarity of the mat-covered plot and the grassed plot, in comparison with the bare soil plot, would suggest that the mats performed very well in reducing runoff. It was anticipated that sediment concentration in the runoff would show a similar reduction, but due to the problems outlined earlier, no sediment data was obtained from this trial site. However, that hypothesis is tested at two of the other trial sites, as will be shown in the next section.

6.2 LADYBRAND, FREE STATE PROVINCE

As part of a project sponsored by the South African National Department of Agriculture, a trial was laid out at the beginning of the 2007-2008 rainfall season at the Phama Land Care research site, approximately 5 km north of Ladybrand, in the south of the Free State Province (see Figure 6.1).

6.2.1 Site conditions

The site (co-ordinates 29^{o} 10’ 21.5” S 27^{o} 24’ 55” E) comprised a uniform, north-facing slope of 9% in a footslope position, with a small perennial stream approximately 60 metres downslope. The stream has been badly eroded by water (see Figure 6.5), mainly due to the highly erodible, duplex soils (derived from sodium-rich Elliott mudstones) occurring in the area.

Figure 6.5 *Erosion at Ladybrand site*

Elevation is 1 655 metres above sea level. The area has a long-term annual rainfall of 676 mm per annum, falling mostly in summer. The area has warm summers and cool to cold, dry winters. Frost is common, and snow may even be experienced on occasion.

The main climate parameters, derived from the closest weather station (Modderpoort, ±10 km NE), are given in Table 6.3 (ARC-ISCW, 2006).

Table 6.3 Ladybrand climate

Month	Rainfall (mm)	Min. Temp (°C)	Max. Temp (°C)
Jan	94.8	13.0	27.9
Feb	86.9	12.7	27.2
Mar	97.6	10.6	25.3
Apr	50.9	6.1	22.4
May	21.9	0.7	19.5
Jun	11.1	-3.4	16.4
Jul	5.6	-3.8	16.6
Aug	20.8	-0.8	19.1
Sep	29.9	3.8	22.3
Oct	74.3	7.6	24.2
Nov	83.5	9.9	25.8
Dec	99.0	12.0	27.1
Year	**676.4 mm**	**14.3°C (Average)**	

The average daily relative humidity varies between 22.5% (minimum) and 85% (maximum) in winter to between 46% (minimum) and 94.5% (maximum) in summer.

The soil occurring has a grey-brown, sandy loam orthic topsoil horizon overlying a grey-brown, sandy loam E horizon abruptly overlying a reddish-brown, prismatic structured, clay subsoil horizon grading into underlying mudstone. The soil belongs to the Estcourt form (Soil Classification Working Group, 1991), approximately equivalent to an Albic Planosol (WRB) or Rhodustalf (USDA). Soil colours given are from the Munsell system (Munsell Color, 2000).

The abrupt transition from topsoil to subsoil means that the soil is regarded as a "duplex" or double-layer soil and is especially susceptible to erosion if the vegetation covering is removed, as evidenced by the badly eroded surroundings.

The soil description and analysis is as follows:

Table 6.4a Ladybrand site: soil description

Profile Site: Phama, near Ladybrand
Co-ordinates: 29° 10' 21.5" S 27° 24' 55" E
Altitude: 1655 m
Soil Form: Estcourt
Soil Series: Zastron (1100)
Classification (WRB): *Albic Planosol*
Classification (USDA): *Rhodustalf*

Terrain Type: Upper footslope
Slope Angle: 9%
Parent Material: Mudstone of Elliot Formation, Karoo Sequence

Horizon	**Description**	**Diagnostic**
A1 *(0-250 mm)*	Dry colour 5YR4/3, moist colour 5YR4/4; few, fine, faint red and brown mottles; fine sandy loam texture; apedal massive structure; slightly hard consistence; few, fine cracks; common roots; gradual, smooth transition.	**Orthic**
E *(250-450 mm)*	Dry colour 5YR5/1, moist colour 5YR5/2; few, medium, faint yellow and grey mottles; fine sandy loam texture; apedal massive structure; slightly hard consistence; few, fine cracks; few roots; abrupt, wavy transition.	**E horizon**
B1 *(>450 mm)*	Dry colour 5YR3/3, moist colour 5YR3/4; many, coarse, prominent red and brown mottles; clay texture; moderate, coarse prismatic blocky structure; very hard consistence; common, medium cracks; very few roots.	**Prismacutanic**

Table 6.4b Ladybrand site: analytical results

Horizon	**Particle Size (%)**							**pH (H_2O)**	**CEC (cmol kg^{-1})**
	Sand				Silt		Clay		
	coarse	*medium*	*fine*	*v fine*	*coarse*	*fine*			
A1	0.1	1.0	14.1	40.8	18.9	7.8	15.4	6.98	7.33
E	0.1	0.4	14.0	23.9	20.2	21.3	18.5	6.07	7.82
B1	0.2	0.4	2.8	15.6	14.7	16.5	48.3	6.76	17.59

The trial comprised seven Wischmeier plots, each of 22 m by 2.5 m, with one plot left bare, and the other six covered by a variety of materials, namely:

- Jute matting (coarse weave),
- Jute matting (fine weave),
- MacMat (a synthetic, wire-reinforced geotextile sheet),
- Stone terraces (where parallel rows of large stones were placed at intervals perpendicular to the slope),
- Half moon shaped basins (excavated so that the open end of the basin faces up the slope),
- Palm mats.

The aim of this trial was to test the effect of the geotextiles on runoff **and sediment concentration**, as well as their effectiveness in promoting re-vegetation (Paterson, Smith & van Greunen, 2013). The background to the project and full details of the trial are given in the research report (Smith *et al.*, 2009).

Results for the palm mats were obtained for the 2008-09 and 2009-10 seasons, with the sole difference being that for the latter season, the mat coverage was reduced from 100% to 50%, in order to look at the effects of having a reduced surface coverage, which would also mean less mats being required for a given area. This was achieved by having the palm mats laid out in parallel strips, with equivalent gaps left in between, so that mat coverage is interspersed with bare soil strips. This is illustrated in Figure 6.6.

Due to the fact that one of the aims of the trial was to promote re-vegetation, the plots were not sprayed with herbicide during the growing season.

Figure 6.6 *Palm mat layout for 2009-10 season (parallel strips)*

6.2.2 Results

6.2.2.1 Runoff

For the recording period of 2008-09 season (mid-December to mid-March), 347 mm of rain was recorded and the number of tips from the palm mat-covered plot was 1 283 (equivalent to 112 mm), compared with 1943 tips (170 mm) for the bare plot (Figure 6.7), a factor of 0.64. There was a good relationship between the runoff recorded from bare and palm mat plots, with an r^2 value of 0.87.

For the recording period of the 2009-10 season (1 October to 31 March), 660 mm of rain was recorded and the number of tips from the palm mat-covered plot was 2 608 (equivalent to 228 mm). This compared with 4 446 tips (388 mm) for the bare plot, a factor of 0.58 (compared to 0.64 for the previous season). This is shown in Figure 6.8. The relative similarity of these figures would suggest that the 50% reduction in mat coverage did not have a significant effect on the

relative effectiveness of runoff control. In absolute terms, the runoff increased by 228%, but most of this could be attributed to the 190% increase in rainfall. The similarity in the runoff factor between the two seasons would seem to be mainly due to the fact that, while an increased area of soil is left exposed between the parallel strips of palm mats, the distance that any surface runoff can travel before being arrested is short (one mat width, ±0.5 m), and the runoff thus does not have the opportunity to increase speed, which could potentially remove more surface sediment.

The relative increase in the number of tips between the two seasons (203% for the palm mats, 228% for the bare plot and 190% for the rainfall) would also not seem to be out of proportion, again suggesting that a 50% reduction in mat density would not cause a corresponding increase in runoff ***under similar conditions***.

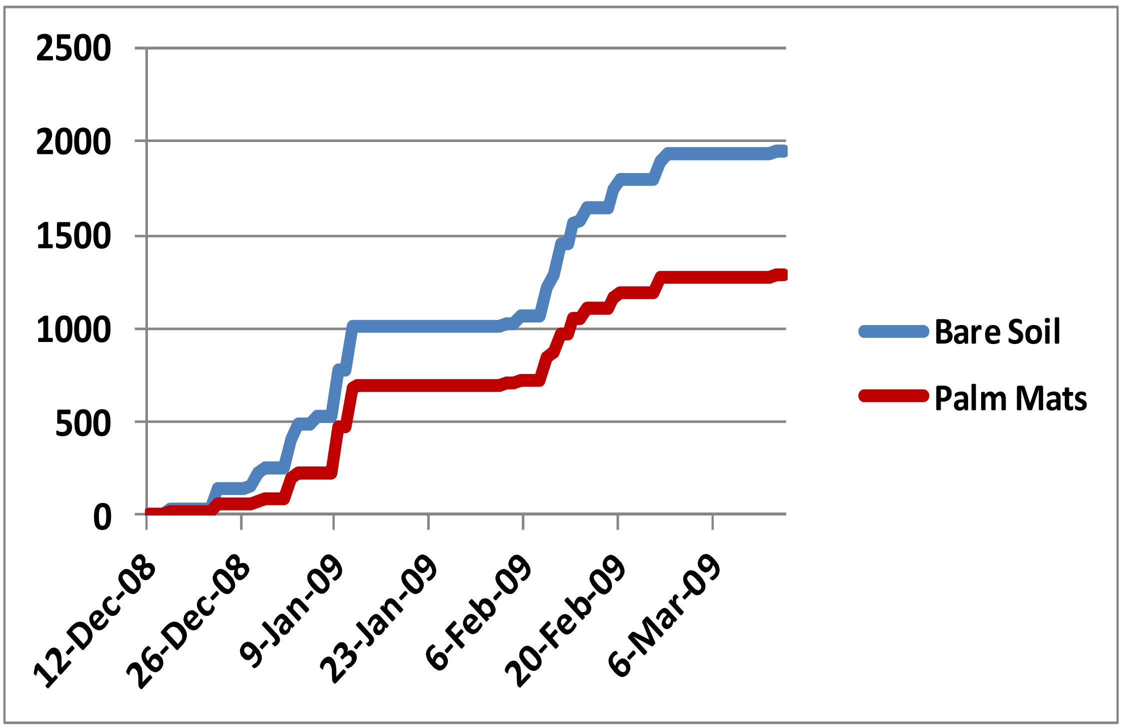

Figure 6.7 Runoff values at Ladybrand, 2008-09

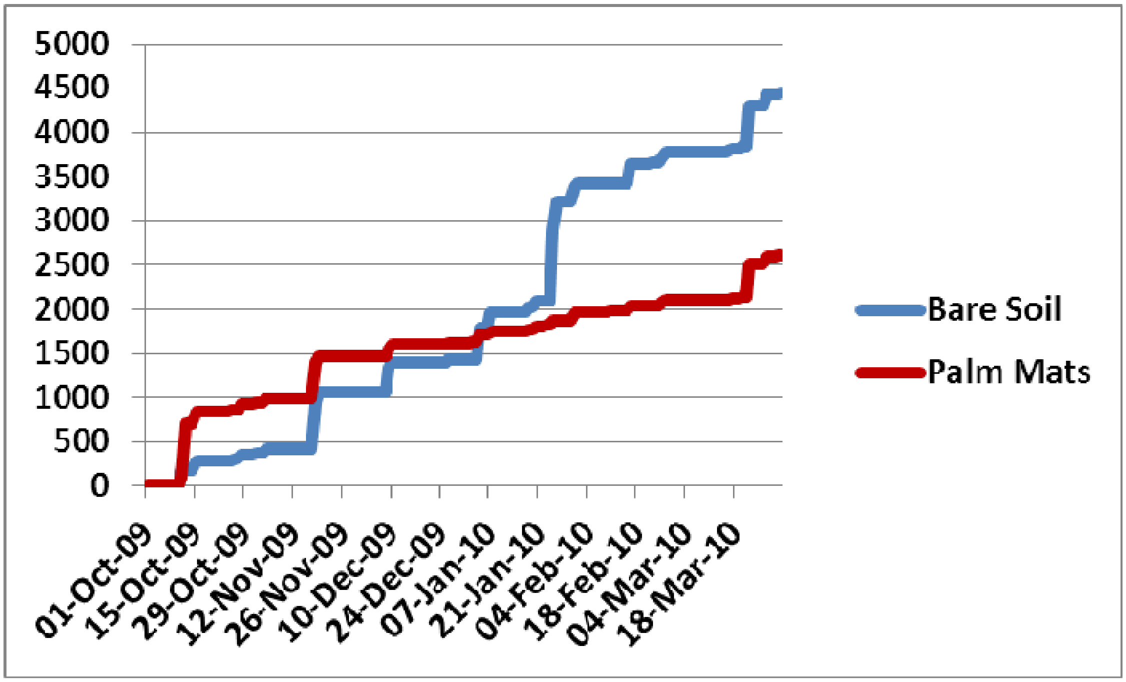

Figure 6.8 Runoff values at Ladybrand, 2009-10

6.2.2.2 Sediment Concentration

Sediment concentration samples were collected after each significant rain event (or close sequence of events). Inside each collection drum, a 25 litre bucket was placed to collect the runoff, and a representative 2 litre sample was collected by thoroughly stirring the runoff before decanting into a plastic collection bottle. The samples were taken to the laboratory, where they were allowed to settle, before most of the run-off was siphoned off. Then the remaining mixture was poured into a pre-weighed beaker, once again allowed to settle before the excess run-off was once more siphoned off. Finally, the sample was oven dried overnight at 105^{o}C, so that the dried sediment could be accurately weighed.

