CEH Technical Report

Desert Margins Programme   Phase II

Final Report

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Executive Summary: Activities and results in Phase II of Desert Margins Program

Following presentation of options for CEH activities in Phase 2, by Andre Bationo at the meeting of the DMP Steering Committee in South Africa, in March 2005 (see Annex 1) and discussions with the Programme Manager, the following activities were agreed for Phase 2:

1. Completion of studies of climate-forcing gas emissions from Mali
2. Completion of publications from Phase I
3. Studies on glomalin content of soils from different land uses and locations
4. Visit to project partners in South Africa to explore potential collaborations, which led to
5. Pilot survey of mycorrhizal populations in degraded South African soils

Due to problems in receiving full payments for Phase I and delays in agreeing a contract for Phase II, most activities under Phase II did not commence for some months after the official Phase II start date.

In 2005, CEH established new collaborations with DMP partners in South Africa and Kenya and consolidated collaborations with NARS, ARIs and IARCS in Senegal and Mali. The ongoing collaboration from Phase I which focussed on climate-forcing gas emissions and development of carbon and nitrogen budgets for land-use systems culminated in the production of publications for refereed journals. A considerable amount of effort was directed at developing methods of measuring glomalin in soils, and the first measurements for Africa were obtained. A visit to South Africa was made and agreement obtained for topics of future collaboration.

In 2006, publications appeared in print and a pilot survey of mycorrhizal populations in South African soils was completed. Analyses of 'recalcitrant' proteins ('glomalin') in soils from Kenya, Mali and Senegal were completed.

Studies have shown that

1. Measurements of annual N_2O emissions from agricultural land in Mali revealed that there was no adverse effect of cereal and legume crops growing in rotation on the emission of N_2O to the atmosphere. This result has important implications for tropical countries in respect of their negotiating ability at United Nations Framework Convention on Climate Change. Currently the Intergovernmental Panel on Climate Change advise that an emission factor of 1.25% should be used for agricultural land growing biological N-fixing crops, while this study indicates that there should be no additional emission factor.
2. Selection of types of improved fallows for short-term fertility enhancement has implications for regional N_2O emissions for dry land regions. N_2O emissions from *Gliricidia sepium* treatments were six times higher, evolving 69.9 ng N_2O - N g^{-1} soil h^{-1} after a simulated rainfall event, compared with only 8.5 and 4.8 ngN_2O - N g^{-1} soil h^{-1} from soil under traditional fallow and continuous cultivation, respectively.
3. Developments in the study of glomalin during the course of this project, have led to adjustments in our study programme and in the conclusions which can

be drawn from the work. Studies of soils from three DMP countries found good correlations between abundance of recalcitrant soil proteins, soil aggregation and soil organic matter, which were also related to land use. These proteins became increasingly important components of soil organic carbon as carbon levels declined. However, these recalcitrant soil proteins cannot be categorically assigned to glomalin which is produced by mycorrhizal fungi.

4. Mycorrhizal spore numbers in soils from test sites in South Africa, determined just before the growing season, were low. With the generally poor vegetation cover, it is probable that the number of infective propagules available for the next crop, will also be low, resulting in low levels of mycorrhizal infection on plants. It is likely that this will have an adverse impact on plant growth, especially for mycorrhizal-dependent crops. If more detailed studies confirm these observations, actions to improve inoculum potential, such as improving natural vegetation cover, or nursery-based low-tech methods of inoculum production, are likely to be beneficial to establishment and growth of crops.

1. Completion of studies of climate-forcing gas emissions from Mali

Studies which commenced under Phase 1 in 2004 were completed in the early months of Phase 2. This work was conducted in collaboration with Institut d'Economie Rurale, Mali (IER) and the World Agroforestry Centre, Sahel Program (ICRAF) to address project objective 1.12 'Assessment of climate forcing gas emissions from contrasting land use options within agroecosystems and extrapolation to determine regional contribution of desert margin soils to total global annual emissions'. We also addressed objective 1.9 'Collaboration with colleagues in NARS to develop training in fieldwork strategies, instrumentation techniques and data handling'.

The final measurements from the field experiment investigating nitrous oxide emissions near Ségou, Mali were completed in 2005 and a paper produced. This study, which measured annual N_2O emissions from agricultural land in Mali revealed that there was no adverse effect of cereal and legume crops growing in rotation on the emission of N_2O to the atmosphere. This result has important implications for tropical countries in respect of their negotiating ability at United Nations Framework Convention on Climate Change. Currently the Intergovernmental Panel on Climate Change advise that an emission factor of 1.25% should be used for agricultural land growing biological N-fixing crops, while this study indicates that there should be no additional emission factor.

2. Completion of publications from Phase I

An output from the studies in Mali under Activity 1 above has been the preparation and acceptance of a paper by the journal 'Soil use and management'. Previous work in Mali, also conducted in Phase I of DMP, resulted in a publication in Biology and Fertility of Soils in 2006. The abstracts of both these papers are given below:

The contribution of agricultural practices to greenhouse gas emissions in semi-arid Mali

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Abstract
The flux of nitrous oxide (N_2O) emitted from soil was monitored over one year (Jan 2004 to Feb 2005) from a total of eight land management treatments. The treatments were four cropping regimes with or without manure, 8000 kg dry matter ha^{-1}. The four cropping regimes were (i) continuous cereal, (ii) legumes/cereal in rotation, (iv) cereal/legume in rotation and (iv) continuous cereal production with added urea (50 kg ha^{-1}).The cereal grown July-Oct in 2003 and 2004 was pearl millet (*Pennisetum glaucum)* and the legume was a bean (*Phaseolus vulgaris*). The plots (10 m x 10m) were established on three farmers' fields in parklands near the village of Siribougou, approximately 250 km northeast of Bamako, Mali. The addition of organic and inorganic fertilizer both increased yield and N_2O emissions. There was a significant interaction between the addition of organic and inorganic fertilizer in N_2O emissions. Cereal plots treated with both organic and inorganic fertilisers emitted significantly less N_2O (annual average 9.3 µg N_2O-$Nm^{-2}h^{-1}$) compared with plots, which did not receive organic fertiliser (annual average 16.3 µg N_2O-$Nm^{-2}h^{-1}$). Growing N-fixing crops in rotation did not significantly increase N_2O emissions. This study of N_2O emissions supports the new agricultural practice of growing cereal and legumes crops in rotation as an environmentally sustainable land use system in semi-arid Mali.