Samples were collected on a total of 19 occasions, and these results (for the 2008-09 and 2009-10 seasons) are shown in Table 6.5.

The amount of sediment obtained on each sampling date is from a well-mixed, representative **2 litre runoff sample**. The amount of sediment contained in the runoff will vary with rainfall intensity, which could not be measured, but the values do provide a good idea of comparative relationships.

Table 6.5 Ladybrand sediment concentration (g), 2008-09 and 2009-10 seasons

Date	Palm Mats	Bare Soil	Bare/Mats ratio
2008-09 (100% mat coverage) **Rainfall = 347 mm**			
19/11/08	10.92	21.15	1.94
06/12/08	2.24	3.62	1.62
06/01/09	6.08	15.57	2.56
12/01/09	19.47	23.74	1.22
30/01/09	0.51	1.25	2.45
06/02/09	3.39	91.75	27.06
16/02/09	7.21	43.45	6.03
30/03/09	0.39	2.29	5.87
Seasonal Total	50.21	202.82	
Average	6.28	25.35	6.09
2009-10 (50% mat coverage) **Rainfall = 660 mm**			
16/10/09	17.85	18.15	1.02
28/10/09	5.64	11.09	1.97
20/11/09	11.23	36.47	3.25
09/12/09	11.39	15.92	1.40
10/12/09	14.83	15.02	1.01
04/01/10	4.71	20.03	4.25
29/01/10	5.90	12.75	2.16
10/02/10	4.11	35.95	8.75
26/02/10	4.87	5.03	1.03
01/04/10	7.54	10.75	1.43
09/04/10	7.31	23.41	3.20
Seasonal Total	95.38	204.57	
Average	8.67	18.60	2.68
Cumulative Total	145.59	407.39	
Overall Average	7.66	21.44	4.12

There is a clear and consistent reduction in sediment concentration comparing the palm mats to the bare soil surface ($p<0.01$). The amount of sediment collected on 06/02/2009 is very high, and does not seem to be correlated with a marked spike in runoff (Figure 6.7), although it is possible that the flow mechanism through the tipping bucket apparatus became blocked before suddenly releasing excess sediment. If this seemingly anomalous value is discarded, the average bare/mat ratio for 2008-09 falls from 6.09 to 3.10. The average ratio of 2.68 for the 2009-10 season, with the 50% reduction in mat coverage, then constitutes only a 16% reduction, despite much more rainfall across the season.

If the sediment concentration values are combined with the runoff values (represented by the number of tips, an approximation of erosion severity (in tons ha^{-1}) may be obtained, as follows:

- ***Multiply the volume of the tipping bucket (4.8044 litres) by the number of tips to obtain the volume of runoff per 55 m^2 plot per season.***
- ***Multiply this by 181.8 to get the volume of runoff (litres) per hectare.***
- ***Multiply this by the average sediment load / 2 to obtain the approximate soil loss per ha (g).***
- ***Divide by 1 000 000 to obtain the approximate soil loss per ha (t).***

This is shown in Table 6.6.

Table 6.6: Approximate soil loss per treatment (t ha^{-1} yr^{-1})

Treatment	2008-09 (full mats)	2009-10 (half mats)	Average
Palm Mats	3.519	9.875	6.669
Bare Soil	21.463	36.115	28.789

In South Africa, classes of soil erosion severity (t ha^{-1} yr^{-1}) have been assessed as ***low*** (0-5), ***low to moderate*** (5-12), ***moderate to high*** (12-25), ***high*** (25-50) and **very high** (>50) (Le Roux *et al.,* 2006). If the data from Ladybrand are used, the combination of runoff and sediment concentration shows that the average soil loss from the bare soil is in the ***high*** class, but that the treatments reduce this to ***low to moderate*** or even ***low***.

There is a strong probability that the data from Ladybrand show an under-estimation of both runoff and sediment concentration. This is due to periods of intense rainfall erosion leading to spillage from the tipping buckets during the data recording process as well as sedimentation in pipes and channels as well as possible overflow of the collecting buckets. However, observation over a number of seasons has indicated that this factor is likely to be around 5% or so at most.

6.2.2.3 Re-vegetation

At the end of both the 2008-09 and 2009-10 rainfall seasons, the plots were examined to determine relative degrees of re-vegetation (Smith *et al.,* 2009), for both ***basal cover*** (the proportion of the plant that extends into the soil) and ***foliar cover*** (a vertical projection of the exposed vegetative extent). Both types of coverage are important in the re-establishment of surface vegetation. Basal cover is important to produce a root volume sufficient to bind the soil mass together, while foliar cover is important to produce a canopy or shield whereby raindrops can be intercepted before they impact upon bare ground. The arrangement of the mesh holes in the palm mats functions as a series of micro-basins that retain water, while the gaps themselves allow vegetation to emerge.

The assessment of vegetation cover was done using the Step-Point Method (Evans & Love, 1957), whereby point assessment is done at regular intervals. In this case, a sampling grid of 0.5 x 0.5 m was used, giving approximately 150 sampling points in each plot. The presence or absence of vegetation cover at each point was recorded and the results are given as a percentage of the total number of sampling points.

Table 6.7 Vegetation Cover at Ladybrand Plots, 2008-09 and 2009-10 seasons (all figures in %)

Treatment	2008-2009 *(Rainfall 347 mm)*		2009-10 *(Rainfall 660 mm)*	
	Foliar Cover	Basal Cover	Foliar Cover	Basal Cover
Palm Mats	48	5	68	6
Bare Soil	30	3	48	2

Season 2008-09 can be regarded as a relatively dry year in relation to the long-term annual average (Table 6.3), while 2009-10 can be seen as relatively “normal”. Despite the lower than average rainfall of the first season, the palm mats enabled a foliar vegetation cover of around half of the surface area to establish in only one season, and this cover increased the following season, despite half mat density. This could also be due to the damming effect that each row of mats would have, so that water would accumulate on the upslope side of each row, also helping to retain soil moisture for the establishment of plants.

For 2009-10, where the palm mat coverage density was reduced from 100% to 50% (as shown in Figure 6.6), the rainfall was significantly higher (660 mm, as opposed to 347 mm). This led to more vegetation generation. Interestingly, despite there being 50% less surface coverage on the palm mat plot than the previous season, actual re-vegetation still increased, re-enforcing the theory that a reduction in mat density does not necessarily adversely affect the ability of a soil surface to retain water so that a vegetation layer can re-emerge.

6.3 ROODEPLAAT, GAUTENG PROVINCE

As a result of the problems encountered at Bergville (Section 6.1.1), and following a *Borassus* Project concertation meeting in Thailand in January 2008, it was decided that a trial should be established close to Pretoria, specifically to obtain sediment concentration data in a controlled setting. Consequently, a trial was laid out in the middle of 2008 on the Roodeplaat Research Farm of the Agricultural Research Council, some 25 km north-east of Pretoria, in Gauteng Province (see Figure 6.1).

6.3.1 Site conditions

Two sites were selected (Site 1 co-ordinates 25^{o} 36’ 06.1” S, 28^{o} 21’ 50” E; Site 2 co-ordinates 25^{o} 35’ 18.9” S, 28^{o} 21’ 03.7” E), approximately 1.9 km apart, selected on the basis of a variation in slope angle as well as potential erodibility. The lower site (Site 1) comprised a north-facing slope of approximately 5% in a lower footslope position, with elevation being 1130 metres above sea level, while the upper site (Site 2) had a south-west facing slope of approximately 2.5%, in an upper midslope position, elevation 1162 m. The area has a long-term annual rainfall of 641 mm per annum, falling mostly in summer. The area has warm to hot summers and cool, dry winters. The main climate parameters are given in Table 6.8 (ARC-ISCW, 2006).

The average daily relative humidity varies between 21.5% (minimum) and 75% (maximum) in winter, to between 31.5% (minimum) and 87.5% (maximum) in summer.

Table 6.8 Roodeplaat climate

Month	Rainfall (mm)	Min. Temp (°C)	Max. Temp (°C)
Jan	117.13	16.72	29.54
Feb	85.44	16.45	29.11
Mar	71.91	14.63	28.04
Apr	44.89	10.72	25.58
May	16.88	5.85	23.13
Jun	6.66	2.33	20.50
Jul	2.90	2.07	20.76
Aug	5.44	4.45	23.48
Sep	17.77	8.93	26.89
Oct	66.84	12.76	28.19
Nov	102.30	14.72	28.16
Dec	102.83	16.04	28.80
Year	640.99 mm	**18.24°C (Average)**	

The soil occurring at Site 1 has a grey-brown, sandy clay loam orthic topsoil horizon overlying a brown, sandy clay loam, moderately structured, calcareous blocky sandy clay loam subsoil horizon (Table 6.8). The soil belongs to the Sepane form (Soil Classification Working Group, 1991), approximately equivalent to a Haplic Lixisol (WRB) or Eutrudept (USDA). At Site 2, the soil has a reddish-brown, sandy loam orthic topsoil horizon overlying a grey-brown, mottled soft plinthic subsoil horizon (Table 6.9). The soil belongs to the Westleigh form (Soil Classification Working Group, 1991), approximately equivalent to a Haplic Plinthisol (WRB) or Plinthic Alfisol (USDA). Soil colours given are from the Munsell system (Munsell Color, 2000).

The soil descriptions and analysis are as follows:

Table 6.9a Roodeplaat soil parameters (Site 1)

Profile Site:	Site 1, Roodeplaat Research Farm
Co-ordinates:	25^{o} 36’ 06.1” S 28^{o} 21’ 50.0” E
Altitude:	1130 m
Soil Form:	Sepane
Soil Series:	Muiskraal (1120)
Classification (WRB):	*Haplic Lixisol*
Classification (USDA):	*Eutrudept*
Terrain Type:	Lower footslope
Slope Angle:	5%
Parent Material:	Alluvium

Horizon	**Description**	**Diagnostic**
A1 (0-300 *mm)*	Dry colour 7.5YR5/4, moist colour 10YR3/4; few, fine, faint red and brown mottles; fine sandy clay loam texture; weak, medium subangular blocky structure; slightly firm consistence; common roots; gradual, smooth transition.	**Orthic**
B1 *(300-* 900 mm)	Dry colour 10YR4/6, moist colour 10YR3/6; many, medium, faint yellow and brown mottles; fine sandy clay loam texture; moderate, medium subangular blocky structure; firm consistence; moderately calcareous; few roots; gradual, wavy transition.	**Pedocutanic**
G *(>900 mm)*	Moist colour 10YR6/3; many, medium, prominent yellow and grey mottles; massive apedal structure; firm consistence; moderately calcareous; few roots.	**Unspecified material with signs of wetness**

Table 6.9b Roodeplaat soil parameters (Site 2)

Profile Site:	Site 2, Roodeplaat Research Farm
Co-ordinates:	25^{o} 35' 18.9" S 28^{o} 21' 03.7" E
Altitude:	1162 m
Soil Form:	Westleigh
Soil Series:	Helena (1000)
Classification (WRB):	*Haplic Plinthosol*
Classification (USDA):	*Plinthic Alfisol*
Terrain Type:	Upper midslope
Slope Angle:	2.5%
Parent Material:	Shale of Silverton Formation, Transvaal Sequence

Horizon	**Description**	**Diagnostic**
A1 *(0-250 mm)*	Dry colour 7.5YR4/4, moist colour 7.5YR3/4; few, fine, faint brown mottles; coarse sandy loam texture; weak medium subangular blocky structure; slightly hard consistence; common roots; gradual, smooth transition.	**Orthic**
B1 *(250-550 mm)*	Dry colour 7.5YR5/3, moist colour 7.5YR4/3; many, medium, distinct yellow and black mottles; coarse sandy clay loam texture; apedal massive structure; slightly hard consistence; few roots.	**Soft Plinthic**
C *(>550 mm)*	Weathering saprolite.	

The soil analysis results showed that Site 1, which had a steeper gradient than Site 2 (5% compared to 2.5%), also had a higher clay content with finer sand grade (Table 6.9c), the combination of which could be expected to increase the inherent erodibility of the soil.

Table 6.9c Roodeplaat soil analysis results (topsoil)

Site	Particle Size (%)							pH (H_2O)	CEC (cmol kg^{-1})
	Sand				Silt		Clay		
	coarse	*medium*	*fine*	*very fine*	*coarse*	*fine*			
1	**5.5**	**15.7**	**24.2**	**10.3**	**11.0**	**9.4**	**23.9**	**6.32**	**13.96**
2	**23.4**	**9.4**	**15.6**	**12.1**	**10.8**	**11.3**	**17.4**	**6.74**	**10.58**

The trial comprised two run-off plots, each measuring 10 m by 2.5 m, at each site. One plot was left bare, and the other was covered by palm mats. The aim of this trial was to specifically test the effect of the geotextiles in reducing sediment removal, so the plots were kept in a vegetation-free state by periodic application of a broad-spectrum herbicide ("Round-Up" (glyphosate) or equivalent).

The same arrangement as for Ladybrand was employed, whereby a collecting bucket was sunk in the ground on the downslope side of each plot and following each significant rainfall event (or close sequence of events), the runoff in the bucket was thoroughly mixed, and a representative 2 litre sample was collected, before the bucket was emptied and cleaned. The runoff samples were taken to the laboratory at ARC-ISCW, where the runoff was drained through previously weighed filter paper cones to leave the sediment behind. This was then oven-dried at 105^{o}C overnight and then re-weighed, taking the mass of the filter paper into account.

6.3.2 Results

6.3.2.1 Sediment concentration

The results of the sediment concentration sampling at both sites at Roodeplaat for the 2008-09 season are shown in Table 6.10. Samples were collected on twenty occasions between 22nd October 2008 and 13th May 2009.

Table 6.10 Rainfall and sediment concentration, Roodeplaat, 2008-09 season

Date Sampled	Rainfall prior to sampling (mm)	Max. Daily Amount (mm)	Rainfall Intensity (mm/5 min)		Roodeplaat Site 1 (5% slope)			Roodeplaat Site 2 (2.5% slope)		
					Sediment Conc. (g)		B/M Ratio	Sediment Conc. (g)		B/M Ratio
			Average	Maximum	Mats	Bare		Mats	Bare	
22/10/08	22.1	9.2	0.22	1.2	0.109	0.588	5.39	0.332	0.880	2.65
11/11/08	41.3	11.2	0.21	1.7	0.108	0.557	5.15	0.079	0.425	5.38
17/11/08	61.7	32.6	0.53	4.4	1.511	71.274	47.17	3.826	13.090	3.42
28/11/08	21.4	18.8	0.96	4.7	1.193	22.352	18.74	2.629	8.229	3.13
08/12/08	34.6	15.3	0.47	5.5	0.270	13.334	49.39	0.363	3.987	10.98
17/12/08	47.9	32.0	0.45	4.0	0.862	31.342	36.36	1.546	5.932	3.84
28/12/08	16.3	11.2	0.54	3.2	0.736	11.531	15.67	0.363	3.910	10.77
02/01/09	59.3	37.5	0.84	5.2	0.895	44.216	49.40	1.887	9.794	5.19
06/01/09	8.1	5.3	0.41	1.0	1.907	27.840	14.60	0.425	0.832	1.96
13/01/09	52.1	43.0	0.78	7.3	1.708	132.268	77.44	0.445	2.700	6.07
16/01/09	10.2	7.2	0.36	2.2	1.612	125.004	77.55	0.278	1.230	4.42
22/01/09	44.8	25.4	1.24	9.0	11.263	82.256	7.30	0.771	6.376	8.27
29/01/09	16.1	15.6	0.48	5.7	0.940	42.734	45.46	0.203	0.466	2.30
02/02/09	10.2	10.1	0.53	3.9	7.630	85.374	11.19	0.455	1.343	2.95
05/02/09	41.0	40.9	0.63	6.2	3.867	36.627	9.47	0.530	1.188	2.24
11/02/09	32.0	12.2	0.34	2.7	3.230	39.465	12.22	0.603	1.784	2.95
23/02/09	28.8	22.8	0.27	1.5	4.496	95.312	21.19	0.390	2.578	6.61
03/03/09	26.1	20.7	0.33	4.8	4.632	134.031	28.94	0.426	0.612	1.44
19/03/09	63.0	41.1	0.37	8.6	10.153	43.679	4.30	0.180	2.711	15.06
13/05/09	45.9	14.0	0.42	6.4	9.576	184.941	19.31	0.550	4.628	8.41
	Total 682.9		Ave. 0.52		66.698	1224.94	18.36	16.281	72.695	4.47
				Averaged per event	**3.335**	**61.236**	**27.81**	**0.814**	**3.636**	**5.40**

The plots with palm mats clearly produced less sediment than those with the bare soil, more than 18 times less at Site 1 and almost 4.5 times less at Site 2. If the average of the comparisons per rainfall event is used, at Site 1 (5% slope), the average was 27.8 times more sediment for the bare plot, compared to the palm plot and at Site 2 it was 5.4 times more. This variation would seem logical if the assumption is made that the lesser gradient of Site 2 (2.5% slope) led to slower runoff velocity and therefore less sediment.

The rainfall station on the research farm, which is located approximately 900 m from Site 1 and 1.7 km from Site 2, provided rainfall intensity data from each 5 minute period throughout the day. When this data was used to study the occurrence and intensity of rainfall prior to each sampling date, there is a slight relationship, although with a lot of variation. When the period between sampling dates is longer, and when the amount of rainfall experienced is greater (more than 40 mm was recorded on several occasions), then the amount of sediment seems to be higher, but the correlation overall is poor, with r^2 values in the order of 0.30 or worse. Maximum intensity throughout the season also varies, with the highest recorded rate of 9.0 mm in a 5 minute period equating to 54 mm in half an hour. However, such intense rates of over 5 mm in 10 minutes were rarely sustained for more than one or two such periods at a time. It would therefore appear that the relationship between rainfall, intensity and sediment production is complicated and would need a much more detailed, continuous investigation that is outwith the scope of this study.

For the 2009-10 season, it was decided to repeat the trials, but the mat coverage was changed to parallel strips, with a gap in between (similar to the Ladybrand plot), so that mat coverage was reduced from 100% to 50% (see Figure 6.9)

Once again, both sites were used, with vegetation coverage controlled by herbicide. Samples of sediment concentration were collected on a total of 19 occasions.

The results of the sediment concentration sampling for 2009-10 are shown in Table 6.11.

Figure 6.9 *Mat layout at Roodeplaat, 2009-10*

Table 6.11 Rainfall and sediment concentration, Roodeplaat, 2009-10 season

Date Sampled	Rainfall prior to sampling (mm)	Max. Daily Amount (mm)	Rainfall Intensity (mm/5 min)		Roodeplaat Site 1 (5% slope)			Roodeplaat Site 2 (2.5% slope)		
					Sediment Concentration (g)		B/M Ratio	Sediment Concentration (g)		B/M Ratio
			Average	Maximum	Mats	Bare		Mats	Bare	
50% mat coverage, normal mesh size										
30/09/09	38.6	26.6	0.35	3.6	0.328	9.255	28.21	0.977	3.305	3.38
16/10/09	40.9	27.3	0.50	4.7	4.605	69.224	15.03	4.253	10.103	2.37
21/10/09	8.7	7.6	0.27	1.3	1.384	13.054	9.43	0.918	2.393	2.61
27/10/09	32.8	29.3	0.54	5.0	2.696	37.662	13.96	2.937	4.659	1.59
05/11/09	26.1	14.3	0.38	2.2	3.684	18.347	4.98	1.922	2.690	1.40
20/11/09	65.7	36.9	0.27	2.6	1.630	15.553	9.54	0.250	2.218	8.87
01/12/09	46.1	25.8	0.46	3.3	0.574	13.793	24.03	1.125	7.377	6.58
11/12/09	75.1	35.6	0.60	7.5	3.017	32.497	10.77	2.356	16.78	7.12
17/12/09	11.5	11.4	0.29	1.9	1.916	25.104	13.10	1.358	2.504	1.84
22/12/09	24.1	20.1	0.37	1.2	2.194	8.336	3.80	0.415	1.595	3.84
07/01/10	85.0	46.2	0.62	4.8	6.431	35.407	5.51	5.151	14.010	2.72
	Total 454.6		Ave. 0.42		28.459	278.32	9.78	21.662	67.634	3.12
				Averaged per event	2.587	25.294	12.578	1.969	6.149	3.85
50% mat coverage, increased mesh size										
19/01/10	31.1	11.7	0.48	5.1	*Not used (insufficient mats available)*			6.558	15.229	2.32
25/01/10	15.8	6.3	0.20	1.9				1.323	2.708	2.05
08/02/10	17.6	11.1	0.40	1.6				4.578	5.577	1.22
19/02/10	25.7	11.3	0.35	3.7				1.081	2.178	2.01
26/03/10	35.7	20.9	0.36	5.6				4.372	6.968	1.59
07/04/10	134.9	67.4	0.42	8.6				6.605	8.479	1.28
22/04/10	41.9	24.8	0.31	2.0				1.036	1.460	1.41
29/04/10	27.2	17.6	0.20	7.1				0.349	0.389	1.11
	Total 329.9		Ave. 0.35					25.902	42.988	1.66
	Season Total 784.5						Averaged per event	3.238	5.624	1.63

For the first half of the season (September to January), rainfall intensity was similar to the previous season (average of 0.42 mm/5 minute period, compared with 0.46 mm in 2008-09). Decreasing the mat coverage between 2008-09 and 2009-10 from 100% to 50% actually led to the average sediment concentration decreasing from 3.34 g to 2.59 g for Site 1 (5% slope), while it increased from 0.81 g to 1.97 g for Site 2 (2.5% slope) ($p<0.001$). The average amount of sediment from the bare plots also decreased from 61.24 g to 25.3 g (<1%) for Site 1, and increased (3.64 g to 6.15 g) for Site 2. It is unclear why there should be a decrease in sediment concentration with a decrease in mat coverage. Rainfall patterns were similar, and average rainfall intensity was only slightly less.

From mid-January 2010, a further refinement was made (Site 2 only due to a shortage of mats), namely to physically enlarge the mesh size of the mats by removing every second strand, so that the gap was approximately 10 x 10 cm instead of 4.5 x 4.5 cm (shown in Figure 6.10, with the enlarged size of mesh on the left).

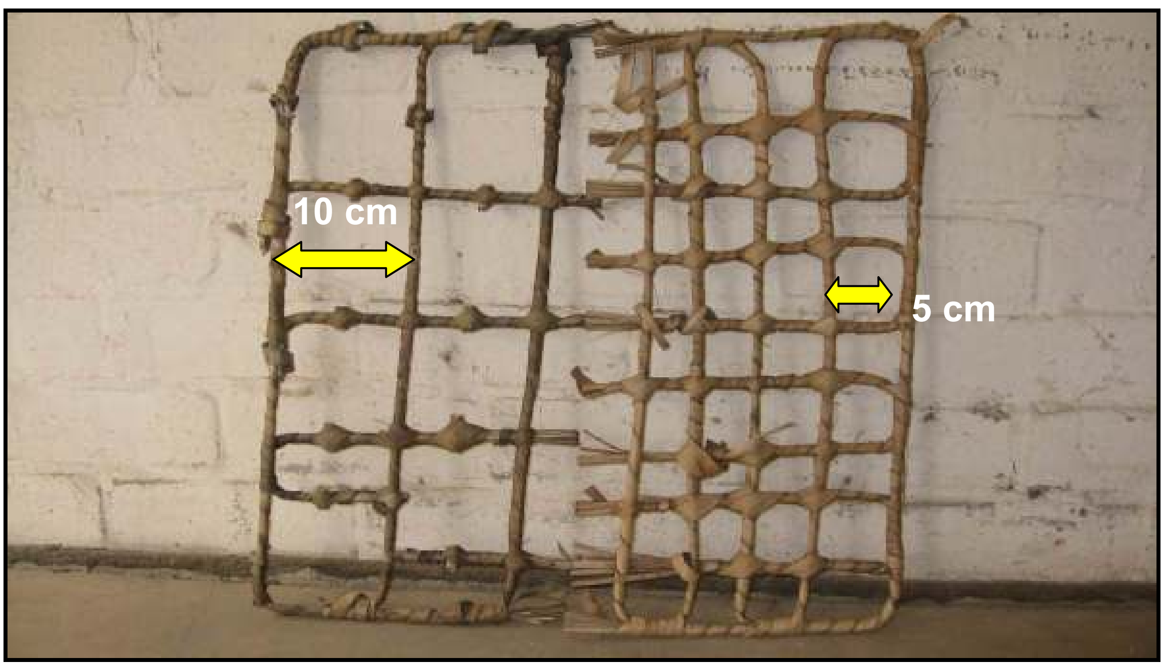

Figure 6.10 *Palm mat showing increased mesh size*

This had the effect of reducing the cover percentage of the mats from approximately 40-45% to around 30% (confirmed by digital measurement of a photograph of the two mats). Tests in Belgium using a rainfall simulator (Smets *et al.,* 2007) suggested that a mesh size of 12 x 12 cm produced approximately twice as much sediment as a mesh size of 5 x 5 cm. For Roodeplaat Site 2, the results were similar, increasing from an average of 1.969 g sediment concentration per rainfall event to 3.238 g. If the 17% reduction in 5 minute rainfall intensity (average of 0.42 mm for the first half of the season, 0.35 mm for the second half) is taken into account, the difference would have been extremely close to the Belgian figure. This would suggest that the original mesh size would seem to be close to optimal, whether used as full surface coverage or reduced (placed in strips at intervals), but that reducing the mesh size reduces the ability of the mats to retard the surface flow, along with the associated sediment removed in the surface runoff process.