Effect of improved fallow on crop productivity, soil fertility and climate-forcing gas emissions in semi-arid conditions

Hall NM, Kaya B, Dick J, Skiba U, Niang A, and Tabo R

BIOLOGY AND FERTILITY OF SOILS 42 (3): 224-230 FEB 2006
The impacts of fallow on soil fertility, crop production and climate-forcing gas emissions were determined in two contrasting legumes, *Gliricidia sepium* and *Acacia colei*, in comparison with traditional unamended fallow and continuous cultivation systems. After 2 years, the amount of foliar material produced did not differ between the two improved fallow species; however, grain yield was significantly elevated by 55% in the first and second cropping season after *G. sepium* compared with traditional fallow. By contrast, relative to the unamended fallow, a drop in grain yield was observed in the first cropping season after *A. colei,* followed by no improvement in the second. *G. sepium* had higher foliar N, K and Mg, while *A. colei* had lower foliar N but higher lignin and polyphenols. In the third year after fallow improvement, a simulated rainfall experiment was performed on soils to compare efflux of N_2O and CO_2. Improved fallow effects on soil nutrient composition and microbial activity were demonstrated through elevated N_2O and CO_2 efflux from soils in *G. sepium* fallows compared with other treatments. N_2O emissions were around six times higher from this nitrogen- fixing soil treatment, evolving 69.9 ngN_2O - N g^{-1} soil h^{-1} after a simulated rainfall event, compared with only 8.5 and 4.8 ngN_2O - N g^{-1} soil h^{-1} from soil under traditional fallow and continuous cultivation, respectively. The findings indicate that selection of improved fallows for short- term fertility enhancement has implications for regional N2O emissions for dry land regions.

3. Studies on glomalin content and aggregation properties of soils from different land uses and locations

Background

Studies in Phase 1 highlighted the need for further research into useful indicators of soil biological condition as a prerequisite for evaluating sustainability of land-use in the desert margins. Following on from this, it was agreed that studies would focus on developing methods of evaluating glomalin. Glomalin, a glycoprotein produced by arbuscular mycorrhizal fungi, has important properties linked to key determinants of soil structure. Since its discovery (Wright and Upadhyaya 1998), evidence about the properties of glomalin include its permeation throughout soil organic matter, its ability to bind to silt, sand, and clay particles, and the role it serves in the development of soil aggregates which provide structure to soil and lock up longer term carbon stores.

With such properties, it was hypothesised that glomalin would be particularly important for soils in the desert margins, where sustainability of cultivation systems depends greatly on levels of organic carbon for soil structure, fertility and moisture retention. Techniques have been developed and calibrated, and this study has found significant differences in glomalin abundance in soils from three different rainfall zones and cultivation systems in dryland Africa. In addition, glomalin was found to be an important constituent of soil organic carbon (SOC), particularly in soils with lower overall levels of SOC, and correlated highly with soil aggregation.

However, recent developments (Rosier et al. 2006) throw the selectiveness of the extraction method for glomalin into doubt. The assay may not simply measure recalcitrant proteins arising from mycorrhizal fungi, but may also measure recalcitrant proteins of other orgins. The technique is still useful for assessment of levels of long-lived proteins, important for soil stability, but is less specific than previously thought. The majority of publications on glomalin in soils which precede Rosier *et al.*, probably measured total soil recalcitrant proteins rather than glomalin *per se*. In the following text, ‘glomalin’ may be equated with recalcitrant soil proteins which are extracted by citric acid buffer and autoclaving and detected using the Bradford Assay, whereas glomalin means the specific molecule, a putative gene product of arbuscular mycorrhizal fungi.

‘Glomalin’ accounts for a large proportion of soil carbon and nitrogen stores, up to 27 percent of the carbon in soil, and is a major component of soil organic matter (Nichols and Wright 2002). ‘Glomalin’ is a highly recalcitrant substance in the soil, which locks carbon and nitrogen into subunits that last from 7 to 42 years, depending on conditions. With such properties, it is likely to play a key role in determining the rate of formation and stability of soil organic matter in soils, features which are particularly important in vulnerable agricultural systems. Thus far, ‘glomalin’ levels have never been examined in African soils or any other dryland soils with relatively low organic carbon content, therefore its role in these soil types requires investigation. The only comparable study from a tropical forest found ‘glomalin’ levels to be a lower proportion of the total carbon content, and had a shorter lifespan than expected, which it was suggested was due to the higher breakdown rates in systems with higher soil temperature and moisture (Rillig et al. 2001). The recalcitrance of 'glomalin' carbon in dryland soils is still unknown, however at lower soil moisture levels it would be expected that the lifespan of this carbon sink would be greater than in the wet tropics.

Function of 'Glomalin' in soils

'Glomalin' is believed to give soil its tilth, the characteristic which provides soil with good texture and ease of cultivation, properties most desired by farmers for creating optimal seed beds for crop establishment. In such conditions, roots can develop and grow easily, and drainage ensures that water permeates the soil but also drains well.

Arbuscular mycorrhizal fungi, found living on plant roots around the world, appear to be the only producers of glomalin. These mutualistic fungi use carbon from the plant for their growth, and in return provide water and nutrients, particularly phosphorus, to the plant through their hairlike hyphae which extend beyond the absorption surface and reach that can be achieved by the plant's roots. Glomalin is detectable on the surface of these hyphae, and is believed to provide the rigidity required by the hyphae to grow into the air spaces between soil particles. When older hyphae stop transporting nutrients, their protective glomalin coating is sloughed off into the soil, where it attaches to mineral particles and organic matter, forming microaggregates. By contrast 'glomalin' arises from a variety of recalitrant soil proteins, including glomalin. Soil with good aggregate formations is considerably more stable, with higher levels of porosity and hence hydraulic conductivity. The soil surface is also more resistant to capping, crusting and compaction, which makes it better able to withstand the eroding properties of wind, heavy raindrops and surface water flow.

It is therefore likely, although untested in dryland conditions, that agricultural management which sustains 'glomalin' and glomalin in crop and fallow will lead to the benefits of improved tillage, soil organic carbon, enhanced nutrient content, erosion prevention and ultimately more stable and sustainable systems. It has been found in other soil and climate conditions that 'glomalin' levels are manageable through different agricultural practices, such as minimum tillage, cover crops, reducing phosphorus inputs, and a reduction in the use or distribution of non AM crops, which primarily constitutes the Brassica family. Although fallow systems have never been tested, it is likely that improved fallows in particular could similarly be used to increase soil 'glomalin' levels. A study of no tillage systems found that 'glomalin' content increased from 1.3 mg/g soil after the first year to 1.7 mg/g after the third, while ploughed fields in the study experienced a decline to 0.7 mg/g. By comparison, in the same study a 15-year-old buffer strip of grass was found to have 2.7 mg/g.

In this study, soil from a range of cultivation and tree systems in DMP countries were assayed to determine 'glomalin' levels. In addition, an assessment was made of soil aggregation and soil organic carbon content in order to assess the association between 'glomalin' and soil aggregation, and the relative abundance of 'glomalin' in relation to levels of soil organic carbon.

Methods and materials

A range of soils from DMP partner countries were tested: agroforestry and natural forest sites from semi-arid Kenya, dryland agricultural soils from Mali and dryland plantation and parkland soils from Senegal. The agroforestry system in Kenya (tree and crop zones) was first planted 18 months prior to this study and had previously been a natural fallow.