6.3.2.2 Splash Erosion

The detachment of soil particles from the bare soil surface due to the direct impact of raindrop action is the initial phase of the water erosion process (Ellison & Pomerene, 1944). In most cases, only once this process has occurred can the detached particles then be physically removed by the action of surface flow. This means that although the splash erosion process itself may not contribute a great deal to the transportation of soil particles, the action of raindrops is necessary for initial detachment, which is then acted upon by the flow of water along the surface. Splash erosion is also proportional to the area of exposed soil (Jomaa *et al.*, 2012), so the presence of a geotextile, such as the palm mats, could be expected to have a beneficial effect on the reduction of particle detachment by splash erosion.

At the start of the 2009-10 rainfall season, a small splash erosion trial was established at Site 2. The procedure is similar to that described by Battacharyya *et al.* (2008), who established similar trials in Shropshire, UK. According to them, less than 5% of detached particles travel more than 50 cm, so that large surface areas are not necessary for such a trial. In addition, it has been found that raindrop splash patterns show a rapid exponential decay away from the source (van Dijk *et al.*, 2002). Thus, four adjoining areas of approximately 1.5 x 1.5 m each were laid out, of which two were covered with mats, while two were left bare. The mat-covered and bare areas were separated by a metal frame, so that no contamination that would influence the results could occur. Cylinders were sunk into the ground, with approximately 2 cm protruding above ground level, to ensure that no surface runoff would infiltrate, and funnels were laid on top, leading to collecting bottles (2 litres in volume) inside the cylinders.

In addition, measuring posts, painted white, with a 1 cm interval measuring scale on the side, were sunk into the soil, so that the height of the splash erosion above the soil surface could be determined. As was the case for the adjacent runoff plots, following every significant rainfall event (or close sequence of events), the samples of splashed water containing sediment were collected, so that the mass of sediment contained in the runoff could be determined. In addition, visual examination of the painted measuring posts (which were cleaned after each inspection), enabled the pattern and height of the splashed particles to be measured.

The layout, including the measuring posts (white rectangles) and collecting bottles (black cups) is shown in Figure 6.11.

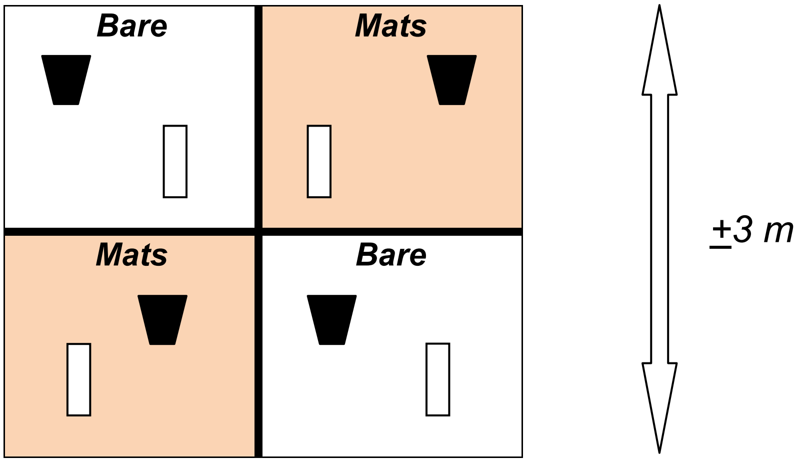

Figure 6.11 *Layout of splash erosion trial*

Results from the splash erosion trial showed that the average ***amount*** of detached sediment per rainfall event that was collected on the bare areas was 6.76 g, compared to an average of 2.57 g for the areas with mat cover, an increase of 2.6 times (n=18). The ***height*** to which the detached particles were transported also showed a significant increase ($p<0.001$), with an average of 8.67 cm for the bare plots compared with 2.50 cm for the mats, an increase of almost 3.5 times (n=20). Comparable results in the UK by Battacharyya *et al.* (2008) using 1 litre collecting bottles, showed a 9-fold increase in sediment from the palm mats to the bare soil, but with "only" a twofold increase in splash height.

However, this seemingly disproportionate increase in detached material could be due to the fact that the soil in Shropshire was much sandier (4.4% clay) than the soil at Roodeplaat (17.4% clay), with consequently much less coherence between particles. In addition, the overall intensity of the rainfall, and associated raindrop energy, will be much lower in the UK than under South African conditions.

From mid-January 2010, the same adjustment as for the runoff plots was made, namely to increase the mesh size from approximately 5 x 5 cm (n=20) to 10 x 10 cm (n=18) (Figure 6.10). When this was done, the increase in soil surface caused the average splash height to increase dramatically from 2.5 cm to 6.75 cm (170% increase), while sediment concentration increased slightly, from an average of 2.55 g to 2.72 g (7% increase). The reason for the fact that the amount of detached sediment did not increase in proportion to the splash height could lie in the fact that this occurred in the second half of the rainy season, when a surface crust had formed, making particle detachment somewhat less.

6.4 MABULA, LIMPOPO PROVINCE

A trial was established at Mabula Game Reserve, approximately 40 km west of Bela-bela (Warmbaths), in Limpopo Province (see Figure 6.1). The aim of this trial was to assess the effectiveness of the palm mats in helping to prevent the spread of erosion in an already eroded area (Figure 6.12).

Mabula is a private game reserve established in the 1980's from existing farmland, some of which had been overgrazed, leading to erosion, especially in footslope areas with erodible duplex soils. The nature of these soils meant that rehabilitation of these areas is difficult, and the erosion is continuing today, even long after the livestock (the original cause of the loss of topsoil vegetation) have been removed. This eroded area is slowly but steadily cutting back into the surrounding veld. Using historical aerial photo records, and comparing affected and unaffected areas in the reserve, the eroding areas are advancing at a rate of approximately ten to twenty times faster than for the rest of the property (MacMillan, 2005).

6.4.1 Site Conditions

The site chosen (co-ordinates 24^{o} 43' 03.3" S, 27^{o} 53' 21.1" E) is located in a part of the Mabula Game Reserve called "No Man's Land", where severe sheet erosion has occurred, causing almost total loss of topsoil (Figure 6.12).

Figure 6.12 *Eroded area of "No Man's Land", Mabula*

The site is in an upper footslope position, with a north-west facing slope of approximately 4% and lies at an altitude of 1 192 m. The climate of the area can be described as typical of the bushveld, with warm to hot, moist summers and cool, dry winters. The long-term average annual rainfall from the closest station (Towoomba, some 49 km to the east) is 628 mm. The climatic parameters are given in Table 6.12 (ARC-ISCW, 2006).

Table 6.12 Towoomba climate

Month	Rainfall (mm)	Min. Temp (°C)	Max. Temp (°C)
Jan	111.18	17.12	29.75
Feb	93.94	16.73	29.29
Mar	73.64	15.09	28.22
Apr	35.67	11.58	26.41
May	13.06	6.68	23.68
Jun	5.37	3.28	21.01
Jul	3.38	3.02	21.37
Aug	4.78	5.82	24.44
Sep	13.63	10.37	27.92
Oct	53.57	13.91	29.50
Nov	96.57	15.51	29.36
Dec	123.32	16.57	29.59
Year	628.11 mm	**19.01°C (Average)**	

The average daily relative humidity varies between 20.5% (minimum) and 60.5% (maximum) in winter to between 30.5% (minimum) and 81% (maximum) in summer.

However, the variability of the climate can be gauged from the fact that rainfall figures obtained at Mabula Game Reserve show that the rainfall for 2006-07 was 311.1 mm, for 2007-08 the figure was 820.2 mm and for 2008-09 it was 660.2 (average of these three years is 597.2 mm, reasonably close to the long-term average).

The soil occurring at Mabula comprises a grey-brown, loamy sand orthic topsoil horizon (occasionally on a yellow-brown, sandy loam subsoil) on a mottled, gravelly soft plinthite subsoil horizon. The soil belongs to the Westleigh form (Soil Classification Working Group, 1991), approximately equivalent to a Haplic Plinthosol (WRB) or a Plinthic Alfisol (USDA). Soil colours given are from the Munsell system (Munsell Color, 2000).

The soil description and analysis is as follows:

Table 6.13a Mabula site: soil description

Profile Site:	"Badlands" site, Mabula Game Reserve
Co-ordinates:	24^{o} 43' 03.3" S 27^{o} 53' 21.1" E
Altitude:	1192 m
Soil Form:	Westleigh
Soil Series:	Helena (1000)
Classification (WRB):	*Haplic Plinthosol*
Classification (USDA):	*Plinthic Alfisol*
Terrain Type:	Upper footslope
Slope Angle:	4%
Parent Material:	Quartzite of Magaliesberg Formation, Transvaal Sequence

Horizon	**Description**	**Diagnostic**
A1 *(0-300 mm)*	Dry colour 7.5YR4/4, moist colour 7.5YR5/3; few, fine, faint brown mottles; coarse loamy sand to sandy loam texture; weak medium subangular blocky structure; slightly hard consistence; common roots; gradual, smooth transition.	**Orthic**
B1 *(300-650 mm)*	Dry colour 7.5YR5/3, moist colour 7.5YR4/3; many, medium, distinct yellow and black mottles; coarse sandy clay loam texture; apedal massive structure; slightly hard consistence; few roots.	**Soft Plinthic**
C *(>650 mm)*	Weathering saprolite.	

Table 6.13b Mabula site: analysis results (topsoil)

Horizon	**Particle Size (%)**			**pH (H_2O)**	**CEC (cmol kg^{-1})**
	Sand	Silt	Clay		
A1	77.2	6.8	16.0	5.12	5.74
B1	73.8	3.2	23.0	5.54	4.67

6.4.2 Results

Originally, four areas of geotextiles were laid out, namely one area of palm mats and one area of jute netting in two different micro-terrain sites, namely:

- ***Within a developing gully*** ("donga"), approximately 2-3 metres wide by 0.3-0.5 m deep and
- ***Across the edge of the active erosion "front"*** (see Figure 6.13), so that the geotextiles covered both the natural veld and the already eroded zone.

The geotextiles were laid out at the start of the 2006-07 rainfall season and were held in place by logs of *Terminalia sp*, placed parallel to the slope in order not to unduly influence the surface runoff. At the end of that season, however, it became clear that the jute netting was unsuited to either of the micro-terrain environments, degrading very quickly (similar to observations made at the other sites at Bergville and Ladybrand), as well as proving to be little in the way of a barrier to sediment transport. The palm mats placed in the small donga fared slightly better, but also started to disintegrate after one season. This indicates that for such severe erosion environments involving the commencement of gullies, where surface water flow becomes more concentrated, geotextiles alone are not sufficient, and that more aggressive measures, such as sediment traps constructed across the dongas, are required.

For the palm mats, it was therefore decided to concentrate on the transition across the edge of the active erosion area (Figure 6.13), so palm mats were re-laid there and assessed over two rainfall seasons, namely 2007-08 and 2008-09. A combined area of approximately 5 x 10 metres was assessed.

In the photo, the edge of the eroding area is clearly shown by the dotted line, and the erosion is progressing in the direction shown by the arrows. Although it would appear that the vegetation and its associated root system should be able to resist the spread of the erosion "front", according to the chief conservation officer at the reserve, isolated "tongues" of bare soil often advance more rapidly, leaving isolated grass tufts in between, which are then more susceptible to undermining and removal from more than one direction, especially in times of heavy rainfall (Jock MacMillan, Mabula Game Reserve, personal communication).

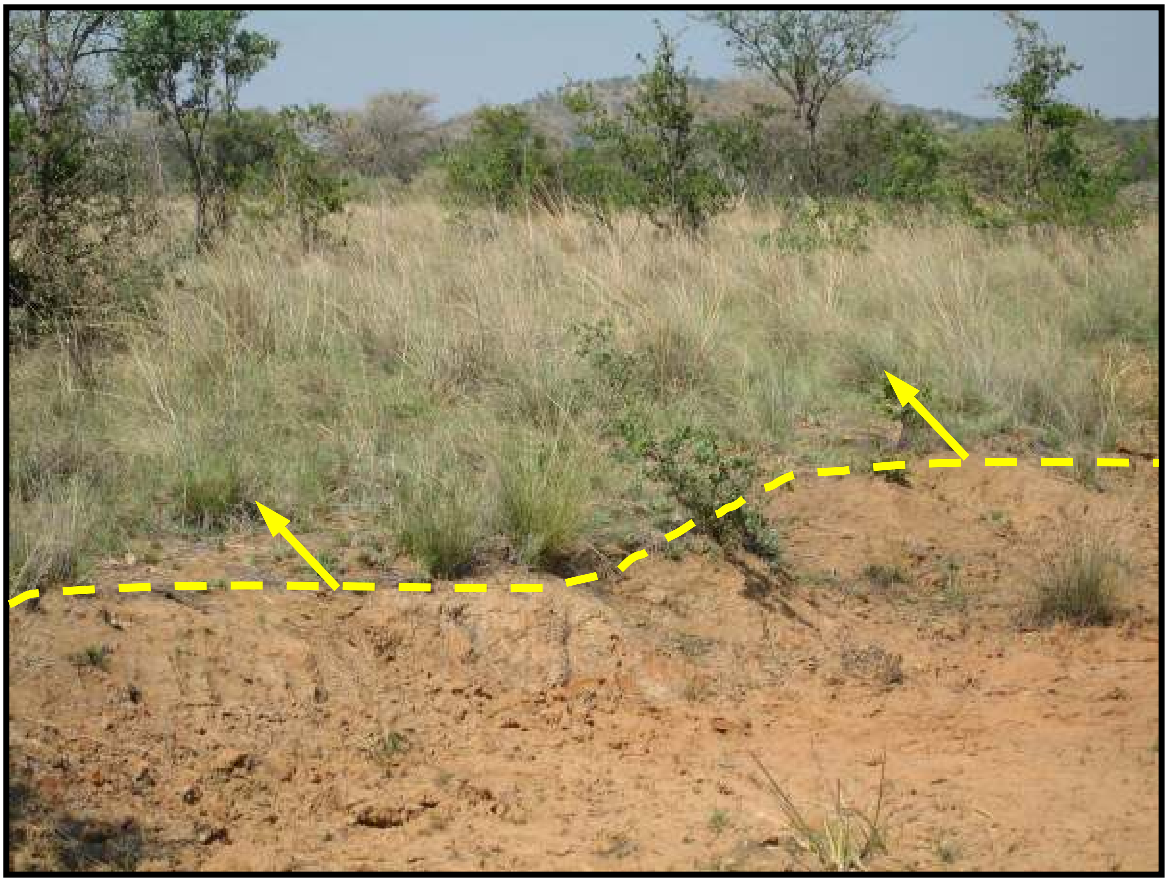

Figure 6.13 *Mabula site showing edge of eroding area*

6.4.2.1 Measuring posts

In order to test the hypothesis (Chapter 3) that the palm mats would allow the entrapment of sediment that would otherwise have been removed by surface runoff, a series of five painted metal posts were driven into the soil at the start of the 2007-08 rainfall season and the level of the original soil surface was marked using an indelible marker. The difference in soil surface level over time (either positive or negative) could then easily be seen and measured.

The results of this procedure for the period comprising the following two rainfall seasons (2007-08 and 2008-09 combined) are as follows:

Table 6.14 Topsoil accumulation, Mabula (October 2007-May 2009)

Post	**Position**	**Result** (as of May 2009)
1	Natural veld, no mats	1.5 mm soil gain
2	Natural veld, no mats	1.0 mm soil gain
3	Veld, **with mats**	**3.5 mm soil gain**
4	Eroded, **with mats**	**5.0 mm soil gain**
5	Eroded, **no mats**	2.0 mm soil ***loss***

These results clearly show the beneficial effects that the micro-basins within the mesh of the palm mats had on sediment build-up over just two rainfall seasons, especially in the eroded area, where little or no vegetation existed without the covering of palm mats. The mats enabled the build-up of more than twice the soil that accumulated under natural vegetation, while in the eroded area, the accumulation was even greater, especially when compared to the ***loss*** of soil where no mats were placed.

6.4.2.2 Re-vegetation

At the end of the second rainfall season (May 2009), an assessment of the vegetation situation was made. Due to the comparatively smaller size of the study area, compared to the larger plots at Ladybrand, this could be done across the whole area, and not just using representative sampling at selected points. At Mabula, by comparing the number of grass tufts within the portion of the eroded area covered by mats and the adjoining, non mat-covered portion, the result showed that the number of grass tufts (equivalent to the basal cover recorded at Ladybrand) within the bare portion comprised only 42.2% of the number of grass tufts under the mat coverage. If the ***approximate*** area of a grass tuft and its associated underground root system can be taken as 10 x 10 cm, the amount of re-vegetation for the study area at Mabula can be extrapolated. For the eroded area, the proportion is 1.1% for the portion under palm mats and 0.5% for the portion under bare soil. If one compares the results from the first season at Ladybrand (100% mat coverage), where basal cover for the palm mats and bare soil was 5% and 3% respectively, the results for Mabula are reasonably similar. This is especially so when the less favourable soil and climatic conditions at Mabula, with existing loss of topsoil, are taken into account.

In addition, the organic carbon content of the topsoil in the undisturbed veld was also beneficially affected by the mats. Prior to commencement of the trial (November 2006), a soil sample showed the initial organic carbon content to be 0.48%. By the end of the trial (May 2009), after a period of 30 months, two separate soil samples indicated that this had increased to between 0.75% and 0.92%, while the values recorded in the eroded area were between 0.35% and 0.37%.

When taken in conjunction with the results shown by the measuring posts (Section 6.4.2.1), this increase in organic carbon is especially encouraging, given the fact that the site is badly eroded (see Figure 6.12), with almost total topsoil loss, as well as surface crusting. In an ideal situation, livestock numbers and stocking practices would be managed and regulated, so that erosion does not occur. Unfortunately, however, such levels of management do not always exist, so that loss of vegetation cover often leads to erosion, as has happened previously at Mabula. In such a harsh environment, coupled with the prevailing hot, dry climate, the palm mats have shown significant promise in slowing down, or even stabilizing, the rate of advancement of erosion.

7 SOIL EROSION MODELS

It is often helpful to be able to obtain an estimate or prediction of the amount of soil erosion (usually indicated by soil loss, given in tons ha^{-1} yr^{-1}) whereby the potential erodibility of a specific site may be assessed by means of some type of predictive model. Most of these models are empirical, based on defining the most important factors involved in the erosion process and, through observation, measurement, experimentation and statistical techniques, relating them to soil loss (Merritt *et al.*, 2003; Morgan, 1995). However, according to Le Roux (2012), it would appear that the inherent erodibility, mostly derived from parent material, of the soil body is the main erosion risk factor, rather than the climate and slope gradient as determined in USA and Europe (Vanmaercke *et al.,* 2011), so that important parameters, such as degree of soil weathering and stability (or otherwise) with respect to dispersion and crusting are largely excluded or severely underestimated (Laker, 2004).

This section is not a detailed study into the construction and calibration of such models, but rather a rapid comparison of two of the most applicable models with the results from the field sites.

7.1 (R)USLE

The main model that has been used in soil erosion prediction is the Universal Soil Loss Equation (USLE), which was specifically designed for rill and inter-rill erosion. It was developed in the USA over a period of years, eventually being modified and updated by Wischmeier and Smith (1978) with a revised version (RUSLE) produced by Renard *et al.* (1994). According to Le Roux *et al.* (2008), USLE/RUSLE gained widespread acceptance due to the fact that:

- it distils erosion into a set of measurable primary soil-erosion factors;
- this factor-based approach allows easy analysis of the role and contribution of the individual factors;

- It has a simple mathematical form facilitating the handling of large datasets covering large areas.

The model takes the form of an equation:

$$A = R.K.L.S.C.P$$

where ***A*** is the mean annual soil loss (tons ha^{-1}), ***R*** is the rainfall erosivity factor, ***K*** is the soil erodibility factor, ***L*** is the slope length factor, ***S*** is the slope steepness factor, ***C*** is the crop management factor and ***P*** is the erosion control practice factor.

The rainfall erosivity index ***R*** is a combination of annual rainfall (mm) and intensity while the soil erodibility factor ***K*** is a combination of the silt + very fine sand content, % organic matter, structure and permeability class of a soil, expressed graphically in the well-known K-Nomograph diagram (Wischmeier *et al.*, 1971). The K-Nomograph diagram is shown in Figure 7.1.

The slope length factor ***L*** and slope steepness factor ***S*** are usually combined in a single index (related to a base value for a 22 m long slope of 5% gradient), while the crop factor ***C*** can accommodate various crop types (as well as a bare soil surface), if necessary aggregating changes throughout the seasons of the year. Finally, the erosion-control practice factor ***P*** incorporates various conservation practices such as contouring, terracing or ridging.

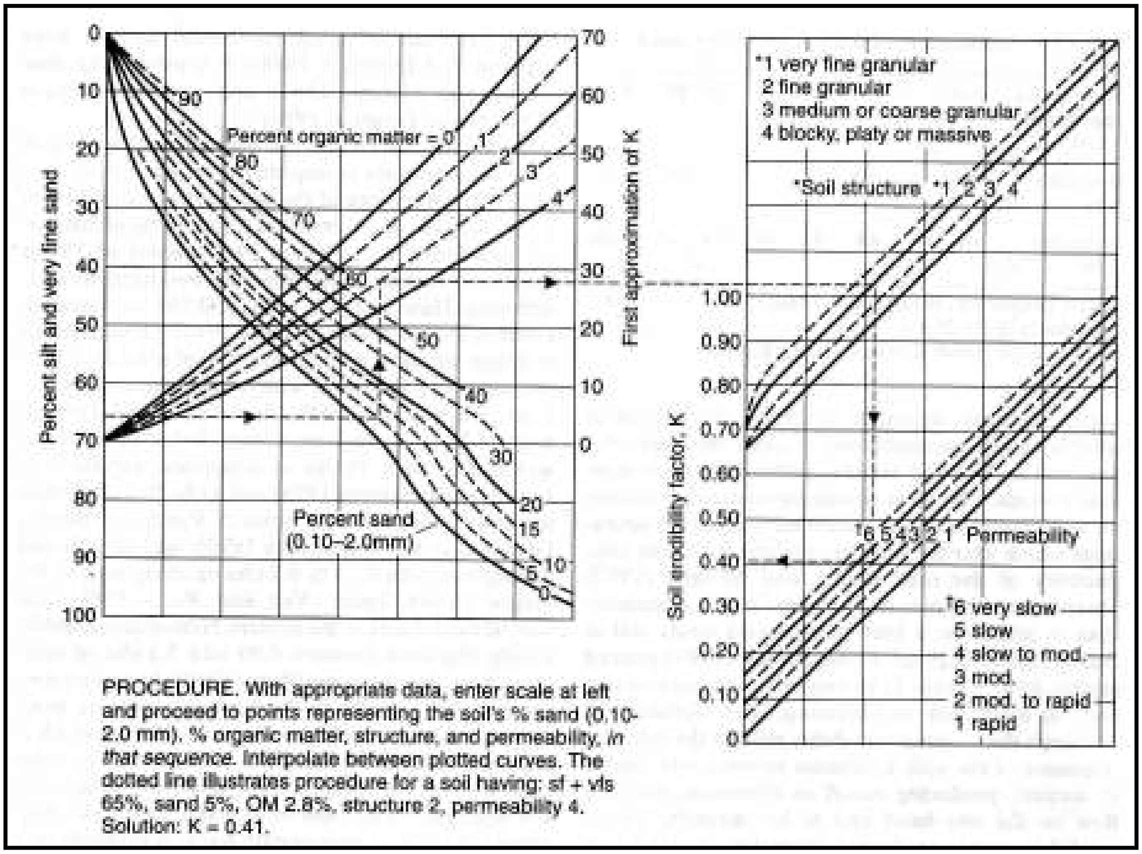

Figure 7.1 *Nomograph for computing **K** value*

As with any such model that involves so much estimation, there are limitations. For the climatic aspects, the factor of rainfall intensity and northern hemisphere-based rainfall seasons perhaps leads to an under-estimation of rainfall erosivity under sub-tropical, southern hemisphere conditions. For the soil factor, the use of classes rather than values for soil structure and permeability leads to inaccuracy, and the model does not take clay mineralogy, which is extremely relevant in the South African environment, into account. The variation in crop canopy cover is large, with ranges of values given, while not every cover crop or vegetation type can be accommodated. Finally, there is a very limited number of erosion-control practices, and for the purposes of this exercise, no form of surface cover, such as natural or synthetic geotextiles, is accommodated. However, despite these restrictions, it does provide an empirical value for most soil sites.