Glomalin assay

Soil samples were extracted to remove recalcitrant proteins into solution by adding 20mM sodium citrate and autoclaving for 30 minutes, following the protocol of Wright and Upadhyaya (1998), extracts were then assayed by the standard Bradford assay (Bradford 1976) using BioRad Coomassie Blue reagent, read against a bovine serum albumin dilution series to calibrate spectrophotometer readings.

Soil aggregation

Soil aggregation was assessed by a standardised comparative method which determined the percentage dry weight of soil remaining after wet sieving. 25g of dry soil was placed in a 106 micron sieve, then pre-wetted to thoroughly saturate the soil. Sufficient water was then added to cover the soil, and the sieves were then shaken for 20 minutes. Soil remaining in the sieves was washed onto pre-weighed filter paper with a standardised volume of water, then dried and reweighed.

Soil organic carbon

The organic carbon content of soils was assessed by the loss on ignition method (Rowell 1994).

Results and discussion

'Glomalin' protein

Protein concentrations in the soils ranged from 0.56 to 3.1 mg g^{-1} soil, with higher levels found in the agroforestry soils from Kenya (1.8 - 2.5 mg g^{-1}), and lower levels in lower rainfall agricultural systems in Mali (1.2 - 1.6 mg g^{-1}) and the plantation and Parkland soils from Senegal. The highest glomalin levels were found in soils from a natural mixed species forest in Kenya (3.1 mg g^{-1}), where soils are likely to have been undisturbed for many decades, if not longer.

Within each geographical area and system, differences could be detected between soil conditions and under different species, which supports previous findings of changes in 'glomalin' levels with land use (Rillig et al. 2003; Wright and Anderson 2000). In the agroforestry system (Figure 1), a significant difference was found between the planted areas (tree, crop and border) and the grassy verge separating plots. In the lower rainfall areas of Mali, a significant decline in soil proteins was found from undisturbed soil to natural fallow on previously cultivated soil, and then lower levels in soils under continuous cultivation (Figure 2). No differences in glomalin proteins were detected in soils under differing tree species in a Senegalese plantation, however there were higher levels from soils under the trees than in open areas of adjacent Parkland outside the plantation (Figure 3).

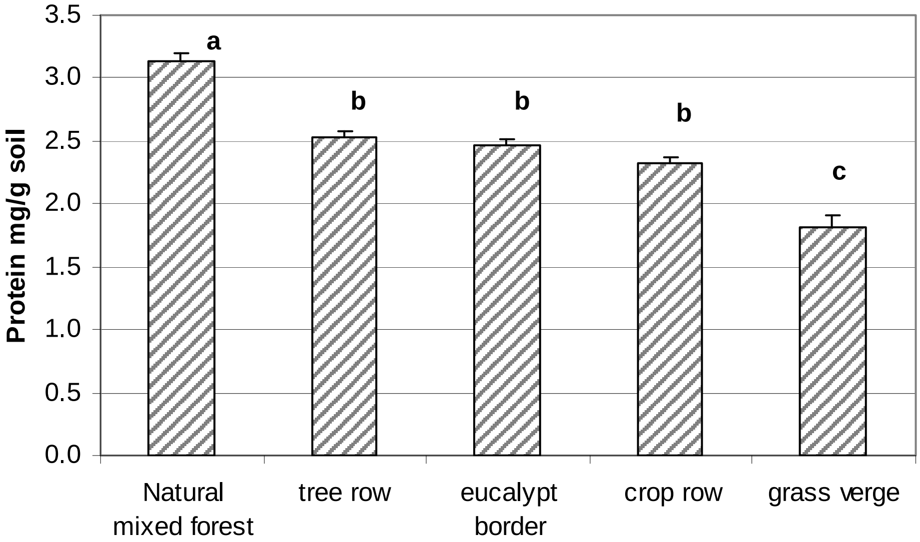

Figure 1 'Glomalin' protein in soil extracts from an agroforestry system in Kenya, including tree and crop rows (maize), a *Eucalyptus camaldulensis* border, grass verge and comparison with nearby soil from a natural mixed species forest on the same soil type.

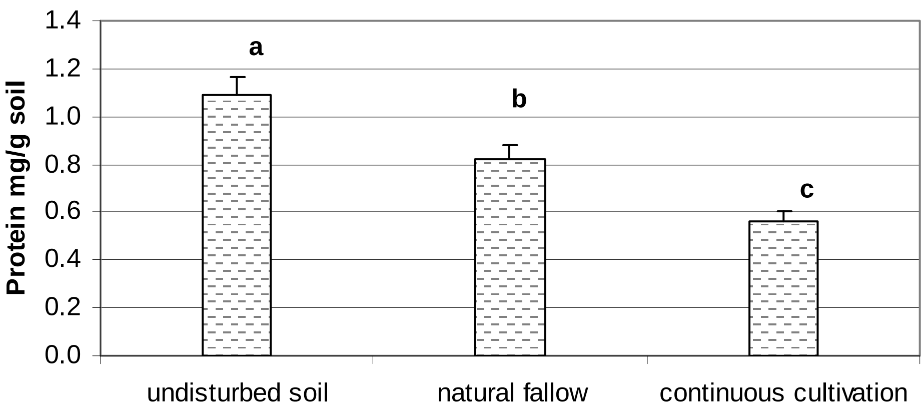

Figure 2 'Glomalin' protein in soil extracts from a farm in Northern Mali, comparing soils in continuous cultivation with a 5 year old natural fallow, and nearby soil from an undisturbed site that had never been cultivated.

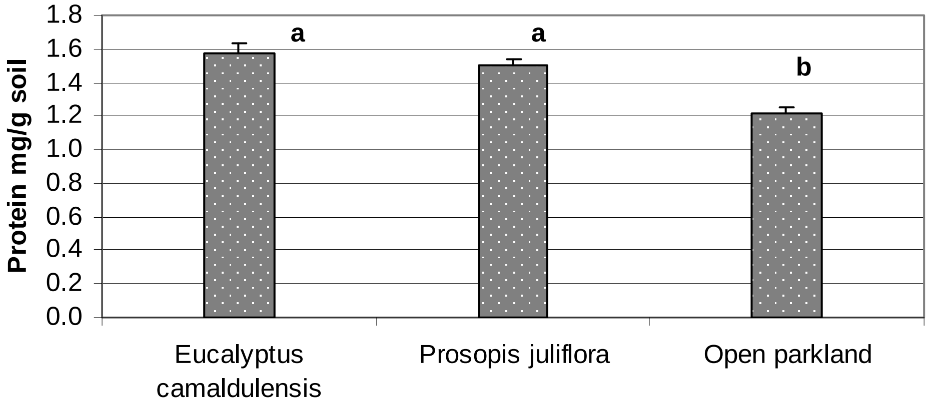

Figure 3 'Glomalin' protein in soil extracts from a tree plantation in Senegal, in comparison with soil from an open area of adjacent parkland.

Soil aggregation

The methodology used for comparing soil aggregation was effective in differentiating structural differences between the Kenyan and Malian soils involved in this study (Figure 4). The Senegalese plantation soils were not included as no species differences in 'glomalin' were detected. Highest levels of aggregation were found in undisturbed soils from the natural mixed species forest in Kenya, and significantly lower levels from the undisturbed, fallow and cultivated soils from Mali.