7.2 SLEMSA

Using data originally obtained from sites on the Zimbabwe Highveld, the Soil Loss Estimator for Southern Africa (SLEMSA) was developed to provide a more locally applicable method of estimating erosion in southern Africa (Elwell, 1978).

It also uses an equation, namely:

$$Z = K.X.C$$

where ***Z*** is the mean annual soil loss (tons ha^{-1}), ***K*** is annual soil loss (tons ha^{-1}) from a standard field plot (30 m long, 10 m wide, 5.6% slope) for a soil of known erodibility under a weed-free bare fallow, ***X*** is a combined slope length and steepness factor and ***C*** is the crop management factor.

The soil loss factor ***K*** is a combination of mean annual precipitation (P), annual rainfall energy (E) and a soil erodibility factor (F), while the slope factor ***X*** combines slope length (*l*) and steepness (*s*) in a similar way to USLE. The crop management factor ***C*** simply assesses the percentage crop/canopy cover for each portion of the year, multiplied by the percentage rainfall in that portion.

As is the case for USLE, SLEMSA also has its limitations. These include the lack of rainfall intensity adjustments, again failing to adequately distinguish variability between more temperate and sub-tropical conditions. The soil erodibility factor is both somewhat subjective and relatively coarse, while there is no soil surface conservation or treatment factor. However, it is simpler to use than (R)USLE and has been designed very definitely with southern African conditions in mind.

7.3 Results

Using both USLE and SLEMSA, the relevant data from each of the field sites reported in sections 6.1 to 6.4 was used to obtain the best estimate of predicted soil loss for both the bare soil as well as the soil covered with the palm mats at each site.

According to guidelines given in Morgan (1995), the various factors were determined as accurately as was possible, given the specifications of the parameters for each model.

7.3.1 USLE

The long-term average rainfall figure for each site was used to calculate the ***R*** factor. For the ***K*** factor, all necessary soil parameters were available, while the ***LS*** factor could be calculated from measured slope parameters at each site.

The main area of uncertainty was the crop management factor, ***C*** and erosion control practice factor, ***P***. Here, an estimate of the beneficial effect of the palm mats had to be made. The contribution of this factor to the model varies from 1.0 (bare soil, no erosion control) to 0.01 (full vegetation cover, complete erosion protection). Based on the guidelines, a factor of 0.4 was chosen for the full mat coverage, 0.7 for the wider mesh option (Figure 6.10) and 0.8 for the parallel strips (Figures 6.6 and 6.9), to estimate the respective contributions.

7.3.2 SLEMSA

For SLEMSA, the main restriction was the somewhat arbitrary nature of the soil erodibility factor ***F***. Here, an initial value of 3, 4 or 5 (depending on texture class) is adjusted for improvements or restrictions based on drainage restrictions or surface tillage/soil conservation measures. It was decided to add on a figure of

0.5 to accommodate the initial placement of palm mats. Once the ***K*** and ***X*** factors were determined from the specific site data, the single attribute crop cover factor ***C***, which uses the percentage of the surface where the bare soil is protected, could be used as for the ***C*** factor for USLE.

There was no need to assess seasonal changes, as would be the case for a developing crop, as the conditions remained uniform from the start of the growing season.

The results of this exercise are shown in Table 7.1.

Table 7.1 Soil loss predictions from erosion models (t ha^{-1} yr^{-1}) **Actual recorded figures in red**

Trial Site	USLE				SLEMSA			
	Bare Soil	Palm Mats			Bare Soil	Palm Mats		
		Full Mesh	Wide Mesh	Parallel Strips		Full Mesh	Wide Mesh	Parallel Strips
Bergville	104.98	16.79	29.39	33.59	33.19	19.44	20.67	21.60
Ladybrand	113.34	18.13	31.73	36.29	24.08	13.52	15.03	14.38
(2008-09)	**21.46**	**3.52**	-	-	**21.46**	**3.52**	-	-
(2009-100	**36.12**	**-**	-	**9.87**	**36.12**	**-**	-	**9.87**
Roodeplaat 1	54.19	8.67	15.17	17.34	9.58	4.65	5.17	4.95
Roodeplaat 2	31.40	5.02	8.79	10.05	10.37	5.74	6.37	6.10
Mabula	18.14	2.90	5.08	5.81	15.64	8.57	9.53	9.12

From the table, it can be seen that USLE estimates much higher values than SLEMSA for the erodibility of the bare soil environment, due mainly to the more inflexible ***K*** and ***C*** factors, as well as the lack of either a Reduction due to a ***C*** or ***P*** factor. However, when allowance is made for the various types of mat placement, the difference between the two models becomes much less.

There is also a variation in the relative erodibility assessment between the various soils, probably due to the extra factors in the USLE model, whereby more accurate allowance is made for particle size and organic matter.

In South Africa, classes of soil erosion (t ha^{-1} yr^{-1}) severity have been assessed (Le Roux *et al.*, 2006) as ***low*** (0-5), ***low to moderate*** (5-12), ***moderate to high*** (12-25) and ***high*** (>25). If the data from Ladybrand for the 2008-09 and 2009-10 seasons are used (Table 6.6), where both runoff and sediment load were measured, those determinations give results of 26.9 t ha^{-1} yr^{-1} and 45.2 t ha^{-1} yr^{-1} respectively for the bare plots, dropping to 4.4 t ha^{-1} yr^{-1} (full mat coverage, 2008-09) and 12.3 t ha^{-1} yr^{-1} (50% mat coverage, 2009-10) respectively for the plots with the palm mats.

The relative soil loss figure predicted by USLE for the palm mats at Ladybrand is 15.99% of the bare soil figure. Although the actual recorded figures were much less, the percentage reduction was amazingly similar, namely 16.36%. For the 50% mat coverage (parallel strips), the predicted soil loss figure of 32.02% of the bare soil compares well with the actual recorded value, which was 27.34%.

There is actually a strong likelihood that the data from Ladybrand show an under-estimation of both runoff and sediment concentration. This is due to periods of intense rainfall erosion leading to spillage from the tipping buckets during the data recording process as well as sedimentation and possible overflow of the collecting buckets. However, this factor is likely to be around 5% or so at most.

Regarding the change in mesh size, the predictions from the models are for an increase in soil loss of around 75% (USLE) or around 10% (SLEMSA). This can be compared to the results from Roodeplaat (Site 2), where the average sediment concentration per sampling event increased by 64.4%. It would seem that the occurrence within USLE of a cover factor as well as a soil protection factor makes better provision for the application of geotextiles than in SLEMSA (if careful assessment of the contribution is made).

Snyman *et al.* (1986) also found good correlation between measured (using a rainfall simulator) and modeled (using the USLE model) values of soil loss under bare soil and natural veld conditions, although the model also tended to overestimate the actual soil loss recorded.

8. SOCIO-ECONOMIC FACTORS

Within the broader framework of the Borassus Project (see Section 1), one of the objectives of that project concerned the degree to which the manufacture of palm mat geotextiles could contribute to alleviation of poverty within local (rural) communities in the various countries. These processes, and their beneficial effects, varied between participants (Subedi *et al.*, 2012). In Gambia (West Africa), where large areas of the Borassus palm have been over-utilised, projects were established in local villages to create tree nurseries to re-establish the trees in agro-forestry projects, with the products being used for soil conservation.

In the Asian countries, the emphasis was on contributing to soil conservation within the existing agricultural practices, where the steep slopes contribute to high rates of soil erosion. The most successful case study involved participants in Vietnam, who were able to manufacture mats in their spare time and earned as much as €60 (R700) per month (Subedi *et al.*, 2012).

In the South African context, a wide variety of geotextile products are available from several manufacturers or suppliers. These are either synthetic or natural and are used in a variety of situations, such as road, stream or railway embankments.

However, for many potential users of geotextiles, the price of the materials remains a significant limiting factor. Synthetic products, such as “MacMat” by Maccaferri, or “ECP2” by Kaytech cost between R30 (no wire re-enforcement) and R97 (with wire re-enforcement) per square metre, to which VAT (14%), cost of delivery and labour to apply to the relevant surface must be added.

The most easily obtainable natural products are the jute-based “BioJute”, from Maccaferri, which costs from R6.45 (density of material: 0.25 kg m^{-2}) to R9.70 (density of material: 0.5 kg m^{-2}) per square metre, or “SoilSaver”, from Kaytech, which costs R5.10 (density of material: 0.29 kg m^{-2}) per square metre, again plus delivery and labour costs. It must be borne in mind that these densities are significantly less than the $\pm$1.3 kg m^{-2} of the palm mats (Section 4.2.1)

In order to evaluate the manufacture of palm leaf mats, a pilot training course was held in the Tshongwe area of Maputaland, northern KwaZulu-Natal, which is an area where there is a strong tradition of weaving, typically of baskets, floor mats and other products. Some of these are for personal use, while some are of better quality and are sold to tourists and other buyers.

Figure 8.1 *Participants in the mat training course, KZN*

At the training course, around thirty unemployed community members were trained in mat manufacture (see Figure 8.1) and within two days, they were able to easily produce one 50 x 50 cm mat per hour, or eight mats per day (2 m^2). This is almost exactly in line with reported results from other participating countries (Subedi *et al.*, 2012), where the accepted time to produce one mat was approximately 60 minutes. The minimum prescribed wage in South Africa in 2012 for such basic, untrained labour is R7.71/hr (Department of Labour, 2012), or R1 500/month. Although this figure is still well below the average monthly income of most of the lowest-paid (non-agricultural) permanent employees in South Africa (Statistics South Africa, 2012a), where construction workers and other general workers earn an average of R9 590 and R8 560 per month respectively, in areas where there is virtually no other source of income, it could make a significant difference to poverty alleviation.

The prescribed minimum wage tariff equates to approximately R30 per square metre, which is significantly less than the re-enforced synthetic geotextiles, but more than three times higher than even the coarser BioJute. However, several aspects need to be taken into consideration. Firstly, the synthetic products will not biodegrade rapidly (if at all), especially the type of product incorporating wire re-enforcement, which will therefore remain on the soil surface.

Secondly, the density of the palm mats is around 1.3 kg/m^2, or more than twice the density of the thickest available jute blanket. This density has a significant advantage, as was evident in several trials where jute was used as a comparison. The jute was clearly shown to be a much less durable product than the palm mats, often only lasting a few months before beginning to disintegrate. Also, the relatively thinner jute ($\pm$0.4 cm) is more likely to become covered by transported sediment than the thicker palm mats ($\pm$1.0 cm), especially in times of extreme runoff.

This is clearly shown in Figure 8.2, where the jute (photo on the left) had begun to disintegrate within one rainfall season (November 2006 to March 2007) at the previously overgrazed site at Mabula (Limpopo Province) and was covered with sediment in many places.

By comparison, the palm mats (photo on the right) in exactly the same landscape position remained intact, despite some sediment inundation. The palm mats at Mabula lasted for a further two seasons before disintegration became almost complete

Figure 8.2 *Comparison between jute (left) and palm mats (right) at Mabula*

If the above-mentioned properties of the various products are taken into account, there should be a good possibility for the creation of local community-based industries to produce the mats in rural areas where the population is culturally and historically focused on weaving. Such a project could take one of two forms.

The first option would be for an outside agency (either government-based, or with outside funding) to sponsor a project whereby payment for mat production is subsidised, in order to stimulate job creation and to help with poverty alleviation, in the areas where the palms grow abundantly in the wild. Depending on the concept of the project, the mats produced by such an initiative could then be utilised either locally, or transported to areas of erosion where they could help with soil conservation measures. The second option would be to provide the local community with the means to produce the mats (such as wooden frames for templates), but the mats would then be sold by the community to obtain an income.

Which of these two scenarios would be preferable would need to be determined by a specific study into the prevailing socio-economic conditions, perceptions of the community as well as supply and demand for mats in the area(s) concerned. However, the areas where the palms are most abundant in the wild (Limpopo, KwaZulu-Natal and Eastern Cape Provinces) are all areas where the percentage of the landscape that is degraded and/or eroded is above the national average of 4.1%, with figures of 10.6%, 8.5% and 7.1% respectively (Van den Berg *et al.,* 2008).

The inception of such a project would logically lead to the promotion of both reforestation and agroforestry, as the seeds of the Lala palm are readily harvested and easily planted. In addition, such a project (both the mat-weaving and tree cultivation) would benefit socially disadvantaged and vulnerable groups, such as women, youths and elderly people, who are the most in need of poverty relief.

The official prevailing unemployment rate in South Africa is 24.9% (Statistics South Africa, 2012b), and this has been steadily rising since the second half of 2008. However, the rate excludes anyone who worked casually for as little as four hours per month, so the actual unemployment rate, especially in rural areas where opportunities are most limited, is likely to be very much higher than the official figure. Among the unemployed population, more than two-thirds have been unemployed for more than one year, and over 80% have only the most basic education, with no school qualification, and it is among this population where employment making mats could be most effective. This is especially relevant given the prevailing situation in many areas of South Africa where the palm trees grow, such as KwaZulu-Natal and Eastern Cape, whereby many breadwinners have died as a result of HIV-Aids, and older members of the population, usually female, have to look after the surviving orphaned children.

Observations from a visit to a mat-producing project in Gambia in 2008 showed how such a communal project, where a number of participants came together to work, allowed joint supervision of the children while still continuing with the work of producing the mats. With some basic sponsorship, and some collaboration between the local structures of various Provincial Departments (such as Agriculture, Rural Development and possibly Labour), a worthwhile co-operative could be established to supply material to participants for weaving, and then apply the mats to sites in the local environment where they are most needed.

9. VARIABILITY IN MAT PERFORMANCE

South Africa is a country with a wide range of physical environments and it was not possible to test the mats under all of these conditions. However, the test sites were located in four different provinces, each of which consists of a different set of soil, slope and climatic characteristics. At three of the sites (Bergville, Ladybrand and Mabula), extensive *in situ* sheet and gully erosion can be observed in the immediate vicinity of the trial sites that were used.

9.1 CLIMATE

9.1.1 Water Erosion

The areas of South Africa that are characterised by high-intensity rainstorms are the northern and eastern parts, where erosivity values (energy produced by rainfall) are four to eight times higher than the southern and western parts (Smithen & Schulze, 1982). All of the sites had a summer rainfall distribution (although it was less pronounced at Ladybrand) which is typical of most of the South African interior. The rainfall varied from 795 mm/yr at Bergville to 628 mm at Mabula, which was the hottest site, being the furthest north. Rainfall in the interior regions of South Africa tends to occur often in heavy bursts, with prolonged dry, hot spells in between. The mats stood up well to all the climatic conditions, easily lasting one to two full seasons *in situ*, thus giving vegetation a good chance to re-establish through the holes in the mats. It seems clear that the mats will be suitable for most climatic conditions that might be encountered locally.

9.1.2 Wind Erosion

In drier parts of South Africa, little cultivation is carried out as the prevailing rainfall is too low (usually coupled with prolonged high temperatures) to have any chance of sustained success. However, in certain marginal areas, usually where the long-term average rainfall is around 450-550 mm/yr, cultivation may take place, even though the risk of a dry season increases significantly. In such areas, as well as comparatively dry areas where livestock graze extensively, there may be a significant risk of wind erosion, especially where the topsoil texture is sandy with a medium or (especially) fine grade of sand. While it was not the intention of this thesis to test the palm mats in such areas, the action of placing a covering on the soil surface will definitely help to reduce the action of the wind in removing the spoil particles, and the mesh-like structure of the mats will provide small micro-sites where water can accumulate to promote re-vegetation. There is no doubt that the palm mats will be effective in areas susceptible to wind erosion, but more specific research is needed to quantify the effects in these areas.

9.2 SLOPE

Many of the research sites used in other countries of the *Borassus* Project involved extremely steep slopes (Fullen, 2009; Smets *et al.,* 2011). Such slopes exceeded 100% in areas such as Thailand (Janeau *et al.*, 2003), where available land shortages force cultivation to take place in severely undulating terrain, as well as Brazil (Guerra *et al.,* 2010), where population pressure in peri-urban areas has led to accelerated erosion. However, erosion by water under South African conditions typically begins at much gentler gradients, especially when coupled with increasing slope length (Smith *et al.*, 1995). The research sites varied between 2.5% (Roodeplaat 2) and approximately 7.5% (Bergville and Ladybrand), which represents a large portion of the cultivated and grazed land in South Africa. At Roodeplaat (for the 2008-09 season), sediment concentration from the steeper plot (5% slope) was on average 17 times greater than the less steep plot (2.5% slope), but the mats still reduced this by more than 27 times.

When the slope angle of the rainfall simulator tests on the four soils from Roodeplaat was increased to 10% and 15% (Section 5.4), the runoff did not increase greatly compared to the 5% slopes. Sediment load did increase as slope angle increased, but the mats reduced this to between 25% and 75% of that from the bare soil.

9.3 SOIL CONDITIONS

The susceptibility of a soil to be detached and removed by water will depend on a combination of factors, the most basic of which include texture class, organic matter content, carbonates, salinity and pH (le Roux *et al.*, 2006). The soil samples collected for the rainfall simulator tests described in Section 5.3 comprised a wide range and combination of properties from both the stable and erodible soil groups. However, the results did not indicate one specific property where there was a clear relationship with either the amount of runoff recorded or the sediment concentration in the runoff. The soils occurring at the various field sites had variable texture, and the four soils which were collected at Roodeplaat for additional rainfall simulator studies were selected to represent a range of topsoil texture, from sandy to clayey.

The range of textures is shown in Figure 9.1

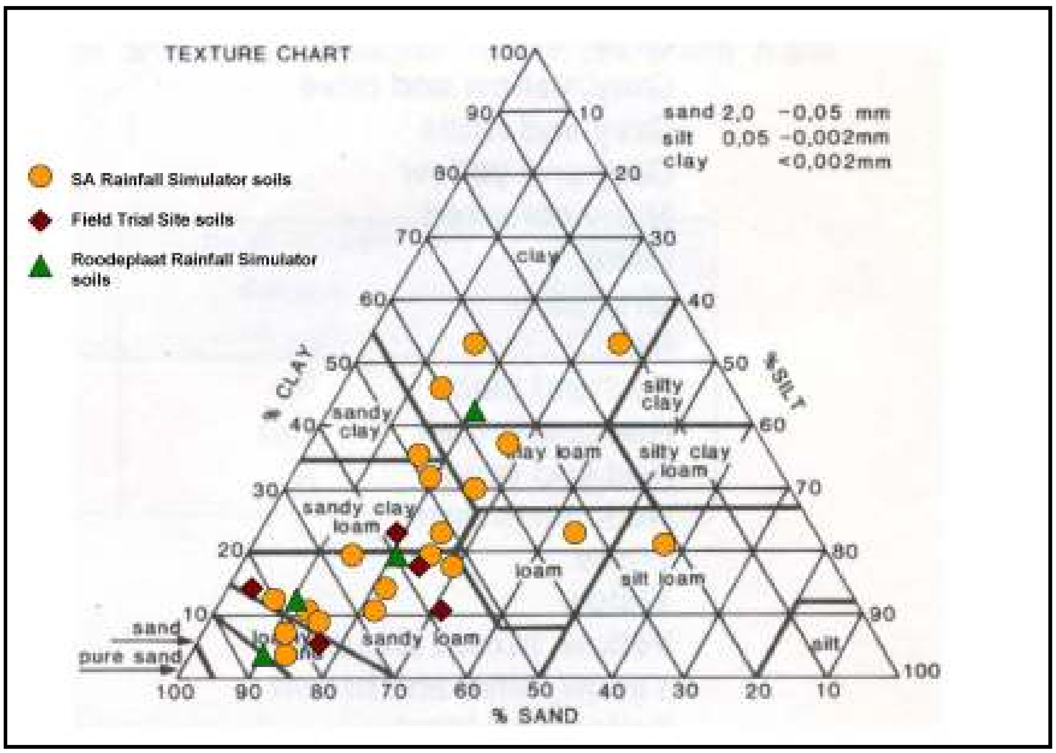

Figure 9.1 *Topsoil texture values of soils used in mat trials*

For the field sites, the soils all showed significant reduction in runoff and/or sediment concentration, although the soils belonged to the loamy sand to sandy clay loam texture classes. When additional tests were done using the rainfall simulator, the four soils sampled at Roodeplaat (Section 5.5) were chosen to have a gradation in topsoil texture (green triangles in Figure 9.1). The results did not show any clear trend by texture, with the clay soil showing a clear reduction in runoff between the bare soil and the palm mats as opposed to the other soils showing little difference. However, as far as sediment concentration is concerned, the sandier soils showed the highest reduction when the mats were applied.

9.4 SURFACE COVERAGE OF MATS

Under natural conditions, a vegetation cover of virtually 100% is generally maintained, which absorbs the rainfall before it can impact on bare soil and whose root network effectively binds the soil together. The mats were thus laid out in a continuous, grid-like coverage in order to optimize their surface coverage properties and this arrangement was shown to be very effective.

For the 2009-10 season, however, it was decided to alter the mat coverage of the plots at Ladybrand and Roodeplaat from ***full coverage*** (100% of the plot surface) to ***parallel strips*** with bare soil in between (50% of the plot surface), as shown in Figures 6.6 and 6.9. This was to try to assess whether the decreased coverage had a markedly detrimental effect on either runoff or sediment concentration.

At Ladybrand, while the rainfall increased by 90% from the first season to the next, the runoff increased by 103% and the sediment concentration in the runoff also increased by 90%. However, the average amount of sediment load per rainfall event only increased by 38%. At Roodeplaat, results were somewhat contradictory, with average sediment concentration on the steeper plot (5% slope) actually decreasing by 32.5% when mat coverage was halved, while on the less steep plot (2.5% slope), it slightly more than doubled. When the size of the holes in the mats was further increased (Figure 6.10) for the second half of the 2009-10 season on Plot 2, the average sediment concentration more than doubled on the runoff plot and increased slightly on the splash erosion trial.

These results would suggest that if it was decided to decrease the mat coverage, it would probably be sensible to use something ***in between*** the full coverage and the 50% strips. A sequence of two mat strips interspersed with one bare strip (67% density) would enable 33% more soil surface to be covered by using 25% more mats (Figure 9.2), and anticipated improvement in soil loss would more than justify the increased cost of the mats.

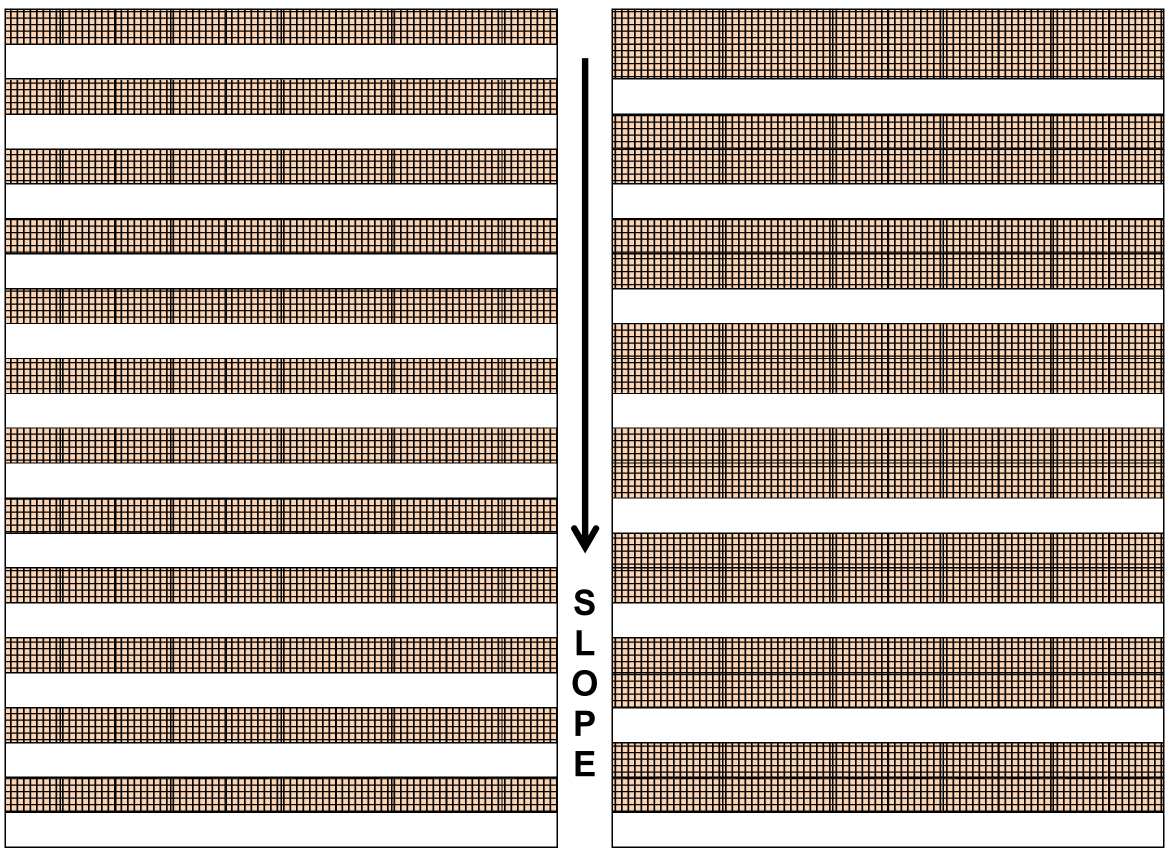

Figure 9.2 Palm mats coverage differences

However, if the erosion is severe, or conditions are extreme, it would strongly be recommended that the palm mats be applied at 100% coverage, or that they be combined with some other technique, such as contour banks or Vetiver grass strips, for maximum initial effectiveness.