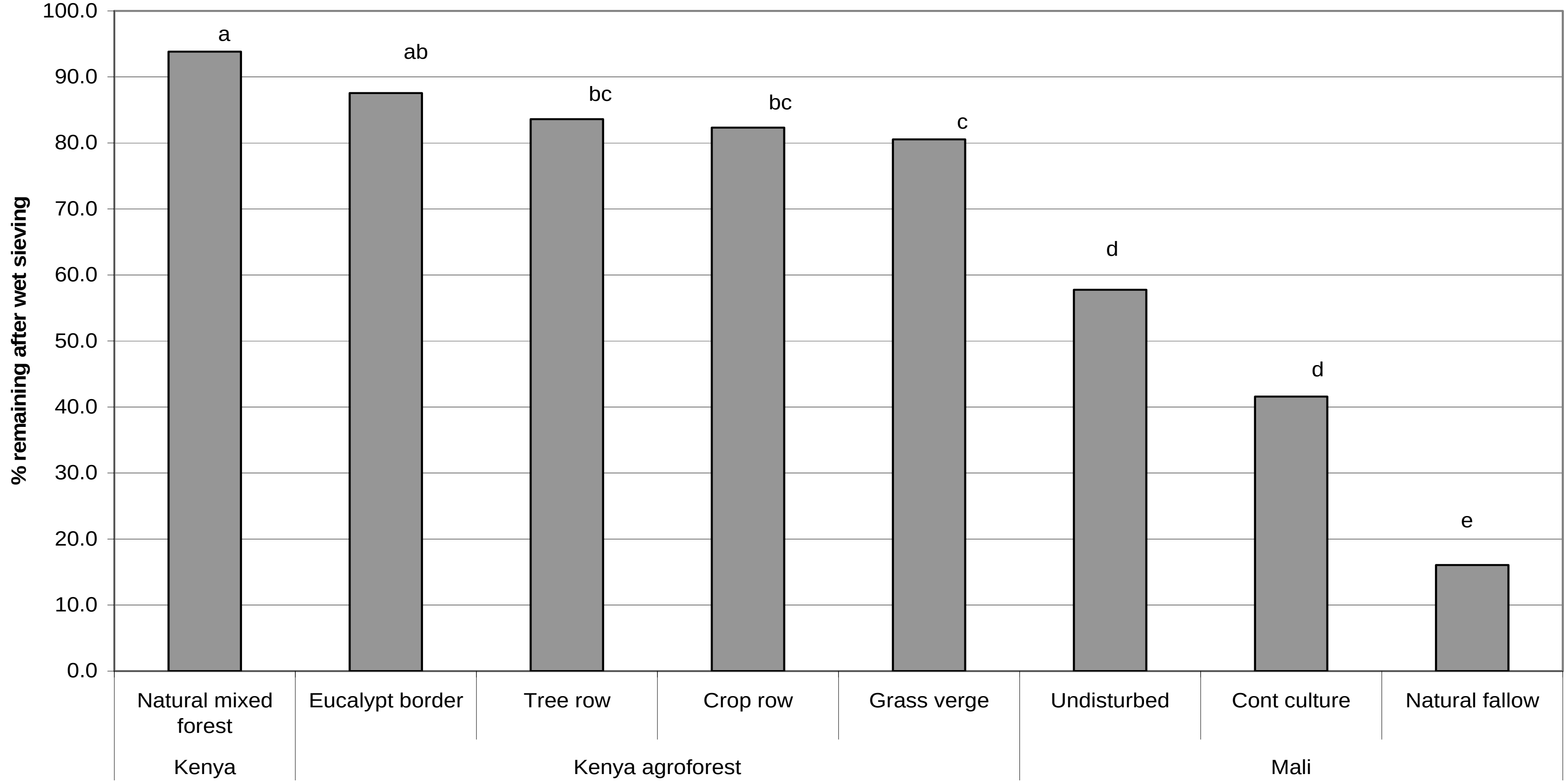

Figure 4 Soil aggregation in Kenyan and Malian soils tested for 'glomalin' protein levels, estimated by wet sieving.

‘Glomalin’ proteins, soil aggregation and soil organic matter

Good correlation was found between abundance of ‘glomalin’ protein and the degree of soil aggregation, as assessed by wet sieving (Figure 5). The relationship was found to be best described by a polynomial curve fit, which may suggest that increasing ‘glomalin’ abundance in soils does not continue to improve aggregation beyond a certain level, as other factors (such as soil type) come into play. Other factors are known to affect soil aggregation, such as the availability and charge of colloidal particles, hence it would be expected that increased abundance of glomalin alone would not determine measurable aggregation.

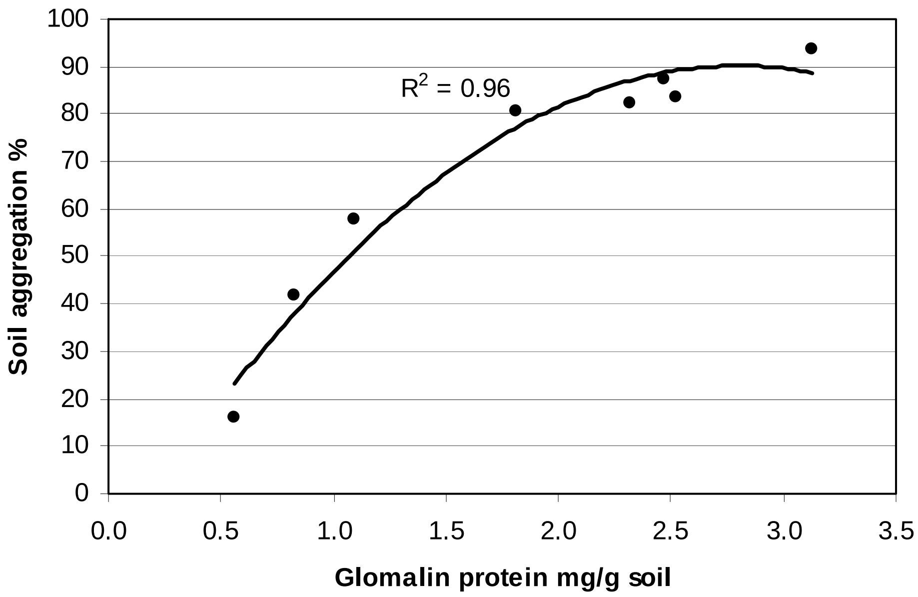

Figure 5 Relationship between ‘glomalin’ protein and soil aggregation. The curve fitted shows the polynomial y = -13.359x2 + 74.888x - 14.74.

A highly positive linear correlation was found between soil organic carbon and ‘glomalin’ protein in these soils (Figure 6). Interestingly it is in the soils with the lowest SOC that ‘glomalin’ makes the greatest contribution to carbon stores, indicating the importance of recalcitrant proteins in maintaining soil C and structure in these light sandy soils.