The mesh hole size used (approximately 5 x 5 cm) in the trials was seen to work well. This size has been evaluated in the manufacturing process as being suitable for the erosion control purpose of the mats, providing a combination of surface coverage and mesh space for water to collect and vegetation to emerge. Increasing this size (to approximately 10 x 10 cm) significantly increased the sediment concentration, while to construct mats with a finer mesh size would be much more time consuming, and more difficult to achieve, given the raw materials available.

9.5 SUMMARY

From the above conclusions, it would appear that neither variation in climate nor slope has a significant inherent effect on the suitability of the palm mats. On steeper slopes, the runoff and sediment concentration is generally greater, but the mats still perform well in controlling these factors. It also appears that the mats work well over a range of soil textures, from loamy sand to clay. Mat density was tested at 100% and 50% surface coverage, while the size of the mesh would seem to be most suitable at around 5 x 5 cm.

9.6 RECOMMENDATIONS

For maximum practicality, the performance of the mats (and therefore their effectiveness in reducing erosion susceptibility) under a range of defined conditions that might be expected in South Africa, can be summarised.

It was obviously not possible to evaluate the palm mats for every possible scenario, or combination thereof. Such an exercise would take a very long time and a huge amount of travelling to find a suitable range of sites. However, the results obtained here, as well as the results from the other participating countries in the *Borassus* project, can be used to make sensible, reasonably confident predictions that should be of use to land owners or users who wish to assess the potential of the mats in a particular environment.

In the following table (Table 9.1), the probable effectiveness of the mats has been shown. Although climate will vary greatly from region to region, and is one of the key parameters in prediction models such as USLE and SLEMSA, the sites used in this study across the north-eastern interior of South Africa, did not show great variation in either the amount (Bergville 795 mm, Ladybrand 676 mm, Roodeplaat 641 mm, Mabula 628 mm) or distribution (between 79% and 89% of the annual average falling from October to March). Climate was not considered to be a meaningful variable in this study so it was decided to select texture and slope angle as the two most important variables.

Due to non-uniform variables, such as plot size, length of record, cover crop etc, it is not practicable or reliable to supply empirical values. Therefore, a comparative value is indicated using stars, whereby five stars indicates the most suitable predicted scenarios for palm mat application, with one star indicating the least suitable. This table is somewhat subjective, but the results obtained from this project have been positive for all sites and scenarios, with the degree of effectiveness being the varying factor.

Table 9.1 Predicted effectiveness of palm mats under various scenarios

Topsoil Clay %	**Texture Class**	**Slope angle**				
		0-3%	**3-8%**	**8-15%**	**15-30%**	**>30%**
0-5	***Sa***	**	***	****	****	**
5-10	***LmSa***	***	****	****	*****	***
10-20	***SaLm***	****	*****	*****	*****	****
20-35	***SaClLm***	****	*****	*****	*****	****
35-50	***SaCl-ClLm***	***	***	****	****	***
>50	***Cl***	**	**	****	****	***

The texture classes illustrated here are those that are most likely to occur in South Africa, where the range of the silt fraction usually ranges from 10-25%, as opposed to 50% or more in other areas, such as the research sites in Hungary (Kertész *et al*., 2007), with 8% clay and 71% silt (silty loam texture) or China (Bhattacharrya *et al.*, 2011), with 14% clay and 41% silt (loam texture).

9.7 FURTHER RESEARCH

Although the use of palm mats has been thoroughly tested, as reported in this thesis, there is still scope for further testing of the mats (or similar geotextiles) in different situations or under different scenarios.

These might include:

- ***Wind erosion*** – the mesh-like structure of the mats, with the small (5 x 5 cm) micropockets, should be excellent at retaining water in dry areas, while also preventing removal of surface materials due to wind action.
- ***Combination of techniques*** – in certain areas, such as steeper slopes or where there has been severe topsoil loss, the mats may be combined with other soil conservation techniques, such as vetiver grass, contours, bound logs or hydroseeding in order to maximise the erosion reduction potential of the various techniques.
- ***Mat Manufacture*** – research needs to be done on how to make the manufacture of the mats faster and more efficient, while still retaining the basic properties of strength and durability that make them so successful. This can be done in conjunction with local populations, where experimentation should be encouraged.

10. CONCLUSIONS

In order to prevent soil erosion, a continuous vegetation cover is necessary. If this is in place, few soils will erode, even on relatively steep slopes. However, if the vegetation cover is removed or degraded so that the topsoil is exposed, then erosion will take place, even on gentle slopes with stable soils.

Many parts of South Africa are losing significant amounts of irreplaceable topsoil annually. One of the effects of this is the silting up of several dams, especially in areas where large scale overgrazing and vegetation removal has taken place, such as in the vicinity of the Lepellane Dam in Limpopo Province (Papenfus, 2005). The Welbedacht Dam, on the Caledon River in the Eastern Cape Province lost 73% of its storage capacity within 15 years of construction in the mid-1970s (de Villiers and Basson, 2007). In addition, the flow of sediment-rich water into the sea after every large-scale rain event is a commonly-observed event at almost every estuary along the eastern seaboard.

In order to reduce the removal of soil from the surface, some sort of surface cover is necessary in order to slow down the flow of water sufficiently that re-generation of the vegetation can take place. Although a number of commercial products exist, virtually any material that is placed on the surface will have a beneficial effect in this regard, including grass, stones, sticks/branches or crop residues. However, in many cases, much if not all of this material may be quickly washed away by surface flow, so that there is little beneficial effect.

The requirements of an effective geotextile include:

- **Durability:** in order for the product to last long enough in place for it to have the desired effect of stabilizing the topsoil, it must not degrade too rapidly. Some of the types of jute disintegrate rapidly (within a few months) under South African conditions. However, the palm mats tested remained in place, basically intact for at least two full seasons in all of the trial situations.

- **Bio-degradability**: despite the requirement for a material to remain stable, it must still begin to break down, so that the vegetation that emerges can gradually take over. Many synthetic materials cannot do this and a mesh that is too fine will impede seedling emergence. The palm mats commenced a slow, steady degradation, while still remaining in place, so that the stabilizing effect remained.
- **Flexibility**: any geotextile must be able to be shaped to adhere to the soil surface to the greatest extent possible in order to avoid small patches of concentrated runoff that may still occur. The size and flexibility of the palm mats achieve this aim well, both in the rainfall simulator tests, as well as in the field trials. Very little non-adhesion to the soil surface was observed once the mats experienced the first rainfall.
- **Suitable surface coverage**: there needs to be some spaces available for vegetation to emerge, but still to be protected. The mesh-like pattern of the palm mats provides small “micro-basins”, where water can be held and provide the impetus for re-vegetation to take place.

The potential of woven geotextiles is illustrated by an example of a similar material used in erosion control in Madagascar (Knoll & Noffke, 2011). Here, locally produced woven mats were used to stabilize steep, badly eroding slopes, as shown in Figure 9.3 below.

Figure 9.3 Woven geotextile mats in Madagascar

Initially, the woven strips were laid without any gaps (equivalent to the mesh spaces of the palm mats), but this arrangement inhibited infiltration and accelerated runoff, so that erosion was actually increased on the downslope side. Once a mesh with gaps (approximately 15-20 mm, slightly larger than the palm leaf mats) was used, infiltration was controlled and re-vegetation (with the assistance of hydro-seeding techniques) started to take place and will proceed as the geotextile starts to degrade.

However, there was little or no research done to quantify the effectiveness of locally-manufactured woven geotextiles in curbing soil erosion. This knowledge gap led to the commencement of the *Borassus* Project in 2005, to test a range of products under a variety of conditions in several participating countries.

In the countries involved in the *Borassus* Project, environments where the mats were tested included various types of arable agriculture (China, Vietnam and Thailand), orchards and vineyards (Hungary), archaeological sites (UK), urban erosion (Brazil), road construction sites, coastal dunes and natural grassland (Lithuania), all of which produced positive results regarding the effectiveness of woven mat geotextiles.

These results from the other countries involved in the *Borassus* Project, where similar, but varied, locally available bio-textiles were used with success to limit runoff and sediment load, are summarized in Table 9.2.

These results have shown that the potential for such materials to be used in South Africa is significant. Such products might include maize stems, sugar cane residue and a range of other branches or sticks, as long as they can be woven together (no matter how roughly) and can then be laid on the vulnerable bare soil surface and fixed in place.

The sites used for the South African field trials detailed in this study covered a range of conditions that might be expected across the summer rainfall area of South Africa, with soils that have a varying degree of inherent erodibility. **In every case**, the runoff and/or sediment load was significantly reduced, increasing infiltration and allowing the vegetation to re-establish more rapidly. In the case of the site at Mabula, topsoil, along with organic carbon, actually accumulated under the mats over several seasons, even in the harsh, hot conditions prevailing there.

Table 9.2 Runoff results from various countries in the *Borassus* project

Country		Environment	Slope (%)	Material	Reduction	Reference
RSA	Bergville	Research Plot	8	Palm Mats (SA)	45-70%	
	Ladybrand	Research Plot	9	Palm Mats (SA)	38-41%	
Lithuania		Roadside plots on dunes	35	Palm Mats (Brazil/Gambia)	95%	Jankauskas *et al.* (2008)
Hungary		Orchards and Vineyards	8	Palm Mats (Brazil/Gambia)	25%	Kertész *et al.* (2007)
UK		Research Plot	7	Palm Mats (Brazil/Gambia)	83%	Bhattacharyya *et al.* (2008)
Vietnam		Subsistence Agriculture	33-44	Maize Stem Mats	73%	Fullen (2009)
China		Research Plots	5 & 9	Rice Straw Mats	87%	Xing Xiang-xin *et al.* (In press)
Thailand		Subsistence Agriculture	30 & 100	Bamboo Mats	57%	Panomtaranichagul *et al.* (2006)

In the context of the prevailing situation concerning soil erosion in South Africa, there is a large potential to harness such basic, yet effective technology and to combat this present and potential future loss. One area which shows promise is an association with the "Working with Wetlands" organization (WfW), which is a joint initiative with the South African Departments of Environmental Affairs (DEA), Water Affairs (DWA) and Agriculture, Forestry and Fisheries (DAFF). Feedback received from WfW (Dr U.H. Bahadur, SA National Biodiversity Institute, personal communication) has indicated that there is a strong possibility that the palm mats can be utilized as a part of the projects that WfW is undertaking in the iSimangaliso National Park, in northern KwaZulu-Natal. Further discussions regarding funding, training and specific utilization of the mats will be held in the near future.

The results of the trials mentioned in this thesis have shown that woven palm leaf mats have been proven to be beneficial in this regard. They firstly reduce the amount of soil material detached from the surface, as well as slowing down and reducing the amount of runoff considerably, which consequently lessens the amount of sediment carried downslope by such runoff. They remain on the surface for one or more full rainfall seasons without significantly disintegrating, meaning that the vegetation gets an opportunity to develop.

It is clear that the palm mats have a good combination of physical and chemical properties, biodegradability versus stability, ease and level of manufacture in order to make a meaningful contribution to soil conservation in many areas of South Africa. A durable, stable product, which is still bio-degradable, is therefore the optimum means of stabilising eroding areas, especially on steep slopes. If that product can be easily produced by the local population, utilising otherwise discarded plant products, then the benefits are twofold – both as a potential source of income and as a way of stabilising and restoring the environment for future generations.

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