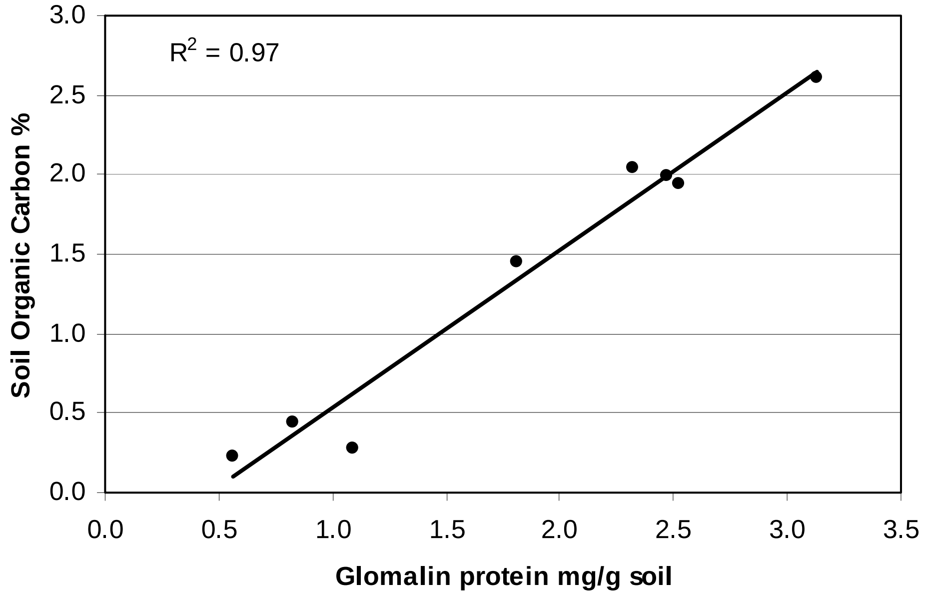

Figure 6 Relationship between 'glomalin' protein and soil organic carbon, with linear curve fit.

Location	Land use	Contribution of 'glomalin' to SOC %
Kenya	natural mixed forest	12.0
Kenyan agroforestry	tree row	13.0
	Eucalyptus border	12.4
	crop row	11.3
	grass verge	12.5
Mali	undisturbed site	39.1
Mali cultivation system	natural fallow	19.0
	continuous cultivation	24.5

Table 1 Contribution of 'glomalin' carbon to the total soil organic carbon stores.

4. Visit to project partners in South Africa to explore potential collaborations

This was reported in full in the annual report of 2005. The report is provided in Annex II.

5. Pilot survey of mycorrhizal populations in degraded South African soils

K Ingleby

Methods

Soil samples were collected by Dr J. Dick in October 2005 during her visit to South Africa. Full details of sites and sampling methods were provided in her report (see Annex II of this document). Arbuscular mycorrhizal (AM) spores were extracted from 40 g sub-samples of each soil using a sucrose centrifugation method (Walker et al. 1982). Spores were classified as 'dead' or 'live' according to their appearance. Live spores were examined microscopically to confirm their status and, when possible, identify them. Differences between treatments were examined by 2-way ANOVA (site*grazing). Data were transformed (log n+1) before analysis.

Results

Overall differences were found between the sites with significantly more spores (total, $P < 0.001$: live, $P = 0.003$) found in Austrey and Eska-Neuham soils than in Tseogue soils. Total numbers of spores across all 3 sites were greater in ungrazed plots compared with grazed plots ($P = 0.019$), with this difference more apparent at the Tseogue and Austrey sites. Of the three sites, only soils from Austrey had significantly more live spores in soil from the ungrazed plot compared to the adjacent grazed plot (Table 1).

Table 1. Numbers of AM spores and species per 40 g of soil collected from ungrazed or grazed plots at 3 different sites in Bophirima District, NW Province

	Austrey		Eska-Neuham		Tseogue		*P* value
	ungrazed	grazed	ungrazed	grazed	ungrazed	grazed	
Total spores	53.0	86.7	66.7	70.3	20.3	42.3	0.158
Live spores	2.33b	9.67a	5.67ab	6.33ab	2.00bc	0c	0.040
N species	1.33	3.00	2.33	2.00	1.67	1.00	0.094

In the householder gardens at Austrey, total numbers of spores and live spores were also low and were similar to, or less than, those found in the grazed plots (Table 2).

Table 2. Numbers of AM spores and species per 40 g of soil from Austrey householder gardens in Bophirima District, NW Province

	S. Letlhogile maize/cowpea	S. Letlhogile maize	M. Magabe no crop	B. Lolokwane maize
Total spores	54	33	39	35
Live spores	0	1	4	0
N species	-	1	1	-

No changes in species composition or AM diversity were found between the different soils (Table 1). As numbers of live, identifiable spores were so low, most samples yielded only 1-2 species with a maximum of 4 in any 1 sample. As a result, it was unlikely that any effects of site or grazing on AM diversity or species composition would be apparent from this data. The occurrence of AM species found in each plot is shown in Table 3.

Table 3. AM species recorded in soils from ungrazed or grazed plots at 3 different sites in in Bophirima District, NW Province

Site	Plot	Species present
Austrey	ungrazed	*Glomus fasciculatum*, *Gigaspora albida, Glomus* sp. 1, *Glomus* sp. 2*, Acaulospora mellea, A. gedanensis,*
	grazed	*Gigaspora albida*, *Glomus fasciculatum*
	gardens	*Acaulospora gedanensis*, *Glomus* sp.1
Eska-Neuham	ungrazed	*Gigaspora albida*, *Glomus fasciculatum, G. clarum*, *Acaulospora mellea*
	grazed	*Gigaspora albida*, *Glomus etunicatum*, *G. geosporum, Acaulospora longula*
Tseogue	ungrazed	*Scutellospora gregaria*
	grazed	*Scutellospora gregaria*, *Acaulospora scrobiculata*, *Glomus clarum*, *Gigaspora albida*

Discussion

Generally, total numbers of spores and the proportion of live spores present in all plots were low compared to similar studies (Diagne et al. 2001; Ingleby et al. 1997). However, it is well known that large seasonal and spatial variation occurs in the numbers and distribution of AM spores in the soil, and that assessment of spore populations often poorly reflects the numbers of AM propagules (spores, infected roots and hyphal fragments) present in the soil. Seasonal variation may explain the low spore numbers found here, as samples were taken at the end of the dry season. However, the time of sampling was appropriate as it assessed the AM spores present in the soils at the beginning of the growing season – when rapid infection of emerging seedlings is important for good growth. Spatial variation (clumped distribution of spores) is often a problem when assessing AM spore populations, but this effect should have been minimised by the sampling strategy employed. Bioassay experiments are a more accurate means of determining the mycorrhizal inoculum potential (MIP) of soils, as they assess the presence of all types of AM propagules (i.e. hyphal fragments, infected root fragments and spores). These should be employed if time allows (Brundrett 1991).

Grazing is associated with a significantly reduced number of AM spores in the soils at Austrey. The reduction in the variety and growth of plants which act as reservoirs for AM fungi and negative impact of animal manuring (Sieverding 1991) may have contributed to this effect. Overall numbers of spores at the Tseogue site were significantly lower than the other sites, which may be explained by the sparser vegetation found here and the lower rainfall (a longer dry season?).

Fertilizer applications have been shown to significantly affect levels of AM fungi in agricultural soils, depending on the nature and amount of fertilizer and the background fertility of the treated soil (Jensen and Jakobsen 1980). This may explain the comparatively low numbers of AM spores in the soils from the householders' gardens. Otherwise, the effect is unexpected, as many studies have shown that cropping and tillage increases AM spore production, while numbers decline when soil is left fallow (Thompson 1987). It was also surprising that no differences in spore numbers were found between these garden soils as cropping sequences can make significant impacts on mycorrhizal populations (Johnson et al. 1991).

Overall, spore numbers, determined here just before the growing season, are low. With the generally poor vegetation cover, it is probable that the number of infective propagules available for the next crop, will also be low, resulting in low levels of mycorrhizal infection on plants. It is likely that this will have an adverse impact on plant growth, especially for mycorrhizal-dependent crops. Thus actions to improve inoculum potential, such as improving natural vegetation cover, or nursery-based low-tech methods of inoculum production, are likely to be beneficial to establishment and growth of crops.

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Annex 1

Outline Proposals for CEH contribution to DMP Phase 2

DMP projects are located on a gradient from semi-natural degraded landscapes through to intensively managed landscapes such as the market gardens. The needs of projects vary according to where they fit on this gradient.

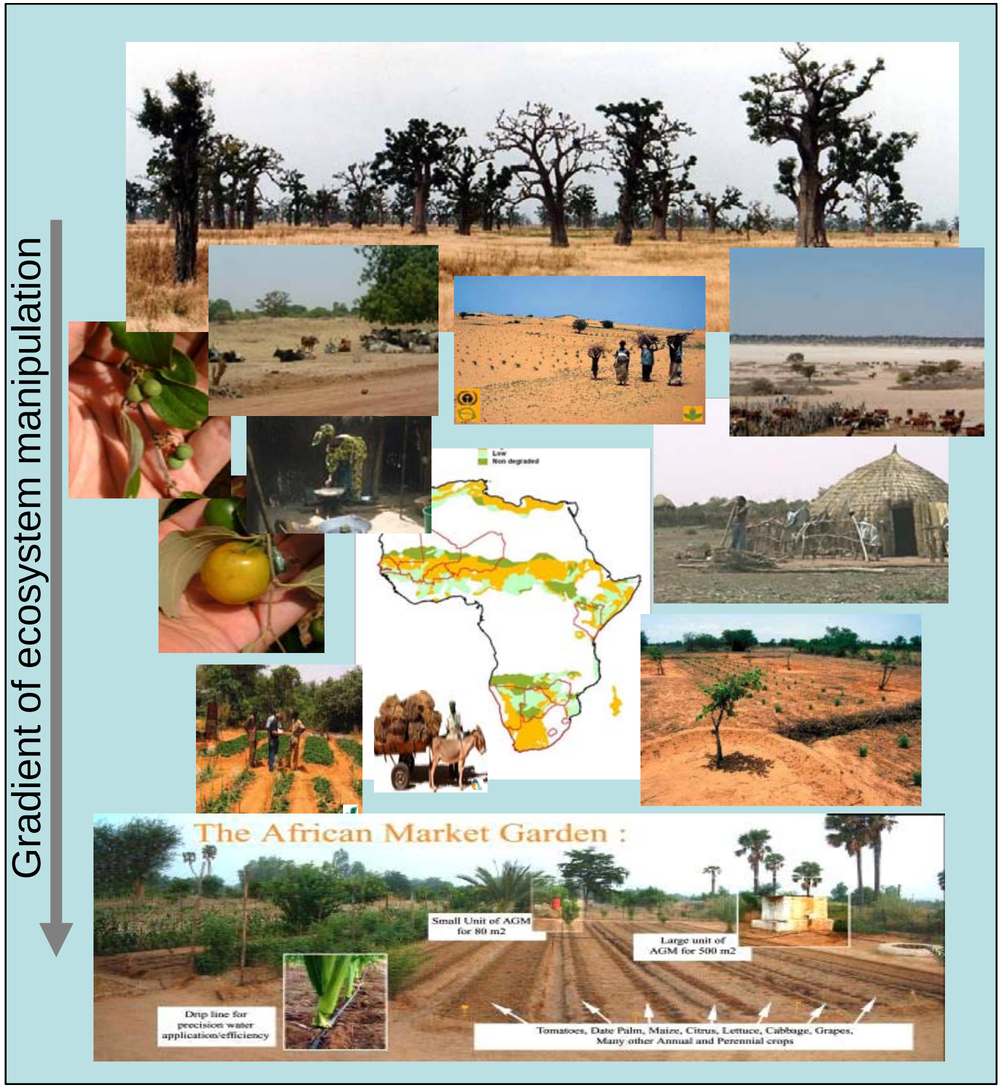
CEH offers work to meet the needs of DMP at different locations on this gradient, working from the landscape to the genotype.

Plant & microbial molecular diversity

Rangewide/ local analysis of plant gene flow

Marker-assisted breeding

Soil microbial diversity and soil fauna populations



Plant & ecosystem functional diversity

Social-ecological-economic 360° evaluation

N & C dynamics

Soil & plant management strategies

Capacity building

Areas of expertise

Plant and ecosystem functional diversity

CEH can provide expertise in plant and ecosystem functional diversity assessment and interpretation which can contribute to:

- Development of tools and management strategies to facilitate conservation, restoration and rehabilitation of landscapes.
- Strengthening the technologies being developed in DMP by ensuring the maintenance of ecosystem stability.

Analytical methodologies employed:

- Development of a database to amass biodiversity survey data and species trait data - analyse in respect to plant and ecosystem functional diversity of the regions.
- Determine species' functional groups and keystone species
- Characterise ecosystems at a functional level
- Identify key elements necessary to sustain ecosystem processes and services

Social-ecological-economic 360° (SEE) evaluation framework

CEH can provide expertise in multi-criteria analysis of landscape evaluation which, in conjunction with national and international partners, can contribute to:

- A truly integrated evidence-based mechanism for valuing ecosystems/landscapes in terms of biodiversity supported, environmental services provided and potential income generated
- Characterisation and valuation of current landscapes and those resulting from the implementation of the new technologies developed within DMP
- Provide national and international policy makers with a valuable robust tool for the formulation of effective policies.

Analytical methodologies employed:

- Quantification of landscapes utilising social-ecological-economic criteria
- Multi-criteria analysis and interpretation of social-ecological-economic criteria assessed

Nitrogen and carbon dynamics of DMP land uses

CEH can quantify emission and deposition of gaseous nitrogen and carbon compounds in DMP soils, which can contribute to:

- Assessment of gaseous nitrogen and carbon loss and gain from soils in natural and farmed land
- Development of strategies to mitigate losses of nitrogen and carbon compounds from soils
- Contribute to the precision of national reports of greenhouse gases to United Nations Framework Convention on Climate Change (UFCCC)
- Quantification of the new technologies developed within the DMP to global warming

Analytical methodologies employed:

- Measurement of a suite of gaseous inputs and emissions from soils e.g. nitrous compounds including wet deposition (NH_3 and NH_4) and dry deposition (NO_3 and NO_2), methane (CH_4) and carbon dioxide (CO_2).
- Scaling up emissions and deposition values to national and regional values
- Calculation of the global warming potential of land uses monitored

Soil condition

CEH can provide in-depth analysis of soil condition, which can contribute to:

- Assessment of the impact of technologies being developed and scaled-up in the DMP, and evaluation of their long-term sustainability.
- Development of soil management strategies to facilitate restoration and regeneration of degraded land.

Analytical methodologies employed:

- assessment of soil aggregate stability and determination of status of important aggregate-forming components
- assessment of soil microbial diversity and soil fauna populations, important for soil nutrient cycling and sustainability
- soil carbon stock assessment and quantification of fractions
- analysis of macro- and micro-nutrients

Mycorrhizal condition and amelioration

CEH can assess indigenous mycorrhizal populations, which can contribute to:

- identification of opportunities for improving plant growth and survival through use of inoculants or adjusting methods of land management

Approaches

- determination of mycorrhizal species diversity, inoculum potential and rates of infection on important plant species under different landuses
- low-tech development of appropriate inoculants and training of staff

Genetic diversity and geneflow, and marker-assisted breeding studies

CEH can apply molecular genetic approaches to assess genetic diversity and geneflow in keystone plant species, contributing to:

- identification of genetic diversity hotspots important for conservation
- identification of populations suitable as sources of planting material
- improved understanding of factors affecting geneflow in populations and the approaches needed to ensure that populations remain genetically diverse
- identification of desirable traits for plant selection

Approaches

- a range of molecular techniques can be applied to address the above questions

Understanding and manipulation of plant-plant-microbial interactions

In dry zones, below ground interactions limit productivity. A variety of approaches can be applied to mitigate these effects, contributing to

- improved ability of farmers to manipulate crops to meet their needs

Approaches:

- Apply understanding of competition, rooting systems etc and manipulation approached to develop less competitive mixed cropping systems
- Examine roles of perennials as reservoirs of microbial activity and assess robustness of different landuse systems

If the committee could indicate which subject areas would be of most interest, and for which countries, we can draw up work plans to fit within the budget allocated to CEH. Although we are offering a wide range of topics, we can support only 2 - 4 of the listed topics within the expected budget. The extent of cofunding from CEH will vary according to topic and location.

We are of course also open to suggestions from DMP partners. In many of the above topics we would be willing to provide a training element in conjunction with the work programme.

Annex II

Desert Margins Programme   Phase II

Fact finding mission to School of Environmental Sciences and Development, North West University (Potchefstroom Campus) South Africa.

October 2005

Jan Dick

Executive Summary

This report details the work undertaken, people consulted and potential collaboration ideas developed during my eight day visit to South Africa. Following a briefing lecture detailing the work of CEH to staff of the School of Environmental Sciences and Development, North West University (Potchefstroom Campus), I accompanied Prof Kellner, and three post graduate students Loraine van den Berg, Abdoulaye Saley Moussa, and Adrian Hudson on a four day mission to the DMP target areas in the Vryburg region, North West Province, to see at first-hand the work conducted under the DMP in the communal land tenure sites. I attended three farmers' workshops at Austrey, Tseoge and Kgokgojane and learned the problems and challenges faced by the various sections of the community, including farmers and agricultural officers. A range of project ideas was discussed and two formulated into concept notes: (i) mycorrhizal potential of home gardens and rangelands and (ii) eco-botanical database of South Africa flora. In addition, collaboration to investigate molecular markers for mycorrhizal fungi was discussed. All agreed that there were insufficient funds in the current DMP project to support this, so opportunities for additional funding would be sought.

South African Desert Margin Program outline

Prof Klaus Kellner outlined the work undertaken by the South African partners within DMP. Research within South Africa is conducted in four areas (Fig 1) and is organised through the National Co-coordinating Unit (NCU) which is chaired by Prof Kellner. The unit's tasks are primarily financial administration, reporting and the funding of regional workshops to explain the work of the project to the farmers. I attended three of these workshops during my visit (5, 6 & 7 October 2005).

The NCU is closely linked to the National Co-coordinating Committee (NCC) which was established at a national workshop in 2003. The tasks of the NCC include the identification and prioritization of the research activities funded by the DMP. It was agreed with Prof Kellner during our preliminary discussions that we should discuss several possible projects as appropriate and then develop one or two into proposals which can be placed before the NCC before approval is sought from Dr Andre Van Rooyen (DMP Regional Coordinator for South and East Africa) and Dr Saidou Koala (Global Coordinator for DMP). In order to identify the most appropriate projects Prof Kellner outlined the project activities undertaken in South Africa.

There are four target areas located in two provinces of South Africa: one in the North West Province in the Molopo region (coordinated by a number of project leaders of North West University and NW-DACET) and three in the Northern Cape Province, in the regions of Paulshoek (coordinated by Dr Nicky Allsopp), Suid Bokkeveld (Mr Noel Oettle) and Mier – Kalahari (Mr Desmond Smith) (Fig 1). These projects are explained in the project flyers and in the various DMP reports.

Figure 1. Map of South Africa showing the four DMP target areas, one located in the North West Province and three in the Northern Cape Province (courtesy of K. Kellner)

Molopo field sites, North West Province

I visited the Molopo region where 5 projects are currently underway, three conducted by researchers of the NW University and post-graduate students, one by the Scientific Technical Support Services (STSS) of NW-DACET and one collaborative project with TSBF-CIAT, Kenya.

1. Assessment Protocol for Birds, Frogs and Trees in the North-West Province Target Area. Mr Adrian Hudson & Prof Henk Bouwman.

2. The evaluation and promotion of best practices for biodiversity restoration in selected arid and semi-arid regions of southern Africa. Loraine van den Berg & Prof Klaus Kellner

3. Selected invertebrate indicators of ecosystem change as a result of bush encroachment and fire treatments in selected areas of the Molopo region, North West Province, South Africa. Kirstin Botha & Prof Huib van Hamburg

4. Best land-use strategies towards sustainable biodiversity and land degradation management in semi-arid western rangelands in South Africa, with special reference to ants as bio-indicators**.** Ms Marisa Coetzee**,** Dr Franci Jordaan & Prof Huib van Hamburg.

5. Impact of communal grazing systems on soil and vegetation characteristics in semi-arid rangelands in the Molopo region, South Africa. Mr Abdoulaye Saley Moussa, Prof Leon van Rensburg, Dr Andre Batiano (TSBF-CIAT Nairobi, Kenya) & Prof Klaus Kellner.

Summaries of the work conducted under projects 1, 2 and 5 above were presented at the farmers' workshops.

Community Farmers Workshops

A series of workshops were held in the community halls at Austrey, Tseoge and Kgokgojane. The workshops were well organized by the Scientific Technical Support Services (STSS) of NW-DACET. The workshops were very well attended with genuine interest from the farmers and wider community. The workshops consisted of a series of presentations concerning primarily environmental problems with farmers asking questions at the end of each session.

The work of the Desert Margins Programme was presented to the participants by Prof Klaus Kellner. In addition, the South African LandCare program was explained and the Department of Conservation Services explained to the people how farming and conservation ideals can work in harmony.

I am indebted to the chiefs of the three areas; Chief A S Lethogile at Austrey, Chief Setlhabetsi at Tseoge and Chief George Kanonoat at Kgokgojane for the warm welcome I received. The presentations were a mix of English and Tswana, the local indigenous language of the region.

Project topics

A range of project topics were discussed including estimating carbon sequestration of the rangelands, measuring vegetation water use and soil water profiling. As funds are limited only the projects considered to be the most promising ideas are reported below.

1. Mycorrhizal inoculum potential for food home gardens

Prof Klaus Kellner explained some of the work done on home gardens in the Paulshoek region by Dr Nicky Allsopp. There they have developed the use of waste water from the house to produce vegetables in home gardens. It was interesting to note that none of the villages I visited harvested water from the house roofs. Such water harvesting opportunities may be important if water is found to be one of the limiting factors for home garden productivity.

During our visits to Austrey when Prof Kellner introduced the DMP in South Africa, a question was asked about the home gardens. Discussion with the group developed and they expressed an interest in trying to establish home gardens in their homesteads. The area around their houses had very little vegetation and concern was expressed about the mycorrhizal inoculum potential of the soils. It was agreed that this was a potential area for collaboration as staff at CEH have the skills for identifying and assessing mycorrhizal spores. Discussions with the community developed during the lunch break. At the end of the day Me Mpho, the local extension officer, took us to three houses in the rural township at Austrey, where we collected soil (Table 1) and also to two areas of rangeland (within and outside a five year exclusion plot). Soil was also collected from within and outside the protected benchmark sites at Tseoge and Eska-Neuham (Table 2).

These soil samples were transported to Scotland on my return as it was pragmatic to do so, but it was fully understood by all parties that this research topic might not have been adopted by the NCU, NCC or CEH at that time. Since then approval has been sought and agreed by all relevant parties.

Table 1. Site characteristics of the householder's gardens

	Plot owner			
	Seboana Letlhogile	Seboana Letlhogile	Mildred Magabe	Betty Lolokwane
Crop 2003	Vegetables	Maize	Maize, beans, pumpkin	Maize
Crop 2004	Maize and cowpeas	Maize	No crop, Pen for ~10 goats and 1 donkey	Maize, grazed off by 3 donkeys
Plot size	35 m x 25 m	50 m x 25 m	20 m x 15 m	50 m x 25 m
Fertilizer	25 kg	25 kg	20 kg	20 kg
Perennial vegetation	None	None	2-3 bushes	No shrubs in plot but hedge border

Table 2. Site characteristics of veldt field sites

	Austrey	Eska-Neuham	Tseoge
Latitude/Longitude	S 26°28', E 24°14'	S 26°38' E 23°51'	S 25°57' E 23°31'
Rainfall (mm)	300-400	300-400	200-350
Geology	Kalahari Group	Kalahari Group	Ventersdorp Group
Soil type	Yellow sands	Yellow sands	Mispah form, with 4-

	(Clovelly form) and red sands (Hutton form), with 3-10% clay, 900-1200 mm deep	(Clovelly form) and red sands (Hutton form), with 3-10% clay, > 1500 mm deep	10% clay shallower (< 250 mm),
Vegetation	Kalahari thornveld and shrub bushveld, described as a generally open savanna of *Acacia haematoxylon* and *Acacia erioloba* (Acocks, 1988; Tainton, 1999). Dominance of Increaser II species characteristic of overgrazed rangeland.		

2. Creation of an eco-botanical matrix database of plant functional attributes

The School of Environmental Sciences and Development, North West University (Potchefstroom Campus) are world experts on rangeland ecology, having a deep understanding of species composition of the veldt and management practices, particularly in relation to rangeland degradation and restoration. They have developed the EcoRestore decision-support system which is an excellent database of methodologies used to control bush encroachment and reclaim bare and denuded areas. The concept of gradients of degradation with indicator keystone species is well established in the region.

This work has synergy with the creation of an eco-botanical matrix database of plant functional attributes of southern African flora which CEH staff are in the process of developing with the Royal Botanic Gardens, Kew. The matrix database of plant taxonomy, morphological, phenological and physiological traits is based on Flora Zambesiaca. The aim of this work is to analyse the database for species' functional gradients.

A project idea was discussed which would essentially involve the School of Environmental Sciences and Development, North West University (Potchefstroom Campus) and CEH expanding the database to include species of the region not already covered by the database and incorporating additional information for species included. The database would be a valuable teaching tool and would be expandable to include other DMP partners in the West, East and Southern regions. The database would also be a depository for species-linked indigenous knowledge.

These ideas will now be discussed by Prof Kellner and myself with our colleagues and the regional and global coordinators of DMP will be informed of the final decision.

A third topic 'Molecular markers for South African mycorrhizal fungi' was also discussed. Mrs Bibi Bouwman attended the presentation I gave at the University and was interested to collaborate on the molecular markers for mycorrhizal species. She and 2 colleagues have received a grant from the South African government to establish a business to market mycorrhizal inoculum – Mycoroot.

Local trials of mycorrhizal inoculum have proved very successful, as South African soils are phosphorus deficit and often degraded. During discussion, ideas were developed for a pilot project examining vegetable gardens with fruit trees, involving the concepts of root pruning and mycorrhizal fungal infection. The funding under the current DMP program would not be sufficient to fully test the idea but the possibility of an exchange visit to CEH was discussed. Other mechanisms for additional funding will also be examined.

Exchange visits

It was agreed between myself and Prof Kellner that if funding was available CEH would happily host South Africa students or fellows to conduct research on the research ideas outlined above. Prof Kellner agreed to send details of funding opportunities under the United Kingdom - South Africa Bi-national Agreement. The fund appears very suitable to finance exchange visits between our two institutions but the time frame for this year was insufficient to identify a suitable student so close to the end of the academic term (closing date 18 November 2005).

Acknowledgements

I am extremely grateful to all the people named in this report and all the participants of the workshops who took the time to explain the environmental, social and economic situation in South Africa. I am particularly indebted to Prof Klaus Kellner for the care and attention he gave me and to Loraine van den Berg, Abdoulaye Saley Moussa, and Adrian Hudson for making my trip so enjoyable. I am also indebted to Hestelle Stoppel for her efficient organization skills which made my trip hassle-free.